INDIAN JOURNAL OF ECOLOGY

Volume 49 Issue-3 (Supplementary Issue) June 2022

ISSN 0304-5250

THE INDIAN ECOLOGICAL SOCIETY

The Indian Journal of Ecology is an official organ of the Indian Ecological Society and is published bimonthly in February, April, June, August, October and December. Research papers in all fields of ecology are accepted for publication from the members. The annual and life membership fee is Rs (INR) 1000 and Rs 8000, respectively within India and US $ 100 and 350 for overseas. The annual subscription for institutions is Rs 8000 and US $ 300 within India and overseas, respectively. All payments should be in favour of the Indian Ecological Society payable at Ludhiana. See details at web site. The manuscript registration is Rs 500.

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Indian Journal of Ecology (2022) 49(3) (SI): 977-986
DOI: https://doi.org/10.55362/IJE/2022/3625

Manuscript Number: 3625
NAAS Rating: 5.79

Transition of Indian Agriculture from Glorious Past to Challenging Future: A Serious Concern

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Abstract: Agriculture is different from socio-economic activities and plays a consequential role in the economic development of a nation. Beginning with the origin of agriculture, Indian agriculture availed its golden period in connection with the prosperity of farmer and farm. But due to the invasion of certain foreign emperors, glorified Indian agriculture got ruined. After independence, some efforts had been taken by Govt. of India such as the Green revolution, etc. to intensify the Indian economy. Despite increasing growth, production, agriculture faces various socio-economic and environmental challenges. Particularly, agriculture participation in GDP decreases from 67.5-14.39% from 1870-71 to 2020-21, which is an alarming signal for the nation. In this respect, there is an urgent need to take some sustainable steps incorporating in policies and planning's towards holistic welfare of agriculture.

Keywords: Ancient agriculture, Disturbing present, Green revolution, Sustainable agriculture, Vedic agriculture

Agriculture plays a significant role in the socio-economic development of a nation. In India, agriculture is considered as a backbone of the economy which incorporates sustainable socio-economic intensification. Occurring from Indus valley civilization, agriculture changed the lifestyle of early man from nomadic hunter to cultivator along with the domestication of various animals (Gupta 2004, Eagri 2011). Plants and animals were considered essential to the survival of ancient Indians, worshiped and venerated in the era known as the 'Vedic period' in Indian history. Along with cultural development, agriculture is also benefited from the wisdom and teachings of great saints. Traditional farmers established environmentally-friendly agricultural techniques and practises such as mixed farming, mixed cropping, crop rotation, and others, which are detailed in ancient Indian literature (Eagri 2011). Following then, India was the victim of invasions by foreign monarchs who came mostly for robbing and by the time commanding. In a similar vein, the East India Company arrived in India, enticed by the trade-in spices and plantation crops, and eventually governs huge swaths of the country. They take Indian agriculture as a source of revenue generation with great zeal. As a result of that much extent of revenue collection, the Indian cultivators and the villagers both were destroyed (Pandhari 2016).

Not only this, the Indian economy had been a victim of enormous exploitation in terms of natural resources (fields and forests), iron ores, gold mines, wealth, and manpower, which were subjected to intense exploitation. Due to these atrocities, even after Independence, the Indian economy showed poor economic growth. Green and White Revolution were commencing to uplifting the agriculture sector in India along with farmer's welfare. The agricultural industry was able to produce substantially bigger quantities of food as a result of the Green Revolution, due to high-yield crops and multiple cropping methods. Operation Flood was launched in 1970 with the goal of increasing milk output, connecting milk producers and consumers, and increasing dairy farmers' revenue (OECD-FAO 2014). No doubt, these efforts increase crop productivity, which made it possible to feed the growing population. But there are several adversities that emerged due to the uncontrolled use of chemical fertilizers, synthetic herbicides and pesticides; India seems on a verge of a critical situation with facing many troubles in the socioeconomic area along with environmental hazards. India still has to face various obstacles to combat hunger. This paper, emphasize India's traditional agricultural wealth, which guides us to overcome all these problems incorporated with new technologies. Therefore, this communication is an effort to deal with the entire scenario of the Indian Agriculture system along with current challenges to overcome.

Indian Agriculture: A Journey from Glorious to Atrocious

India's modern society is one of the world's oldest living civilizations. It has a long history dating back to around 9000 BC, during which the development of agriculture is intertwined as a result of early plant cultivation and domestication of crops and animals. Agricultural technology and practices, including iron instruments, the cultivation of a wide variety of cereals, vegetables, fruits, the use of meat and milk products, and animal husbandry, are all mentioned in the Vedic writings (*Rigveda*) between 3000- 2500 B.P. (Encyclopaedia Britannica, 2019). "Agriculture in the Vedic period was thus a religio-social activity with all its ancillary aspects from soil to weather forecasts". Figure 1 and 2 show how wealthy agriculture technology was adopted by Vedic people in India, exemplifying the level of concern for socioeconomic and environmental welfare. It may be recognized as the "Golden period of Indian agriculture" in the context of welfare in every aspect starting from a farmer to country and environment too.

In the Medieval Period (200-1757CE) irrigation and crop protection methodologies were also practiced for sustained, in addition to previous agricultural practices. During 1325-51, a broad revenue system including related officials also came into existence to assess the financial aspects of the area. Mughals devised and implemented extensive agriculture management practices on a rational basis (Prashant 2011, Richards 2003). In the 14th century, the canal system of irrigation was coming into existence, which was a notable work for agriculture history. But the village headmen and peasants were charged in respect of the canal by the ruler. Overall, the peasants have to pay three major taxes, viz. land revenue (*kharaj-jiziiya*), house tax (*ghari*), and the cattle tax (*charai*) (Raychaudhuri et al 1983). This can be considered as the beginning of downfall of farmer's life in every aspect, which was directly related to the prosperity of agriculture.

In Colonial British Era (1757–1947 CE) agriculture remained more or less stationary during this period. Rather than food grains, the emphasis is on cash and plantation crops. Main focus on commerce leads the lower food crop output, widespread poverty, and farmer destitution. Policies benefited the rulers more than the ruled. During this period while the population increased the food output reduced. Furthermore, between 1600 and 1871, India's per capita Gross domestic product fell substantially. From the mid-17th century, as British living standards rose, India lagged more behind. Whereas Indian per capita GDP was more than half that of the British in 1600, it had dropped to less than 15% by 1871 (Broadberry and Gupta 2009). Under the British, the condition of the Indian peasants deteriorated steadily, though the agriculture sector had a 67.5 % share in the Indian economy at that time (History discussion 2019). Indian peasants were forced to produce cash crops including tea, coffee, sugar cane, jute, indigo, and opium, which ruined the land's fertility and made it impossible to grow any other crop. The growth of a minimum of subsistence crops resulted in the decline and destitution of Indian agriculture and cultivators. The peasant was devastated under the triple burden of the government, landlord, and moneylender. The lack of interest in agricultural development and in the utilization of modern equipment and procedures on the part of the British government also devastated Indian agriculture (Pandhari 2016, History discussion 2019).

Source: Roy 2009, Eagri 2011

Fig. 1. Salient features of Vedic agriculture system

Pre-colonial India was self-sufficient and sustainable since it grew only two crops: rice and wheat. But colonialism introduced the concept of cultivation for the market. Although, agricultural exports from India grew at a fantastic rate and increased by more than 500% from 1859-60 to 1906-19. But Britishers, rich farmers, big Indian traders, and moneylenders reaped the lion's share of the profits generated by the export trade. This posed rural Indian communities at greater risk of damage. Further, the transition from food crops to cash crops exacerbated the disaster in famine years. Even in 1876-77, shortly before one of the century's worst famines, exports grew to stay profitable to meet Land Revenue demand. In the midst of catastrophic famine and starvation in India, it was also continued in 1897-98. The Famine Commission's reports from 1880, 1898, and 1901 provide significant evidence for examining these events, and indicating that food grains were present even during famine years and concluded that "the surplus produce of India, taken as a whole, still furnishes ample means of meeting the demands of any of the country likely to suffer from famine at any one time, supposing such famines to be not greater in extent and duration than any hitherto experienced". Thus, during the years of acute hunger, food grains were exported. These Famine Commission Reports argue that the effects of famine during British India were caused by an insufficient food supply rather than a shortage of food (Environment and Society 2019). Although, an extension of irrigation, banking sector, and agricultural research was the major positive works to develop the agriculture sector. However, the British had played the role of administrator and collection of revenue than the welfare of India. Hence, there was no motivation to increase crop yield. Consequently, the agriculture sector was ruined through exploitation and insecure land ownership in India (Pandhari 2016).

Indian Agriculture Post-Independence: An Urge to Reclamation

In comparison to the pre-1939 period, the decline in productivity has been continued post-independence. During 1946-47 and 1949-50, the average cereal yield per acre fell from 280 to 256 Kg. India's total output fell from 0.9 metric tonnes in 1938-1939 to 0.86 metric tonnes per hectare in 1951. The studies undertaken by ICAR and the Grow More Food Enquiries were reached similar conclusions (Economics Discussion 2019). Thus, to address domestic needs, India relied on imports and food aid. As a result, economic planning was implemented in 1951, with a particular focus on agricultural growth after 1962. Following the economic reforms, the agricultural sector experienced tremendous growth, attributable to the earlier changes as well as contemporary innovations in agro-processing and biotechnology (Balakrishnan et al 2008).

Indian Agriculture: Through Green and White Revolution

The Green and White Revolution are the two key events that have changed the face of Indian agriculture. Interestingly with the usage of high-yielding seed, the Green Revolution in

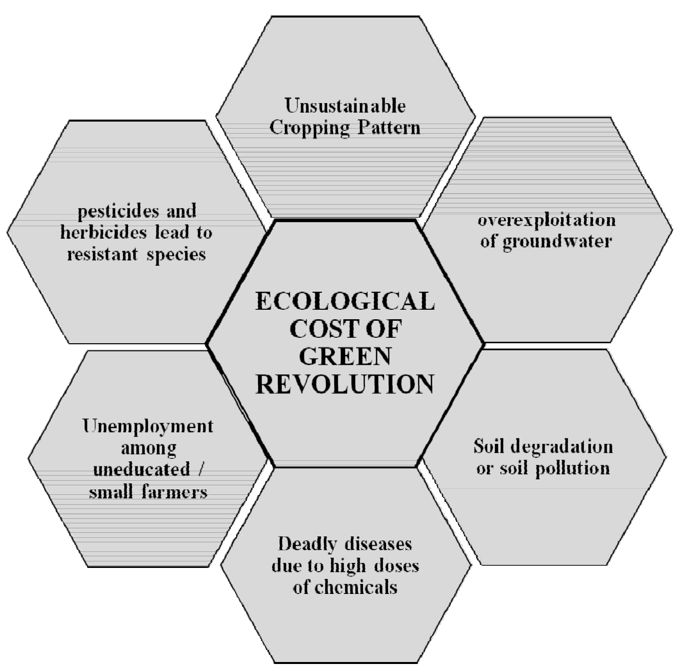

Fig. 3. Effect of green revolution on environment and farmers

the 1960s reflected in enhanced production of the country's major commodities like wheat and rice. White Revolution, which revolutionized the dairy industry with the introduction of Operation Flood in 1970, that boosted milk output and also connect customers and milk producers, and increase dairy farmers' revenue. As a result, India has surpassed the United States as the world's biggest milk producer, accounting for 22 percent of worldwide production in 2019-20, with 198.4 million tonnes estimated to be produced (Economic Times 2020, FAO 2021).

Reformation of Indian Agriculture and Economy by Green Revolution

Agricultural output has been strong over the last three decades, and importantly food production has been able to meet the expectations of a growing population. From the mid-1960s onwards, the introduction of high-yielding seeds (such as improved wheat strains) and the increased use of chemical fertilizers epitomised what became known as the 'green revolution'. Between the mid-1960s to mid-1970s, wheat production climbed by about 150 percent, and the country became grain self-sufficient by the end of the decade. Agricultural production increased, resulting in lower food prices and higher rural incomes (Kumar, 2014). The stagnation of agriculture was reversed with the establishment of economic planning in 1951 and a special emphasis on agriculture growth, particularly after 1962. The average yield per hectare and the area under cultivation both increased steadily. The total production of crops increased as a result of this rising tendency. Food grain production grew at a slower pace of 1.4 % in 1949-50 or 1964-65, and 2.3 % in 1970-71 or 1980-81. In 1991-92, the growth rate of food grain production was regained to 2.8 % (Tripathi et al 2010). In a nutshell, India's green revolution (1967-1978) turned the country from a food scarcity to a surplus market. India has become a net exporter of food grains in the last three decades (Business Standard 2018). As a result of the Green Revolution, 5-year plans, and other government efforts in the Indian agriculture system, new opportunities, difficulties, and downsides have arisen. Figure 3 depicts the negative aspects of the green revolution.

The heavy reliance on inputs without regard for their long-term consequences has resulted in a slew of issues related to sustainability of agriculture. The agro-ecosystems are being threatened by irrational usage of chemical fertilisers, pesticides, and natural resource exploration. Soil health is depleting, water and air are polluted, and plant and animal genetic resources are eroding at an alarming rate. However, it's vital to realise that lower cereal imports did not reduce agriculture's reliance on foreign markets. Whatever gains are made in terms of reduced cereal imports are offset by higher imports of agricultural requisites, particularly fertiliser. Prior to Green Revolution, expenditure on imports of agricultural requisites were essentially almost nil. Seven crore rupees were spent on this head in 1950-51which is extended up to thirteen crores in 1960-61. This expenditure increased to 102 crores in 1970-71, and to 201 crores in 1973-74. Then came the spike in fertiliser prices, which resulted in an expenditure of 532.5 crores on fertiliser imports alone in 1974-75. As a result, Indian agriculture's reliance on imports had been rapidly increasing. Thus, after the Green Revolution, the agriculture sector's reliance on foreign inputs increased in a variety of ways. Previously, only food had to be imported; now, a range of inputs required to be procured. While the government had to rely on foreign countries for many of the new agricultural requirements, farmers had to depend even more on the government and the industrial sector (CPSI 2011). As a result of greater external dependence all around, the “Green revolution turning Brown”.

Current Scenario of Indian Agriculture

India's agriculture industry is projected to account for only about 14% of the country's economy. However, it provides employment to 42% population. One of the major aspects which is critical for economic activity is rainfall because roughly 55 percent of India's fertile land is dependent on it. Agriculture sector's contribution to GDP has curtailed over the past few decades, as compared to the other sectors such as industry and service (Broadberry and Gupta 2009, Deshpande 2017, Balakrishnan 2021, Static Times 2021). Figure 4 depicted that, agricultural contribution in GDP was decline from 67.5 to 20.19 % during 1870-71 to 2020-21, perhaps due to lacking of suitable conditions for holistic development in terms of almost all the factors responsible for agricultural prosperity.

The services sector is the largest sector of India. In 2020-21, the services sector's Gross Value Added (GVA) is expected to be 96.54 lakh crore INR at current prices. While agriculture accounts for 20.19 percent of the economy, with a GVA of Rs. 36.16 lakh crore. But services sector has the lowest growth rate among the three sectors for the first time in 2020-21. Agriculture's performance is substantially better at current prices, as it has grown at the fastest rate of all three sectors since 2012-13 (Trading Economics 2019, Static Times 2021). Agriculture's contribution of GDP has surpassed nearly 20% for the first time in 17 years, making it the only bright point in GDP performance in 2020-21. Agriculture was the only sector to expand at a positive rate of 3.4 percent at constant prices in 2020-21, despite the fact that other sectors dropped. The share of agriculture in GDP climbed to 19.9% in 2020-21, up from 17.8% in 2019-20.

Tillage (*krsi*):

•Ploughing was generally performed with the help of oxen in teams of six, eight or twelve and also with one or two sheep.
•Furrow marks were made in grid pattern: Twelve lines made by plough drawn by twelve oxen were arranged in such a way that three lines arranged vertically, three running over them horizontally and the other six made crisscross.
•Mowing (*matyam*) was the post -plough operation.

Cropping System

•Sowing of seeds of different kinds in grid -pattered furrows and the methodology adopted for rotation of crops.
•Reaping, threshing, winnowing and storing are the post -cultivating processes, noticed from the period of the *Rigveda.*

Irrigation System:

•Natural irrigation, which include rain -supported and river - supported practice.
•Artificial irrigation, which includes two devices non -flowing streamlets formed out of rain water, where water was poured on arable field out of these storages by means of droni (wooden bucket) and the other, was well-irrigation.
•The *Sutra* period (*KausikaSutra* and *Grhya sutra*) shows large-scale use of artificial irrigation by well and reservoir dam. Canal -irrigation is thus envisaged widely used system.

Animal Husbandry

•People in general were familiar with the different breeds of cattle. Among them two were prominent: milch cattle (dhenu) and draught breed (anadvan).
•Horses of Indus and Sarasvati were highly esteemed and so was also the sheep of Gandharva breed which had high food -producing capacity.
•Nourishment of cattle by feeding green grass, water and barley is recommended in the Rigveda for increase of milk-yield.
•Proper penning in two types of pen, open pasturage (gostha) and cow stall (gosala).

Utilizations of animal power in agriculture

•Ploughing by oxen and sheep
•Transportation of agricultural produce by carts drawn by oxen, stallions, rams and dogs
•Carrying water to field
• Use of animal manures
•Along with breeding, rearing and tending of domestic animals, cattle diseases were given proper attention and generally cured by the application of a medicinal plant such as *sahadevi* (a variety of *Sida cordifolia* with yellow flowers).

Meteorological observations in relation to Crop Prospects

•Crop prospects began to be studied in relation to seasonal rain, fogginess and dew under the influence of heavenly bodies. The Rigveda recognizes two seasons of rainfall summer solstice winter solstice.
•The early shower was predicted from the disappearance of *Vrtra* (constellation Hydra) and the rising of two stars: *Ajaekapat* (Pegasi) and *Ahirbudhna* (Andromeda). The second of the rain was supposed to have been caused by the impact of the star *Apamnapat* (apamvatsa of later period, Virgo).

Effect of rain on crops and livestock:

•The summer solstice rains were believed to produce sweet juice in corn and to increase the procreative power of cattle.
•The winter solstice rains were associated with the cool season is clearly specified in the *Rigveda*

Source: Roy 2009, Eagri 2011

Fig. 2. Salient features of Vedic agriculture technology

However, although the overall economy's GVA decreased by 7.2 percent in 2020-21, agriculture's GVA grew by 3.4 percent according to the Economic Survey 2020-2021(Down to Earth 2021).

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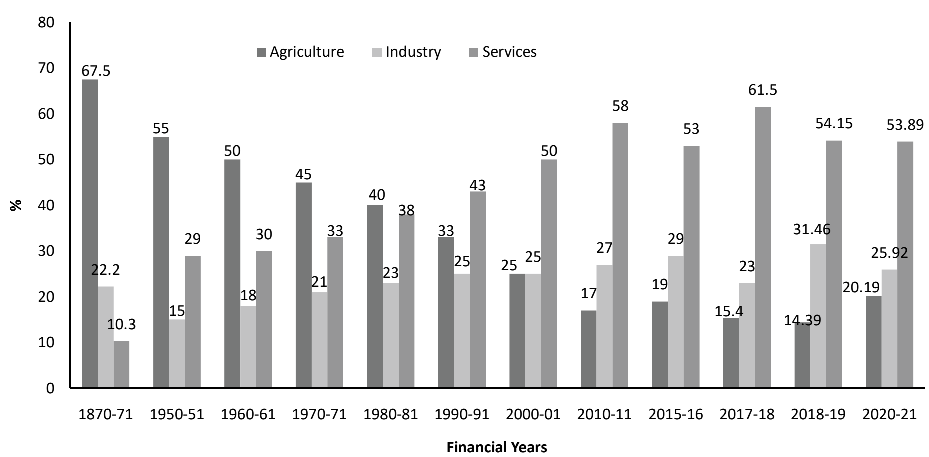
Despite declining Agriculture share, production and yield of agricultural commodities were found to be an increasing pattern from 1950-51 to 2020-21. The production showed gradual increase in pattern up to 2020-21. The agriculture yield takes a significant elevation from 522 kg ha^{-1} (1950-51) to 2325 kg ha ha^{-1} (2019-20). Moreover, the agriculture area has followed the pattern similar to production with 97 million ha^{-1} in 1950-51 to 128 million/ hectare in 2019-20 (Fig. 5). Similarly, the total production of food grains increased from 50.82 million tonnes in 1950-51 to a record 303.34million tonnes in 2020-21. The production of wheat and rice took off after the green revolution in the 1960s, and as of 2020-21, wheat and rice accounted for 109.24 &120.32 million tonne production, respectively in the country (Fig. 6) (Deshpande, 2017, Ministry of Agriculture & Farmers Welfare 2021).

The ministry releases five estimates of food grain production at various stages of crop growth, India's food grain production is expected to increase by 2% in the 2020-21 crop year to an all-time high of 303.34 million tonnes, due to higher output of rice, wheat, pulses, and coarse cereals (Business Standard August 2021). Furthermore, food grain output in 2020-21 would be 24.47 million tonnes greater than in the preceding five years (2015-16 to 2019-20). Rice production is expected to reach a new high of 120.32 million tonnes in 2020-21 that is 7.88 million tonnes greater than the average production of 112.44 million tonnes over the previous five years. Similarly, wheat production also exceeds the average wheat production of 100.42 million tonnes by 8.81 million tonnes and is expected to reach a new high of 109.24 million tonnes in 2020-21 (Economic Times 2020, Business Standard, August 2021, Ministry of Agriculture & Farmers Welfare, 2021). The Indian government is continuously working for the welfare of farmers through the implementation of various schemes (Balkrishna et al 2020).

Challenging Future of Agriculture in India

Nonetheless, the Green Revolution was a huge success. From being a net food importer in the 1950s, India has changed dramatically over the last four decades: India produced a record 303.34 Mt of food grains in 2020-21, up from 82 Mt in 1960-61, owing primarily to a large increase in rice and wheat output. Higher output, on the other hand, has had consequences. However, the agricultural sector's

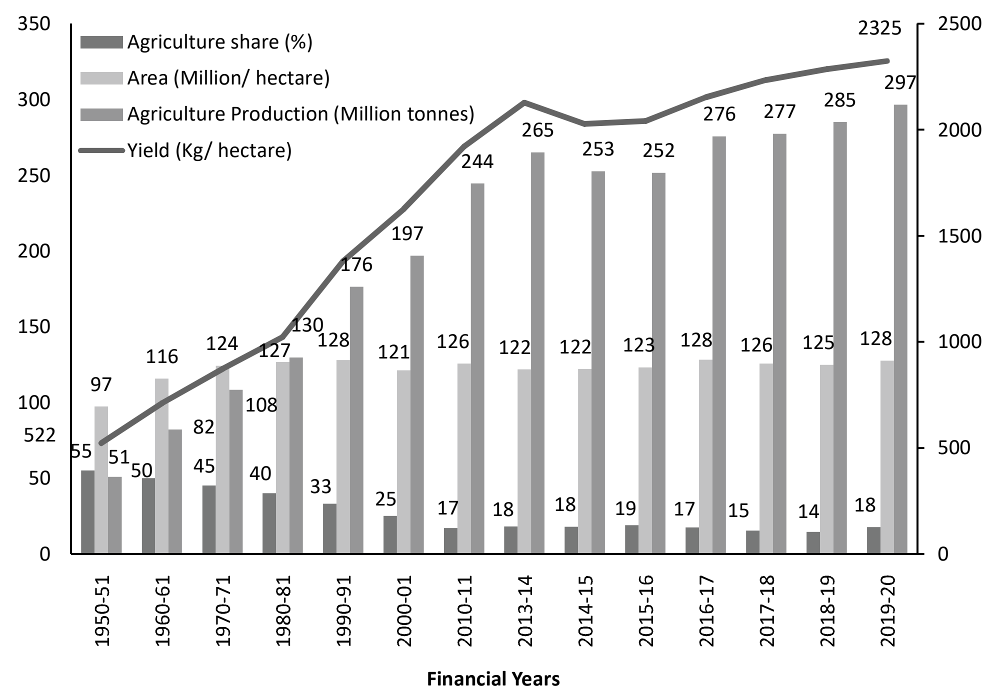


Source: Ministry of Statistics and Programme Implementation (2018-2019), Planning Commission, Govt. of India (2004-05 series)and Statics Times

Fig. 4. Sector wise contribution to gross domestic product (GDP)

growth has been erratic in recent years (Kodidala 2018). Yield gains were unevenly distributed throughout the country, owing to the Green Revolution spreading primarily in favourable locations.

Furthermore, high-yielding rice and wheat varieties led to mono-cropping in some areas, increasing sensitivity to biotic and abiotic stressors (e.g., droughts and pests). The earth's natural resources are depleting. Farmers produce a range of crops in traditional farming, which often has a big supply of unique genotypes. People who use Green Revolution farming techniques plant fewer crop varieties in favor of high-yielding ones. Crop genetic diversity is lost as a result of this form of agriculture. Only ten varieties of rice verities are cultivated in 75% of rice fields in India. When compared to the 30,000 rice types grown 50 years ago, this is a dramatic decrease. Traditional crops have the most gene variety, and as they become scarce, those genes become extinct. These losses in genetic variety can be seen all across the world in places where the Green Revolution farming methods were applied (Sciencing 2018). High-yield varieties are known to involve high costs in terms of energy, soil fertility, environment, and financial implications. This technology is inefficient in terms of energy utilization when compared to older technologies. These types are also extremely responsive to fertilizer and water inputs, resulting in fast groundwater table depletion. Water scarcity for agriculture has reached crisis proportions, particularly in Western Uttar Pradesh, Punjab and Haryana. The upper layer of groundwater in Punjab has been depleted; therefore, farmers' input costs increased due to using the advanced machinery to retrieve water for irrigation. Thus, in Punjab and Haryana, the cultivation of water-intensive paddy is promoted. According to the Economic Survey 2018-19, irrigation uses over 89 percent of groundwater. Furthermore, crops like paddy and sugarcane utilize more than 60% of India's irrigation water, limiting water availability for other crops (Kumar 2014, Sidhu et al 2021). Post-harvest loss is another emerging issue in Indian agriculture. The post-harvest supply chain in India is disjointed, with weak infrastructure and considerable wastage. Supply chain inefficiencies are causing significant losses. Every year, agricultural production is projected to be lost worth Rs. 500-600 billion due to a lack of suitable post-harvest infrastructure and poor supply chain management. Because of insufficient storage and transportation facilities, over 30-40% of horticulture produce is wasted each year. In 2011, the FAO released a report on global food losses and waste, claiming that roughly one-third of all food produced for human consumption is lost or wasted (FAO 2011). These predicaments lead to Food Insecurity. India's population was 1.21 billion people in 2011, up 364 million people in the prior two decades, according to the 2011 census. Despite the addition of 94 million people to India's population over that time period, this progress was made, demonstrating faster



Source: Ministry of Agriculture & Farmers Welfare, 2021, Directorate of Economics & Statistics. 4th Advance Estimates

Fig. 5. Yearly pattern of agricultural components in terms of share, area, productivity, and yield

success in eliminating food insecurity. However, with about one-quarter of the world's food-insecure people within India, improving the country's nutritional condition remains a significant challenge (UNICEF 2015).

A poignant fact emerging after all above-mentioned circumstances is Farmer's Suicide**.** Over 300000 Indian farmers have committed suicide since 1995. Suicides in the agriculture sector declined 32% in 2016 from 2007, the lowest over the last decade. The highest number of farmer suicides was recorded in 2004 when 18241 farmers committed suicide over the last 16 years. Among farmers, indebtedness and crop failure was the major cause of suicide (India News 2017, India spend 2018, OECD-FAO 2014).

Possible Solutions to Combat Current Issues in Agriculture

The works highlighted in this context shows, that there is an urgent need for balanced development in the three main areas such as economic, social, and environmental. These areas play a significant role in the development of a prosperous country. To overcome the above-said

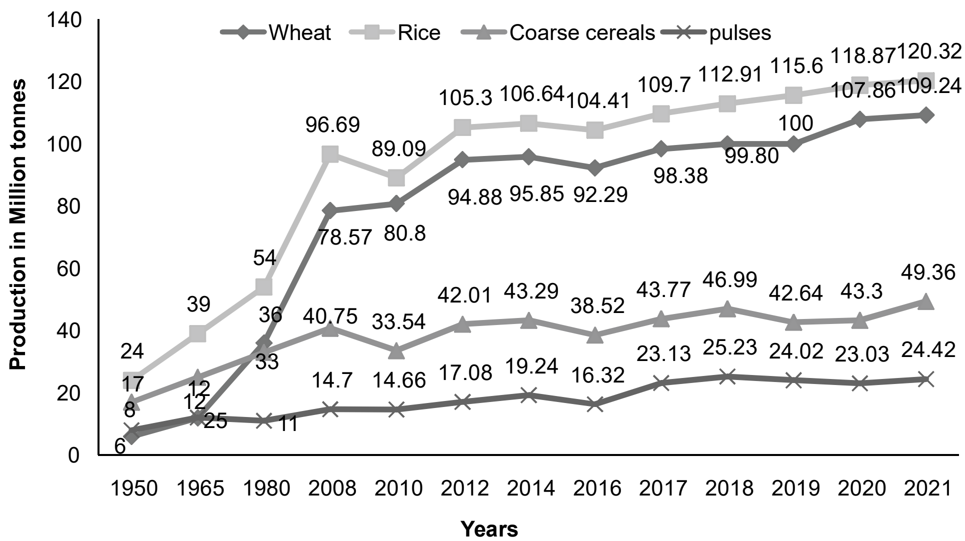


Fig. 6. Production of wheat, rice, pulses, and coarse cereals

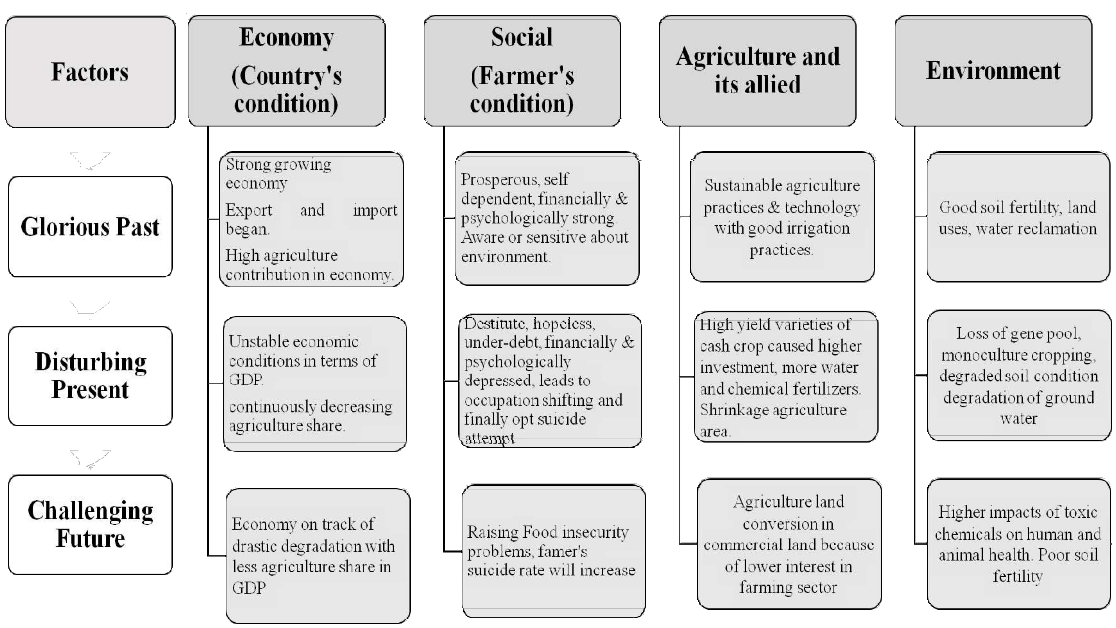


Fig. 7. Analytical vision on Indian agriculture scenario

challenges, there is a need to bring a structural change in the agriculture system with certain effective and efficient measures:

- To overcome the disturbing present situation, there is a need to introduce a transparent system that contains the availability and traceability of agriculture input and output.
- Re-adoption of traditional agriculture practices with sustainable new techniques. Mistakes committed in the past need to be rectified after an in-depth analysis of reasons for failure.
- Farmer income can be boosted up only by connecting agriculture with the advanced technology with transparent mapping, availability, and traceability system from crop to consumer. This will have to contend with all of these challenges over time to succeed in achieving sustainable change.
- Advanced technology should be adopted by analysing its pros and cons in terms of long-lasting economic, environmental as well as social impacts.
- Traditional agriculture knowledge practices and methods should also be incorporated in adopting advanced technology with more emphasis on sustainable agriculture.
- Eradicate the gap between the research & reality needs to be overcome to accomplish the objective. Overall, it can be summarized, that sustainable agriculture seeks interrelation between economy, social factors, and environment.

CONCLUSION

For lifting up the declined share of agriculture and allied sectors in the Indian economy; gearing up for the projected negative consequences of loss in biodiversity, gene pool, variety, and nutrient value in terms of crop and soil; providing food security and food safety; feeding rapidly growing populations; accessing sustainable technologies that are beneficial for farmer and farm in every aspect, strategic planning is quite necessary. There is a need to not only focus to improve the farmer's income but also point to a target to boost agri-based manufacturing growth in rural India.

AUTHOR CONTRIBUTIONS

AB: conceptualized and supervised the study; GS and NS drafted the manuscript and analyzed the data; NR, AK, and VA done review and editing.

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Received 16 January, 2022; Accepted 23 May, 2022

Indian Journal of Ecology (2022) 49(3) (SI): 987-993
DOI: https://doi.org/10.55362/IJE/2022/3626

Manuscript Number: 3626
NAAS Rating: 5.79

Insights of Agri-food in India: Present Trends, Challenges and Proposed Solutions

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Abstract: Agriculture is responsible for feeding the whole population and farmers are its main stakeholders. It accounts for 2.4% of the geographical area and provides nourishment to 17% of the human population. Even though there are 1.3 billion hungry to feed, nearly one-third of the food produced in the world each year is wasted. Food security refers to an individual, household, and community's ability to obtain enough, safe and nutritious food to live a long and healthy life. The agrarian sector has a strong pillar for strengthening the Indian economy as it contributes 20.19% of GDP. Good agricultural production has made India self-sufficient. Productivity is enhanced which has led to surplus agri-food output for India's current population. Despite increased agri-food production, one-fourth of the world's hunger is accounted in India. The government's food-security and anti-poverty schemes, which have critical gaps, inefficient food distribution, interrupted market supply chain, hygienic food packaging, efficient modern retail, and insufficient cold storage are the top issues that must be addressed and worked immediately. These challenges, there should be the implementation of easily assessable common E-commerce platform, management of storage, agri-food logistics, and fixing the loopholes of governmental schemes.

Keywords: Agri-food, Indian economy, Digital marketing, Hunger, Accessibility, Poverty

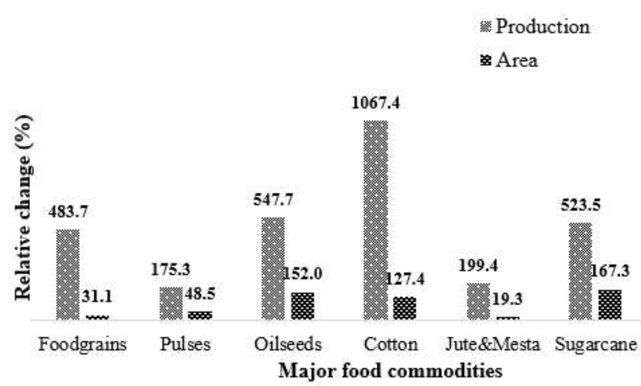
Agriculture is the mainstay of human's daily needs. It is the largest industry and accounts (2.4%) of geographical area and 4% of water resources in the world. As a return, it supports the world's human population by 17% and livestock by 15% (Khatkar et al 2016). Agriculture shows a pivotal role in the financial lift of India (Bose et al 2013). In the whole world, food derived from crops dominate the average per capita energy requirement by 78% while other food sources like milk, eggs, fish, and meat add up the rest 22% (Brevik et al 2013). Consequently, the dietetic requirement of the population is a basic necessity and can be managed by enhancing the production of agriculture (Singh et al 2019). The world's future dream is a "world free of hunger and malnutrition, where food and agriculture help to improve the living standards, particularly the poorest in an economically, socially, and environmentally sustainable manner". Much headway has been made for tackling the issue of hunger and poverty along with improving food security and nutrition but still, around 795 million people are starving, with over 2 billion suffering from micronutrient deficiencies as well over-nourishment (FAO 2017). However, global food security might be in peril, due to increasing pressure on natural resources and climatic change, as these both will result in danger the sustainability of food systems. The main challenges that must be addressed to eradicate hunger and poverty comprise uneven demographic expansion, the threats posed by climate change, the nourishing of natural disasters and increases in trans boundary pests and diseases, and the need to adapt to major changes occurring in global food systems (FAO 2017).

India is capable of a handful of arable land with 15 agro-climatic zones, which is having almost all types of weather conditions, soil types and is thus capable of growing a variety of crops (Department of Water Resources, RD & GR 2021). The agrarian sector has a strong pillar for strengthening the country's economy as it contributes 20.19% of GDP (DAC & FW 2020-21). Good agricultural production has made us self-sufficient and uplifted our condition after independence from begging bowl for food to a net exporter of agriculture and other allied products. India is the second leading country in the terms of agricultural land i.e. 179.9 million hectares (Khatkar et al 2016) and in 2019 the gross cropped area was 195 million hectares. Currently, India ranks second in the world in terms of agricultural production. Nevertheless, of all these facts, the average productivity of many crops in India is quite low. Critical examination of the gaps behind this should be brought forward and actions should be taken to overcome it (Down to Earth 2021). According to UN projections, India's population would reach 1.5 billion by 2030 and 1.64 billion by 2050 (Down to Earth2020). The world's growing population has increased demand for natural resources everywhere, but especially in India, which has only 2.44 percent of the world's geographical area but supports livestock and human population by 15 and 18%, respectively (Khatkar et al 2016). For the welfare of farmers, the Indian government has implemented several programs such as subsidies on various commodities, crop insurance, national and state level schemes (Balkrishna et al 2020).The present study reports about the current status of Indian agriculture with certain gaps which leads to the unavailability of agri-foods to the population despite surplus production.

Present status of the area, production, and yield of major food crops: After US and China, India has the world's third-largest economy with valued at $ 2.1 trillion (FAO 2021). India ranked the world's second-largest producer of agricultural products, with $375.61 billion in production. Although India produces 7.39% of the world's total agricultural output but still lags far behind China (19.49%) with a GDP of $991 billion in the agricultural sector. The United States, the world's largest economy takes third place. Brazil and Indonesia are next in line (Statistics Times 2021). According to the FAO world agriculture statistics (2020-21), the World's biggest producer of milk, jute, and pulses in India and the second-largest producer of rice, wheat, groundnut, sugarcane, fruits, vegetables, and cotton. Along with these, it is also one of the major producers of fish, spices, livestock, poultry, and plantation crops (FAO 2021).The agriculture development has been presented in terms of relative increments in area and production under major crops from 1950 to 2020. The highest relative change has occurred in the production of oil seeds followed by sugarcane, food grains, and pulses with 547.7, 523.5, 483.7, and 175.3 %, respectively. The relative change in area is higher for the cultivation of sugarcane followed by oilseeds, pulses, and food grains with the percent change of 167.3, 152, 127.4, 48.5, and 31.1, respectively (Fig. 1) (Pocket Book of Agricultural Statistics 2020).

In Indian agriculture, grains manufacturing covers the principal part of cropped area (64.3%) followed by oilseeds and sugarcane (Pocket Book of Agricultural Statistics 2020, DAC & FW 2020-21). As per the National Statistical Office and Pocket Book of Agriculture Statistic (2020), the agricultural area of food grains in India was 124.78 million hectares (MH) in the year of 2018-19 which was increased to 127.59 MH in 2019-20 with an increase of 2.76%. There was an increase of 2.25% in oilseeds i.e. (24.79 MH in 2018-19 and 27.04 MH in 2019-20) but in sugarcane decreased by 0.49% (5.06 MH in 2018-19 and 4.57 MH in 2019-20). During the last 5 years (2015-16 to 2019-20), the areas under rice, wheat pulses, and oil have increased by 0.28, 1.03 &0.95 MH, respectively, while the coarse cereals area has dropped by 0.36 MH. In comparison to other cereals, the area under pulses has grown, while wheat cultivation has also accelerated. By 2023, Pulses production is expected to reach 23 million tonnes (Mt), with annual growth in area and yield of 1% and 2%, respectively (ICMR-NIN 2021). In the case of production and yield of food grains, the increment of 4.04 & 1.71 % has been observed from 2018-19 to 2019-20 FY. About 296.65 million tonnes (Mts) food grains production and 2325 kg ha^{-1} yield was recorded in 2019-20. The food grain production is predicted to be 303.34 million tonnes in 2020-21 (Pocket Book of Agricultural Statistics 2020, Business Standard 2021). Out of the total food grains production in 2019-20, cereals, pulses, rice, and wheat accounted for 273.5, 23.15, 118.43, and 107.59 Mts, respectively. The seed oil production was 33.42 Mts and sugarcane 355.7 Mts in 2019-20 (Pocket Book of Agricultural Statistics 2020, DAC & FW 2020-21). The food grain yield in the year 2019-20 was 23.25 q ha^{-1} which was higher than the previous year (2018-19) by 0.39 q ha^{-1}. The yield of oilseed was reported to be 12.36 q ha^{-1} and for sugarcane, it was highest i.e. 778.93 q ha^{-1}. The absolute difference in the yield from 2015-16 to 2019-20 revealed that maximum yield was in sugarcane (71.73 q ha^{-1}) followed by cereals, oilseeds, pulses, cotton by 20.15, 12.34, 4.72 & 0.36 q ha^{-1}, respectively, while the yield decreased for tobacco by 13.81 Quintal/hectare (Pocket Book of Agricultural Statistics 2020).

State-wise it was reported that the maximum increase in cropped area in 2019-20 compared to the previous year (2018-19) was in Maharashtra followed by Rajasthan while the maximum decline was noticed in Madhya Pradesh followed by Bihar. Among the total cropped area 52.2% area is the irrigated area in India as reported in 2016-17(Pocket Book of Agricultural Statistics 2020). States having maximum irrigated area is Punjab (99.1%) while the least irrigated state in Maharashtra (18.7%). Uttar Pradesh results for the largest part by area as well as production by a wide margin and also



Source: Directorate of Economics & Statistics

Fig. 1. Relative change (%) in production and area from 1950 to 2020

contribute nearly one-fifth of food grain production in India whereas Punjab and Haryana have been conventionally considered as the major contributors to the production of food grain. In recent years, Madhya Pradesh, Andhra Pradesh, Rajasthan, and West Bengal have appeared as significant producers of food grains (Pocket Book of Agricultural Statistics 2020). Yields and the share of irrigated land vary greatly between states. A strong correlation can be predicted amid these two variables. In terms of both yields and the share of irrigated land criteria, Punjab ranks first while Haryana ranks second. Madhya Pradesh, Rajasthan, and Maharashtra have the lowest yields among the biggest producers. In Bihar, the proportion of the area irrigated is above the national average but not the yield due to the high frequency of floods that occasionally ruin the standing crops. Horticulture crops currently cover a total area of 26.22 MH in 2019-20, representing a 25.59 percent increase over the previous year's total area of 20.88 MH (2009-10). Despite, production of approximately 319.57 Mts, horticulture production increased by approximately 43.25 percent from 2009-10 to 2019-20.

The productivity of horticultural crops has increased by approximately 14.06% (DAC & FW 2020-21). During 2019-20, the fruit crops area is 6.70 MH, with total production (100.45 Mts). The fruit production enhanced by 40.46 &, whereas the area by 6% during the period of 2009-10 to 2019-20 (3rd Adv. Est.). In the production of fruits like banana, mango, lemon, lime, and papaya, India is in first position (DAC & FW 2020-21).In the horticulture sector, vegetables are an essential crop, engross an area of 10.32 MH in 2019-20 (3rd Advance Estimates) with total production (189.46 Mts) with average productivity of 18.4 Tonnes/hectare. Vegetables compose about 59.3% of horticulture production. The area and production of vegetables elevated by 29.2% and 41.7% respectively during the period 2009-2010 to 2019-2020. After China, the second-largest producer of vegetables in India(DAC & FW 2020-21).During 2019-20 (3rd Advance Estimates), floriculture covered the area of 0.31 MH with flowers production (2.99 Mts). India is the world's biggest manufacturer, buyer,and exporter of spice and spice-related products. During 2019-20 (3rd Advance Estimates), the total production of spices was 9.75 Mts from an area of 4.14 MH (DAC & FW 2020-21).

Per-capita availability of agri-food: For the year 2019, the annual availability of food grains was 180.5 kg per capita as shown in Table 1. After 2015, there has been an annual increase in the availability of food grains. In 2018, the country's population of approximately 1.3 billion people had access to about 214 million metric tonnes of food grain. In India, 492 grams of food grain were available per person per day in 2019. This figure increased significantly since 2015. Rice, wheat, maize, various cereals, and a variety of pulses

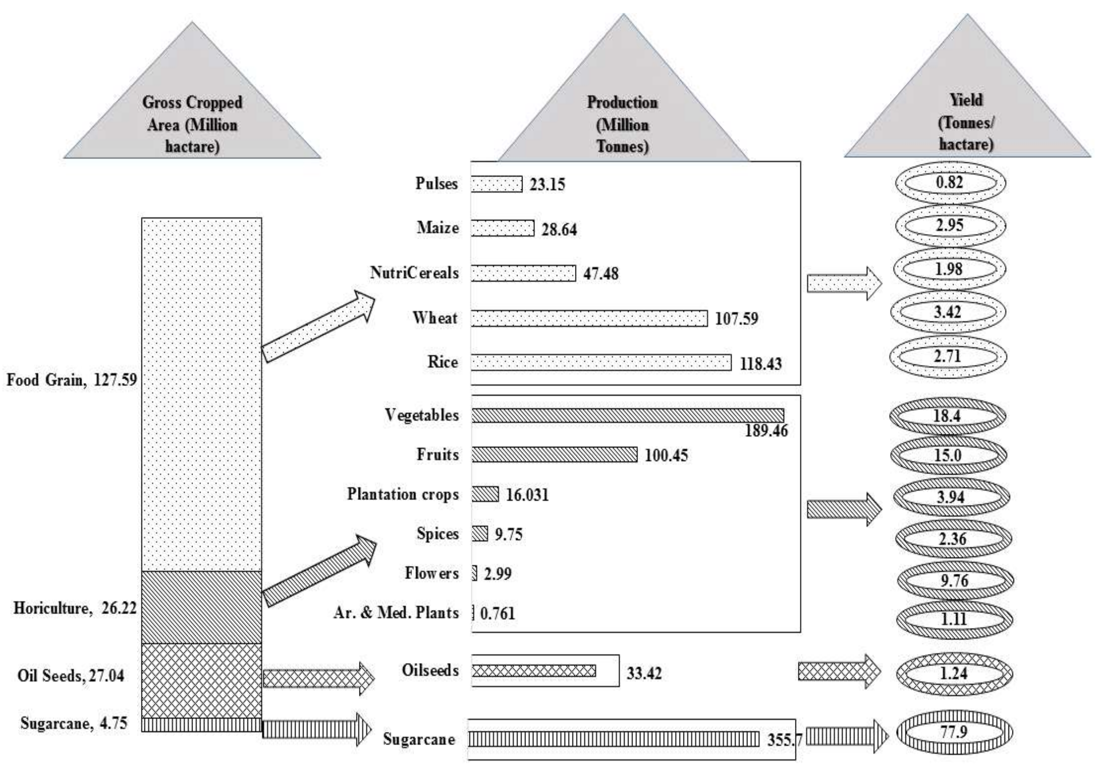


Fig. 2. Area, production, and yield of major food crops (2019-20). Ar: Aromatic; Med: Medicinal

were among the food grains. In that year, India's population of about 1.3 billion people had access to about 236 million metric tonnes of food grain. (Statista 2021, Economic Survey 2021). By 2023, per capita, cereal food consumption is expected to rise to 164 kg/person, up from 155 kg/person in the base period (2011-13), a 5.8% increase. Rice, wheat, and coarse grains per capita food consumption are expected to reach 78.8, 65.5, and 20.4 kg, respectively. Food consumption, which grew at a rate of 5% per year in per capita terms, is expected to reach a rate of 3% per year over the next decade. Imports are expected to increase to 5.1 Mt by 2023 as a result of excess demand (ICMR-NIN 2021).

Surplus to hunger: The unsolved conundrum: Agriculture's current state specifies surplus agri-food output for India's current population. The agricultural investments and technical advancements had succored in increasing productivity. The quandary arises when one considers the statistic that nearly one-third of the food produced in the world each year is lost or wasted, even though there are 1.3 billion hungry people to feed. Despite increased agricultural-food production output, one-fourth of the world's hunger is accounted for in India. The majority of small-scale and marginal farmers are losing access to food. Farmers are unable to reach financial satisfaction and 14.8 percent of the population is malnourished and 38.4 percent of children lack food and nutrition security. If no further efforts are made to promote the 'business-as-usual situation, nearly 653 million people will remain malnourished in 2030 (FAO 2017).The estimated demand and supply estimates of food grains and other major crops in India 2020-21 shows that there is an excess of rice, wheat, and cereals while a shortage of pulses, oilseeds, and sugar (Table 2). The surplus amount should be managed to address the issue of food insecurity, while the loophole should be mended to balance the demand and supply chain.

In India, grain production is continuously facing a burden due to several factors such as steady growth in population (to reach 1366.8 Million by 2020-21), reduction in agricultural land, and several other deterrents. GHI report (2021), states that India holds the 101st position out of 116 countries in the Global hunger index. According to the Reserve Bank of India (RBI), the country has now touched a point where surplus food grain management has become a serious problem. Inefficient food supply chain management has also been attributed to the starving condition of the people whereas headlines proclaim a "resource constraint" that is weighing down the Indian government's frantic attempt to feed a starving population. Food Corporation of India reports that country had saturated its storage options, due to the excess stock of grains (Rawal et al 2020).This appears to be the situation for the previous three years that food stockpiles were hoarded as a result of the chaotic preferential structure of public distribution. A large volume of grain (71.8 lakh tonnes) is supposedly rendered useless throughout this procedure (Rawal et al 2020). This is a heartbreaking scenario where the people are starving rather than sufficient

Table 2. Demand and supply estimates of food grains and other major crops in India (Million tonnes)-2020-21

Commodity	Demand (Million tonnes)	Supply (Million tonnes)	Surplus/ shortage
Rice	108.16	119.76	11.6
Wheat	95.71	107.18	11.47
Coarse Cereals	45.44	46.96	1.52
Cereals	249.31	273.9	24.59
Pulses	26.05	23.73	-2.32
Food grains	275.36	297.63	22.27
Oilseeds	58.92	37.81	-21.11
Sugar	39.66	36.07	-3.59

Source: Directorate of Economics & Statistics

Table 1. Per capita net availability of food grains in India (Kg year^{-1})

Year	Rice	Wheat	Other cereals	Cereals	Pulses	Food grains
2011	66.3	59.7	23.9	149.9	15.7	170.9
2012	69.4	57.8	21.9	149.1	15.2	169.3
2013	72.1	66.8	19.2	158.1	15.8	179.5
2014	72.3	66.8	22.6	161.6	16.9	178.6
2015	67.9	61.3	28.4	153.8	16	169.8
2016	67.2	72.9	26.1	162	15.7	177.7
2017	66.8	66.7	29.4	158.4	20	178.4
2018	69.2	61.5	30.6	161.3	18.7	180.1
2019	70.1	64.6	28.6	163.3	17.2	180.5
2020 (P)	73.4	64.8	31.3	169.6	17.5	187.1

Source: Directorate of Economics & Statistics; (P) Provisional availability due to inefficient resource distribution channels. In India, People are dying and the situation appears to create a surplus of hungry despite a surplus of food. Importing food is akin to importing unemployment is primarily agrarian nations. The Subcontinent must strive for self-sufficiency by safeguarding its genetic heritage and distributing 'extra' grain that, surprisingly, fails to reach people in need. The crucial question of defining surplus who produces it and how it is produced has been uncleared by several racketeers masquerading as philanthropists. The hunger issue is that the so-called international community, which has been at the forefront of a slew of dubious campaigns to benefit transnational corporate interests under the guise of bringing welfare to the masses, has been using its political clout to pursue nefarious agendas. At the first World Food Summit (WFS) in Rome in 1996, Heads of States of all countries of the world had “reaffirmed” the right of people to access “*safe and nutritious food, consistent with the right to adequate food and the fundamental right of everyone to be free from hunger*”. Their unacceptable consideration shows that in the whole world, people more than 840 million did not have sufficient food to meet their basic nutritional needs. As the coexistence of massive extra stocks and a large hungry population in India demonstrates, hunger is more than a matter of productivity and surplus (Eide 1998).

Challenges regarding food accessibility: Environmental breakdowns are also one of the leading shortage of food despite excess production as a result of post-harvest losses, the food-security and anti-poverty schemes of the government seems to have critical gaps such as inefficient food distribution system, interrupted market supply chain, efficient modern retail, Cold storage and hygienic food packaging. Activists and researchers have offered clashing purposes behind suicides, like monsoon failure, high obligation troubles, hereditarily adjusted yields, public psychological well-being, private matters, and family issues. To keep transparency between the farmer and civilian, the government should take some initiatives and try to start a digital marketing platform. Inter-state and-district restrictions on promoting and effort of agricultural goods are heavily regulated within India. By a slow and incapable chain of traders, food travels to the Indian consumer. Through poor roads, basic market organization, and unnecessary guidelines, Farmers' access to markets is vulnerable. In India, rural roads were poor which affected the timely transfer of outputs and supply of inputs from Indian farmers. By a slow and incapable chain of traders, food travels to the Indian consumer. The absence of coordinated retail and contending purchasers in this way restricts Indian farmers' capacity to sell the excess and commercial crops. The farmer of India gets only 10 to 23% of the value the Indian purchaser pays for the very same product, the distinction going to losses, inabilities, and mediators. Cold storage, food packaging other than safe and efficient rural transport system causes the world's highest food spoilage rates, especially during Indian monsoons and other adverse weather conditions. In India, excess production is done in states like Punjab, Haryana, Maharashtra, Karnataka, and Uttar Pradesh but their poor management leaves many people hungry due to the absence of infrastructure such as storage and transportation facilities (Sharma 2016).

Proposed solutions and way forward: The PDS plays an important role in addressing food security and can be made more efficient by reinforcing the role of states in PDS

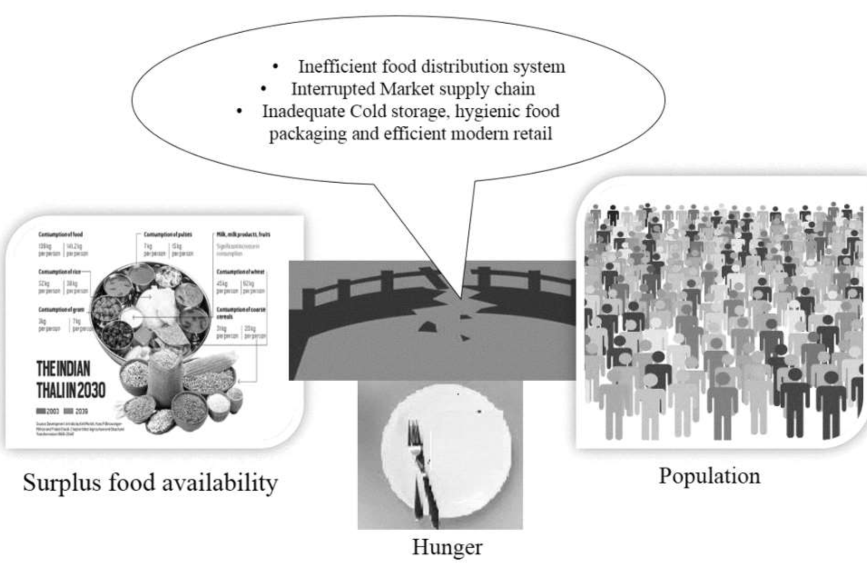


Fig. 3. Challenges regarding food accessibility

coordination, as well as improving transparency and accountability, monitoring measures to address issues of corruption, diversion, and leakages, and better partnerships between the federal and state governments. If supported and implemented, the role of information and communications technology has the potential to be a significant component of success. Computerization can improve the operation of PDS and reduce some leakage as digitalization spreads throughout the public sector. It can help identify beneficiaries and eliminate targeting-related inclusion and exclusion errors while also boosting openness and accountability. The use of a global positioning system to trace the food supply chain is another technology that is now being tested in some locations. This strategy ensures that commodities are scanned in and out at all points of the supply chain, and has proved to reduce corruption, leakages, and diversion, as well as increase the quality of goods given to consumers once the system was implemented (George et al 2019). Agribusiness should be made accessible for producers as well as consumers for providing a good market chain. There should be a common platform for the e-business of agri-food. Although several companies have provided their applications of agri-marketing that is in scattered forms, so an effort should be made to bring them under one platform and make it easy to use for producers as well as consumers. This application will make it easy to select the consumer and farmer's necessities, which will help to maintain transparency between the farmer and consumer. With the help of these applications, farmers may get complete information about eliminating black marketing and inflation. Some features such as feasibility in all languages as well as voice recognition for illiterate farmers should also be introduced in the digital application (Sivakumar et al 2021). There are some benefits of digital marketing which includes-

- Save effort and time.
- Good quality and variety at superior prices.
- Terminating dependency on vendors in prices of agri-food products.
- Reducing wastage and betterment of storage.
- Encouraging the formation of cooperatives.
- Earnings for both civilians and farmers with the least wastage by regular sale.

Digital marketing in the agriculture sectors showed most prominent and valuable importance. Farming and agribusiness should grow in India The global level of farming and agribusiness should be grown in India to compete with the complexity of subsectors like agricultural machinery, precision agriculture, farm equipment, chemicals, crop production, supply-chain services, and many more (Radd Interactive 2021). In India, there are some barriers to using and making the e-Application in the agri-food supply chain. These barriers are deliberately significant for e-Applications which are helpful knowledge to the policymakers and partners by zeroing in on those key boundaries which are significant for successful e-Application in the agri-food store network. Throughout some period, diverse empowering influences especially information technology (IT) helped in spreading the convenience of Proper supply chain management (SCM). Various utilization of SCM with its assistance can be brought about expanded responsiveness, diminished waste, cost-saving, and higher benefit (Kumar et al 2014). In India, up gradation in road and power generation infrastructure can help to increase agricultural productivity between 40-50% within 40 years. Adoption of smart agriculture in the industry farmers all around the world are being introduced to new situations as a result of Industry 4.0. Smart farming encourages not just a rise in agricultural production and revenue, but also the development of resistance to climate change (Kumar et al 2021). Aside from that, the number of cold storage facilities should be raised, and new technical interventions should be implemented to improve cold storage. This will assist to reduce food waste and make food available to those in need.

CONCLUSION

The main goal of this empirical study is to determine the production, availability, accessibility, demand, and supply of agri-foods, amid India's technological transition. Our suggestion for agri-foods insights is to adopt technological intervention at every step of the agriculture value chain that will assist producers and customers in getting the most out of their inputs. Efforts should be made to embrace digitalized agri-food marketing applications, improved agri-logistic facilities, better and technically improved cold storage, digital monitoring for PDS, and to check and rectify gaps in government efforts. All this together will assist in overcoming the obstacles for all, and the surplus will not be wasted, but will instead be put on the table, eliminating hunger.

AUTHOR CONTRIBUTIONS

All authors have made a substantial and direct contribution to the work.

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Received 06 February, 2022; Accepted 22 May, 2022

Indian Journal of Ecology (2022) 49(3) (SI): 994-1004
DOI: https://doi.org/10.55362/IJE/2022/3627

Manuscript Number: 3627
NAAS Rating: 5.79

Heavy Uses of Pesticides in India: A Quantitative Analysis

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Abstract: India is an agrarian country. The pace in the use of agricultural pesticides has increased significantly over the decades. In 2020-21, Maharashtra (13243 tonnes) and Uttar Pradesh (11557 tonnes) would have the highest pesticide use, while Punjab (5193 tonnes) and Haryana (4050 tonnes) pesticide consumption slowly decreased as compared to last year. The states of Punjab, Uttar Pradesh, Maharashtra, Haryana, and Andhra Pradesh consumed 70% of all pesticides. Maximum pesticide usage is harmful to humans, animals, and plants. Many researchers discovered pesticide residue even in fishes (37.56 mg l^{-1}, 38.38 ng g^{-1}, 101.28 ng g^{-1}), and mother milk (43.40±0.064 mg kg^{-1}, 33.33±0.055 mg kg^{-1}, 3.45±0.022 mg kg^{-1}) which is an alarming situation. In this review, we try to analyze and draw the full picture related to the excessive usage of pesticides in different states of India and their hazardous impacts on the human body, water, and the environment.

Keywords: Agriculture, Pesticide residue, Insecticides, Herbicides, Health

The economy of India is predominantly based on agriculture which contributes around 18% to the total GDP (Singh and Neog 2020). Pests are estimated to cause a US $42.66 million annual loss of agricultural production in India (Subash et al 2017). Diseases (26%), insects (20%), rodents and birds (10%), weeds (33%), and some other reasons are the roots of this loss (Chauhan et al 2018). Around 30,000 species of weeds, 10,000 species of plant-eating insects, and 3,000 species of nematodes are known to affect crops. Moreover, the land under cultivation is also decreasing due to a significant rise in urbanization. The use of pesticides plays a key role in improving agricultural productivity (average crop yields per hectare) by reducing crop losses due to insects, pests, pathogens, and weeds. This ensures security for rising food demand driven by the continuously growing population, overcoming the problem of reducing arable land, and generating revenues for farmers (Pawlak and Kołodziejczak 2020, Barrett 2021). The significance of pesticides in agricultural production has led to their unregulated and uncontrolled usage depending on monsoons, pest attack incidence, and inadequate knowledge about usage and hazards of pesticides among farmers. The indiscriminate use of pesticides in improving productivity has resulted in the contamination of the environment, agricultural output foods, and bioaccumulation in animals and humans (Kumar et al 2019, Sharma et al 2020, Mishra et al 2021, Rajput et al 2021). The problem will get worse in the future as new pests, weeds and diseases will attack crops which will further increase the use of pesticides and demand for new forms of pesticides. The well-established correlation between pesticide contamination and hazardous effect on the environment and human health has necessitated the need for new effective and ecologically acceptable methods for pest control.

State-wise pesticide consumption in India: According to the Ministry of Agriculture and Farmers Welfare, Department of Agriculture, Cooperation and Farmers Welfare, Directorate of Plant Protection, Quarantine and Storage, the consumption of pesticides in India was 62193 tonnes during the year 2020-2021. The consumption of pesticides has gradually increased over the years. It has shown a sharp increase from 434 tonnes in the year 2000 to 62193 tonnes in 2021 (GOI 2021).

Similarly, per hectare consumption of pesticides has also increased over the years. It has grown to 600 grams per hectare in 2020 from 290 grams per hectare in 2014-2015 (Subash et al 2017). The increase in both total as well as per hectare consumption is corroborated by an increase in domestic production and imports of pesticides (State of Agriculture). At the global level, per hectare, pesticide consumption of India is low (600g) as compared to Japan (12kg), China (12 kg), United Kingdom (7 kg), and Germany (3kg) (Koli and Bhardwaj 2018, Parajuli et al 2021). In India, Maharashtra is the leading consumer of pesticides and the 2020-2021 consumed 13,243 tonnes of pesticide which accounts for 21.2% share of the total consumption (Table 1). Other leading consumer states include Uttar Pradesh, Punjab, Telangana, Haryana, West Bengal, and Jammu & Kashmir (Subash et al 2018, GOI 2021). A sharp increase in consumption has been observed in Jharkhand, Nagaland,

and Jammu, and Kashmir between 2016-2017 and 2020-2021 (GOI 2021). The per hectare consumption of pesticide is highest in Punjab (0.74 kg), followed by Haryana (0.62 kg) and Maharashtra (0.57 kg) during 2016-17 while the consumption levels were lower in Rajasthan, Madhya Pradesh, Karnataka, and Bihar (Sharma et al 2016, Subash et al 2017).

In India, pesticide consumption from 2016-2021, the maximum pesticide consumption was the 2020-21 meanwhile minimum consumption was in 2016-2017 (DAC&FW 2017, GOI 2021). Pesticides have proven to be a boon to farmers, increasing agricultural yields by a huge margin and providing innumerable benefits to society in terms of food security, both directly and indirectly (Mishra et al 2021). The recent increase in pesticide use is said to be because of the higher use of herbicides as the cost of manual weed control has risen due to an increase in agricultural wages (Dhaliwal et al 2000, Subash et al 2017).

In 2020-21, 38% cereals, 10% pulses and oilseeds, 14% cash crop, 11% vegetables, 9% fibres, 4% fruits, 3% other, and 1% in plantation was used pesticide for production. In 2019-20, 37% cereals, 11% pulses and oilseeds, 12% cash crop, 10% vegetables, 11% fibres, 5% fruits, 2% other, and 1% in plantation was used pesticide for production (Table 2). In 2018-19, 39% cereals, 13% pulses, 11% cash crop and oilseeds, 9% vegetables, 8% fibres, 6% fruits, 2% other, and 1% in plantation was used pesticide for production. In 2017-18, 34% cereals, 14% pulses, 9% cash crop and vegetables, 13% oilseeds, 12% fibres, 5% fruits, 3% other, 1% in plantation was used pesticide for production. During 2016-17, 40% cereals, 13% pulses, 12% cash crop, 11% oilseeds, 10% vegetables, 9% fibres, 2% fruits and other, 1% in plantation was used pesticide for production (Bodh and Yadav 2020, GOI 2021).

3% of the cost of cotton cultivation, 1.9% of rice production, and even less of wheat (0.7%) and sugar cane

Table 1. Consumption of chemical pesticides in various states/Union territories (GOI 2021)

States/UTs	Total pesticide consumption (tonnes)				
	2016-17	2017-18	2018-19	2019-20	2020-21
Andhra Pradesh	2015	1738	1689	1559	1559
Bihar	790	840	850	850	995
Chhattisgarh	1660	1685	1770	1672	1639
Goa*	22	24	25	30	30
Gujarat	1713	1692	1608	1784	1573
Haryana*	4050	4025	4015	4200	4050
Himachal Pradesh	341	467	322	881	56
Jharkhand	541	619	646	681	1161
Karnataka	1288	1502	1524	1568	1930
Kerala	895	1067	995	656	585
Madhya Pradesh	694	502	540	540	691
Maharashtra	13496	15568	11746	12783	13243
Orissa	1050	1633	1609	1115	1158
Punjab	5843	5835	5543	4995	5193
Rajasthan	2269	2307	2290	2088	2330
Tamil Nadu	2092	1929	1901	2225	1834
Telangana	3436	4866	4894	4915	4986
Uttar Pradesh	10614	10824	11049	12217	11557
Uttarakhand	198	210	195	224	135
West Bengal	2624	2982	3190	3630	3630
Assam	306	241	256	410	420
Nagaland*	20	20	21	19	36
Jammu and Kashmir*	2188	2430	2459	2198	3352
Total	58145	63006	59137	61240	63143

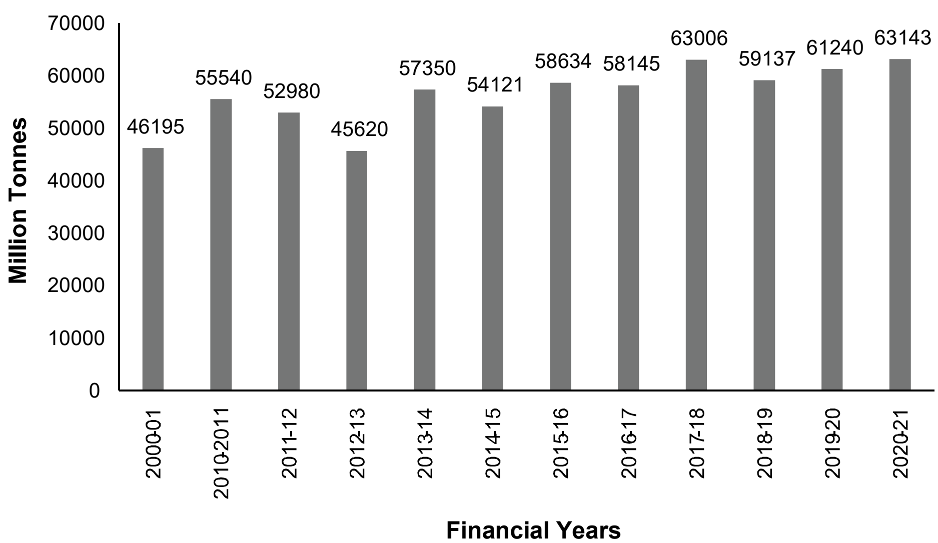
Source: States/UTs Zonal Conferences on Inputs (Plant Protection) for *Rabi* and *Kharif* Seasons
*Figures of 2019-20 for this State have been taken from inputs provided by the States/UTs during Zonal Conference (PP) for *Rabi,* 2020-21 Season

production was made up of pesticides (0.3 percent). According to statistics published by the Agricultural Input Survey (AIS), Cotton (66.70%), followed by Arhar (64.74%), Jute (53.27%), and Rice (48.62%) accounted for the largest share of the pesticide area in 2011-12 (Subash et al 2017, GOI 2021) with the introduction of Bt seed.

Quantitative Analysis of Pesticide Consumption in India

In agriculture, there has been wide use of pesticides to enhance crop yield by saving or losses caused by the pest. Availability of financial help at a low interest rate has also resulted in a hike in the use of pesticides (Krishnakumar 2019, Damalas and Koutroubas 2020). Pesticides are applied at the cultivation time as well as storage time of cereal grains, vegetables, and fruits. The indiscriminate and irrational use of pesticides is resulting in the accumulation of pesticides in food products and the environment. Some of the pesticides or their derived compounds are accumulated in the plant including the plant product (fruits, grains, nuts, vegetable oils, and vegetables) (Grewal 2017, Albuquerque et al 2020). This has finally led to the bio-magnification of pesticide residues in the food chain. Pesticide residues have been detected in fish, humans. Thus, bioaccumulation of pesticides is a serious concern. To keep a check on the quality of food or feed being consumed, the government, as well as other organizations, have set a maximum residue level (MRL) for every pesticide (Abhilash et al 2009, Charon et al 2019, Crépet et al 2021). Different countries have different authorities to regulate MRL values for different pesticides. At the global level, the MRL value remains variable. In India, the MRL value of crops, fruits, vegetables, grains, and other consumed food is set by the Food Safety and Standards Authority of India (FSSAI) (Li 2018, Koli and Bhardwaj 2018).

Water sampling collected from three locations (Palur



Source: Based on the data Ministry of Agriculture and Farmers Welfare

Fig. 1. Trend in total consumption of pesticides (GOI 2021)

Table 2. Demand of chemical pesticides on commodity basis (in million tonnes)

Crops	2016-17	2017-18	2018-19	2019-20	2020-21*
Cereal	18356	15674	17270	14937	17149
Vegetable	4683	4186	3845	3870	4773
Pulse	5837	6594	5759	4390	4567
Oilseed	4979	5707	4881	4565	4723
Fruit	1194	2171	2449	2242	1665
Plantation	327	420	432	310	338
Cash Crop	5429	4144	4995	4832	6090
Fibre	4128	5336	3567	4281	4006
Other	892	1563	1055	861	1388

*The Commodity-wise data for 2020-21 has been provided by 17 States in Zonal Conference agenda for Kh,2021 (As on 31.03.2021)

Bridge, Daya River Estuary, and Makara River) that revealed organochlorinated (OC) pesticide residues were found in nearly a quarter of the water samples (Kunwar et al 2021). So, Hexachlorocyclohexane (HCH) (&), DDD (Di-chlorodi phenyl di-chloro ethane) (op|), DDE (di-chloro di-phenyl di-chloro ethylene) (op|&pp.|), and heptachlor were detected in concentrations ranging from 0.025 to 23.4 g l^{-1}. None of the eight synthetic pyrethroid (SP) pesticides were detected in water, however chlorpyrifos (0.019–2.73 g l^{-1}) and dichlorvos (0.647 g l^{-1}) were discovered among the organophosphates (OP) (Nag et al 2020). Fish samples were found to be 55 percent polluted, predominantly with OCs and OPs residues and less with SPs. However, because their concentrations were below the allowable limit, there is no immediate harm for human health (Dey et al 2021, Kunwar et al 2021a). Sharma et al 2020 stated that in north-western Himalayan region, mother milk was contaminated with pesticide residue such as p-p'- DDE was found in Sub-mountainous subtropics range of 43.40±0.064 mg kg^{-1}, Sub-humid foot hill is 33.33±0.050 mg/kg, wet, temperate high hill is 3.45±0.022 mg kg^{-1}, p-p'-DDT found in range of Sub-humid foot hill (1.96±0.018 mg kg^{-1}), and wet, temperate high hill (3.45±0.010 mg kg^{-1}) (Table 3). Kumar et al 2020 reported that in tomato and okra pesticide residue was found near Navsari district, Gujarat such as Tomato (92.54 ng g^{-1}(acetamiprid), 87.17 ng g^{-1} (tebuconazole) and Okra (86.10 ng g^{-1} (acetamiprid), 85.94 ng g^{-1} (tebuconazole). There are a lot of growing reports on the presence of pesticides in breastmilk samples from India. Organochlorines, organophosphate, and pyrethroid pesticides have been detected in human breastmilk from the population of Haryana (Mehta et al 2020). Pesticides have been also detected from cow milk, packaged water and soft drinks (Bunch et al 2003, Năstăsescu et al 2020, Tsakiris et al 2021). Some more pesticide residue report in research articles such as:

Implications of heavy use of pesticides: In humans, the bioaccumulation of pesticides is through inhalation or dermal exposure at the pesticide production unit, at the time of use in the fields, consumption of food containing pesticides like agricultural food, fish, or meat chain or passed to infants through breast milk feeding. Occupational exposure has higher chances of resulting in bioaccumulation in humans. Owing to the lipophilic character of pesticides, they usually get in stored in adipose tissue (Pyka and Miszczyk 2005, Dhaliwal et al 2010). Toxicity effects of a pesticide are a factor of quantity and toxicological metabolized properties of pesticide. Organophosphates and pyrethroids are readily by enzymes in the body, so they do not get stored or accumulated. Bioaccumulation in humans build to harmful levels is associated with hazardous short as well as long-term effects (Sharma et al 2020, Rani et al 2020, Hassaan and El Nemr 2020). There is a great possibility binding to acetylcholinesterase of the target pest finally leads to the immune system. The mechanism of work of many pesticides which that the human nervous system will be also affected by the accumulation of pesticides in their body because of common brain chemistry (Sharma et al 2020, Amenyogbe et al 2021).

Ecological effects: The concentrations of organochlorine pesticides (OCPs) in the soil were compared with relevant soil environmental recommendations for ecological risk of OCPs in the soil to estimate the possible ecological danger of OCP residues in the soil. As a consequence, our findings were compared to soil quality requirements recommended by the Canadian government, the National Oceanography and Atmospheric Administration (NOAA) of the United States, the Italian government, and the Chinese government (Kumar et al 2018). DDT (Dichlorodiphenyltrichloroethane) concentrations of up to 1200 ng g^{-1} in commercial and industrial soil and 700 ng g^{-1} in residential and agricultural soil are allowed by the Canadian government (Chakraborty et al 2017). Hexachlorocyclohexane (HCH) levels in agricultural soil should range from 50 ng g^{-1} to 2000 ng g^{-1} in residential soil, according to NOAA (Devi et al 2015, Chakraborty et al 2017). The concentrations of HCH and DDT in all soil samples in our investigation were lower than the Canadian government's and NOAA's suggested guideline ranges. In residential and recreational zones, permissible soil concentration limits for aldrin, dieldrin, and endrin are set at 10 ng/g by Italian environmental legislation (Qu et al 2017). Endrin concentrations in eight soil samples and dieldrin concentrations in three soil samples were found to be higher than the Italian government's limit of 10 ng g^{-1} in our study. The Chinese government defined soil quality as low contaminated (less than 50 ng g^{-1}), lightly polluted (50–500 ng g^{-1}), moderately polluted (500–1000 ng g^{-1}), and seriously polluted (more than 1000 ng g^{-1}) based on HCH and DDT concentrations (Kumar et al 2018, Gereslassie et al 2019, Joseph et al 2020). The amounts of HCH and DDT in all of the soil samples in this investigation fell into the low to moderate contaminated category, according to Chinese government recommendations. For the protection of plants, invertebrates, small birds, and mammals, the maximum permitted concentrations of DDTs in soil are 10, 11 and 190 ng g^{-1}, respectively (Yu et al 2013, Qu et al 2015).The common method of pesticide application is spraying over crops. When the crop is irrigated or rain occurs after the application, the pesticides leach into the soil and finally reach the groundwater. This results in contamination of both soil and water with pesticides. Synthetic pesticides have a very

Table 3. Pesticide residue in different samples

Sample	Sites	Analytical method	Major finding	Pesticide	Reference
Ground water	Thiruvallur district, India		Value (µg L^{-1}) (Structure) 0.1-0.8 (op-DDT) 0.9-3.7 (pp-DDT)	DDT	Jayashree and Vasudevan 2007
			0.1-1.8 (αES) 0.3-3.8 (β ES)	Endosulfan	
			0.02-1.5 (α HCH) 0-0.5 (β HCH) O.1-2.3 (γ HCH) 0-0.9 (δ HCH)	HCH	
Pink lady apple		LC- MS	Value (mg kg^{-1}) (Sample Processing) 6 (No wash) 3.5 (lukewarm wash) 2 (Salted water wash)	Diphenylamine	Dasika 2012
			8 (No wash) 5 (lukewarm wash) 4 (Salted water wash)	Phosmet	
			0.14 (No wash) 0.1 (lukewarm wash) 0.08 (Salted water wash)	Chlorpyrifos	
			0.9 (No wash) 0.7 (lukewarm wash) 0.6 (Salted waterwash)	Malathion	
Pear		LC- MS	6.1 (No wash) 4.3 (lukewarm wash) 3.4 (Salted water wash)	Diphenylamine	Dasika 2012
			3 (No wash) 2.1 (lukewarm wash) 1.8 (Salted water wash)	Imazalil	
			11 (No wash) 8.9 (lukewarm wash) 8.8 (Salted water wash)	Phosmet	
			0.6 (No wash) 0.3 (lukewarm wash) 0.2 (Salted water wash)	Chlorpyrifos	
Guava		LC- MS	4.8 (No wash) 2.2 (lukewarm wash) 1.2 (Salted water wash)	Diphenylamine	Dasika 2012
			4.2 (No wash) 3.6 (lukewarm wash) 3.4 (Salted water wash)	Imazalil	
			9.3(No wash) 7.9 (lukewarm wash) 7.2 (Salted water wash)	Phosmet	
			0.43 (No wash) 0.28 (lukewarm wash) 0.18 (Salted water wash)	Chlorpyrifos	
Indian egg plant		LC- MS	9.8 (No wash) 5.3 (lukewarm wash) 4.4 (Salted water wash)	Diphenylamine	Dasika 2012
			4.2 (No wash) 2.5 (lukewarm wash) 1.8 (Salted water wash)	Imazalil	
			9 (No wash) 8. (lukewarm wash) 6.8 (Salted water wash)	Phosmet	
			1.4 (No wash) 1 (lukewarm wash) 0.8 (Salted water wash)	Chlorpyrifos	
Chinese egg plant			2.2 (No wash) 1.9 (lukewarm wash) 1.5 (Salted water wash)	Endosulfan	Dasika 2012

Cont...

Table 3. Pesticide residue in different samples

Sample	Sites	Analytical method	Major finding	Pesticide	Reference
			9.8 (No wash) 7.3 (lukewarm wash) 6.1 (Salted water wash)	Diphenylamine	
			3.8 (No wash) 2.9 (lukewarm wash) 2.4 (Salted water wash)	Imazalil	
			9.3 (No wash) 6.9 (lukewarm wash) 6.4 (Salted water wash)	Phosmet	
Vegetables and Fruits	Bangalore Rural District		Value (mg/kg) (Sample) 0.057-2.818 (Potato) 0.05-2.241 (Tomato) 0.003-0.009 (Grapes)	Endosulfan	Ramesh and Murthy 2013
			0.013-0.372 (Potato) 0.04-0.078 (Tomato) 0.039-0.068 (Grapes)	MethylParathion	
			0.115-0.513 (Potato) 0.02-2.047 (Tomato)	Malathion	
			0.01-0.09 (Potato) ND (Tomato)	Chlorpyrifos	
			0.003-0.009 (Grapes)	Acephate	
			0.039-0.068 (Grapes)	Cypermethrin	
Mango and Grapes		HPLC	Value (μg kg^{-1}) (Collection area) Mango 13.64± 0.43 (Garden) 10.65± 0.28 (Local market) 8.54± 0.55 (Reliance fresh) Grapes 14.85± 0.34 (Garden) 11.27± 0.50 (Local market) 8.63± 0.24 (Reliance fresh)	Methyl parathion	Rao and Kumar 2012
			Mango 7.38± 0.34 (Garden) 6.39± 0.67 (Local market) 5.35± 0.28 (Reliance fresh) Grapes 9.37± 0.09 (Garden) 8.81± 0.64 (Local market) 7.67± 0.45 (Reliance fresh)	Fenvalerate	
Ornamental Plants	(Pakkam, Thiruvallur district, Chennai, Tamil Nadu) Depth of Soil Surface Soil (0-15 cm) Sub-surface soil (15-30 cm) Sub-surface soil (30-40 cm)	GC	Value (mg kg^{-1}) (Collection range) 1.42±0.16 (0-15cm) 0.6±0.14 (15-30cm) 1.5±0.28 (30-40 cm)	α-Endosulfan	Odukkathil & vasudevan 2016
			1.28±0.04 (0-15 cm) 0.3±0.14 (15-30 cm) 0.9±0.14 (30-40 cm)	β-Endosulfan	
			ND (0-15 cm) 0.0005±0.54 (15-30 cm) ND (30-40 cm)	α-BHC(mg/g)	
			ND (0-15 cm) ND (15-30 cm) ND (30-40 cm)	γ-BHC(mg/g)	
			ND (0-15 cm) ND (15-30 cm) 0.013±0.21 (30-40 cm)	β-Cyfluthrin	

Cont...

Table 3. Pesticide residue in different samples

Sample	Sites	Analytical method	Major finding	Pesticide	Reference
Rice		GC	4.6±0.14 (0-15 cm) 1.4±0.28 (15-30 cm) 1.3±0.28 (30-40 cm)	α-Endosulfan	Odukkathil and vasudevan 2016
			3.1±0.08 (0-15 cm) 0.63±0.25 (15-30 cm) 0.34±0.04 (30-40 cm)	β-Endosulfan	
			0.39±0.06 (0-15 cm) 0.23±0.18 (15-30 cm) ND (30-40cm)	α-BHC	
			0.3±0.44 (0-15 cm) Nil (15--30 cm) Nil (30-40 cm)	γ-BHC	
			ND (0-15 cm) ND (15-30 cm) 6.64±0.0 (30-40 cm)	β-Cyfluthrin	
Mother Milk	North- western, Himalayan Region Zone I: Sub-mountainous subtropics Zone II: Sub-humid foot hill Zone III: Wet, temperate high hill Zone IV: Dry and temperate high hill	GC-MS	Value (mg kg^{-1}) Zone I 43.40±0.064 Zone II 33.33±0.050 Zone III 3.45±0.022 Zone IVNil	p-p'- DDE	Sharma et al (2020)
			Zone I Nil Zone II 1.96±0.018 Zone III 3.45±0.010 Zone IV Nil	p-p'- DDT	
Tomato	Navsari District, Gujarat	GC-ECD/LC-MS/MS	Value (ng kg^{-1}) 92.54	Acetamiprid	Kumar et al (2020)
			87.17	Tebuconazole	
Okra			86.10	Acetamiprid	
			85.94	Tebuconazole	
Andrographispaniculata (kalmegh)	Coimbatore(Tamil Nadu)	GC-ECD/FPD	72.3	Chlorpyriphos	Saha et al (2020)
	Maharashtra (Ahmednagar)		79.3	Deltamethrin	
Water (A)	Tapi River, Gujarat	GC	0.86 mg L^{-1} (A) Nil (B) 0.392 ng g^{-1} (C)	Chlorpyrifos	Hashmi et al (2020)
Sediment (B)			0.43 mg L^{-1} (A) 0.77 ng g^{-1} (B) 3.49 ng g^{-1} (C)	Methyl parathion	
Fish (C)			37.56 mg L^{-1} (A) 38.38 ng g^{-1} (B) 101.28 ng g^{-1} (C)	Endosulfan	
Carrot	Karnataka, India	HPLC	Value (mg kg^{-1}) 86.4	Acephate	Gowdaand Ramesh (2020)
			94.6	Chlorpyriphos	
			92.2	Dichlorvos	
			92.1	Phorate	
			86.9	Cyfluthrin-β	
			88.8	Fenvalerate	

low rate of degradation and remain persistent pollutants of the environment. Contaminated soil results in damage to the microflora and other soil organisms like nematodes (earthworms) which play important role in the fertility of the soil. Pesticide residues have been reported to cause a decline in amphibians. Kittusamy et al (2014) reported the presence of pesticide residue to be a reason for deformity in frogs.

Overuse of Pesticides: Prevention Strategy

The implementation of appropriate remedial measures aids in the reduction of pesticide toxicity and other health issues associated with pesticide use. The government is concerned about the negative effects of pesticides on human health and has taken several steps to address this, including banning most toxic pesticides, implementing a national implementation plan, implementing integrated pest management, and limiting the use of toxic chemicals (Yadav et al 2015). The irrational use of pesticides resulting in hazards to animals and the environment can be reduced by practising (Fig. 2) the following strategies:

Awareness of pesticide use: Farmers are unaware of the dangers of severe pesticide poisoning, but it is vital to underline the long-term impacts, which can cause a variety of neurological illnesses. Farmers are unfamiliar with the usage of contemporary pesticide spraying techniques (Ali et al 2020; Bant et al 2020). In India, Modern technology has been adopted by certain educated farmers, the majority of farmers are unable to do so due to a lack of education or money. Farmers are now required to be trained by agricultural producing firms because they are the primary users of the crops. This knowledge aids in the creation of local training programmes tailored to the needs of farmers. Farmers ignore health and environmental hazards in their pursuit of controlling pests and increasing productivity (Ataei et al 2021, Rani et al 2020).

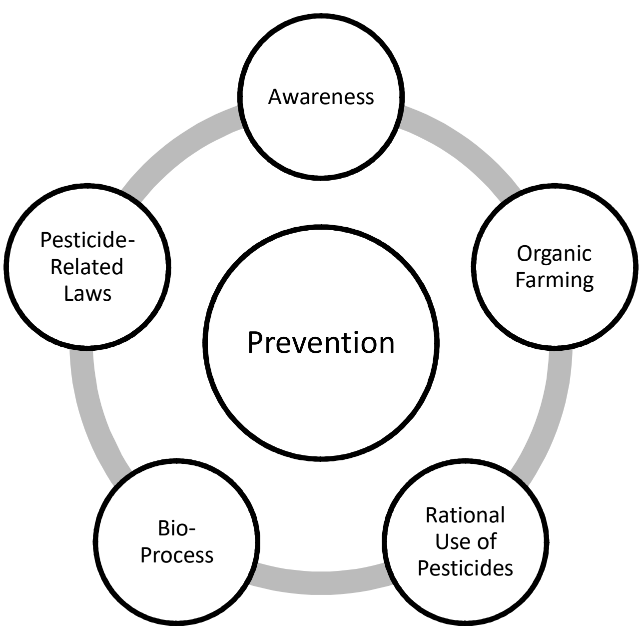


Fig. 2. Prevention of pesticide consumption

Rational use of pesticides (RUP): RUP focused mostly on the subset of IPM (Integrated Pest Management) and integrated Crop management (ICM), which aims to mitigate the negative effects of pesticide use via improved specificity and accuracy in pesticide usage with space and time of the products themselves. The benefits of RUP are boosted by combining all three, and the prospective benefits include lower costs (for pesticides as well as labour), reduced environmental impact (by more efficient spray application and use of selective chemicals such as biopesticides), and improved safety (Gupta et al 2010, Rani et al 2020). Thus, farmers were able to found accurate use of dosages and frequency of application of pesticides for controlling pesticides (GC and Palikhe 2021, Sarker et al 2020).

Green alternative approach: Organic farming is an environmentally adaptable approach, which is based on growing plants that have pest repellent properties. The most important aspect of organic farming is to inspire and increase organic cycles within agriculture structures in order to preserve and enhance extended soil fertility, minimise all types of hazards caused by fertiliser and pesticide use, and harvest food of superior quality in sufficient quantities. Pesticide residues in the food can be reduced by eating organic foods (Thakur et al 2020). Organic crops have more antioxidants, and greater intake of antioxidant-rich diets protects against long-term illnesses including cardiovascular disease, cancer, and neurological diseases (Garay et al 2020).

Bio-processes: Bioremediation is a crucial approach for removing pesticides from polluted areas. It has been regarded as an environmentally beneficial and economically viable method of cleaning the environment. It also doesn't produce any harmful byproducts. Microorganisms are often useful during the bioremediation process in converting pesticides into non-toxic chemicals, and as a result, their widespread usage has been recorded for the onsite breakdown of pollutants present in environmental systems. Microorganisms capable of degrading pesticides are commonly isolated from sludge, dirt, or aqueous solutions such as bio-pesticide, bio-fertilizers, etc (Tian et al 2018, Sharma et al 2016a, Zhu et al 2016). Furthermore, pesticide biodegradation has been done using a variety of fungal strains and bacteria (Maqbool et al 2016). Bioaugmentation involves adding microorganisms to contaminated locations with specified catabolic capacities or into a bioreactor to start the bioremediation process (Perelo 2010). In biostimulation, appropriate physiological conditions and nutrients must be provided for the proper growth of locally available microbes (Baker et al 2020, Fahad et al 2021, Kaur and Kaur 2020).

Implementation and amendment of pesticide-related laws: In India, the production of pesticides is governed by the Ministry of Chemical and Fertilizers, and their usage is monitored by the Ministry of Agriculture (Balkrishna et al 2021). Pesticides should be strictly regulated, and the bill should include measures prohibiting the sale and use of Class I pesticides. The World Health Organization classifies pesticides as extremely dangerous (Class Ia) or very hazardous (Class Ib) based on acute toxicity (Class Ib) (Buckley et al 2021). A clause in the bill should make it unlawful for a pesticide manufacturer to sell a pesticide without providing personal protection equipment or safety gear. There should also be mechanisms and standard operating procedures in place for acute medical crises. Before a pesticide registration application is processed, the registration-related provisions of the pesticide should explicitly contain a need and alternatives assessment. The use of organochlorine pesticides has been banned in 1990 but DDT, OCP, and HCH are still in use in India (Mehta 2020). India lacks defined government rules and regulations on the use of pesticides. Strict regulations should use be set by the government for the use of pesticides (Bonvoisin et al 2020, Hussin and Perbawati 2021). The proper test for efficacy, persistence, degradation rate, and toxicology of pesticides should be done before registering it legalized should be regular testing of environmental samples like soil and water to check for pesticide residues (Oudejans et al 2020).

CONCLUSION

The intended use of pesticides was to enhance crop production but its indiscriminate and excessive use had led to severe implications for humans and the environment. The pesticide residues have been reported to be present in the agricultural product at a concentration that exceeds the maximum permissible limit and have contaminated soil and water components of the environment. They even have entered the food chain and thus have serious long-term consequences. In order to achieve the balance between enhanced crop yields and be a healthy environment, different strategies including integrated pest management should be a major part of our agricultural practices. A nation like India, where there is such a wide array of plants, desperately needs more organic fertilizer that can also be used for pesticide management. If we take small steps toward organic farming, then we will overcome the effect of pesticides.

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Received 27 November, 2021; Accepted 22 April, 2022

Indian Journal of Ecology (2022) 49(3) (SI): 1005-1010
DOI: https://doi.org/10.55362/IJE/2022/3628

Manuscript Number: 3628
NAAS Rating: 5.79

Crop Production Prediction Models in Indian Agriculture: Possibilities and Challenges

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***Abstract*:** Agriculture sector is an important contributor to Indian economy. Wheat yield has decreased from 3.53 kg ha^{-1} (FY 2019) to 3.42 kg ha^{-1} (FY 2020). Crop production is affected by a lot of factors including climatological factors (temperature, precipitation), soil type and seed quality. Crop production prediction is an important aspect for farmers, agro based industries and policy makers. Many technological tools based on data mining models are being developed to draw correlation agricultural datasets and crop yield. The prediction methodology involves learning the pattern of crop yield during a set of conditions based on the previous years' data and thus predicting the yield in the current set of environmental parameters. The present paper focuses on commonly used models for crop yield prediction in Indian agriculture including artificial neural network, bayesian belief network, support vector machine, decision tree regression analysis, random forest, least absolute shrinkage regression operator and elastic net. A comparison of their efficiency has been drawn based on the previous studies.

Keywords: Agriculture sector, Climatological factors, Crop yield, Data mining, Prediction techniques

The agriculture sector is the backbone of India's food supply and economy. Many factors such as temperature, radiation, water availability and other environmental conditions affect the outcome of agriculture by influencing crop growth and development (Balkrishna et al 2021). Crop yield is important to farmers and other agriculture-related organizations and is critical to ensure the food security of a growing population, livelihoods of farmers and other agriculture-based organizations. India has faced several natural disasters such as drought and flooding resulting in loss of agricultural produce. Predicting agricultural yield ahead of time can play important role for quantitative and financial assessment of crop at the field level, planning for timely storage, transportation and marketing of agricultural products, fixing of sale prices by farmers and minimum support prices by policy makers and logistics planning by the agriculture-based industries (Jaiswal and Agrawal 2020). The progress in the latest technologies for global satellite observations and statistical models has led to the development of tools for crop prediction. Crop yield is predicted using various machine learning techniques based on mathematical and statistical methods. These tools help in making the relationship between meteorological factors and crop yield (Josephine et al 2020, Reddy and Kumar 2021, Vishal et al 2021). Data mining is an important approach involving database analysis, statistical analysis, and pattern recognition and thus plays a crucial role in extracting important information from large data. The data used for prediction includes meteorological data (temperature, rainfall, relative humidity), remote sensing data, and field statistics. Different data mining tools used for crop prediction include Artificial Neural Networks (ANN), Support Vector Machines (SVM) (Balkrishna et al 2020). A huge number of databases are used as input for crop prediction. Thus, choice of data mining tool, which can efficiently process the data, is critical for the accuracy of yield prediction. The present study focuses to discuss different data mining methods used for crop yield prediction and comparison of their accuracy.

Process of crop yield prediction: In general crop yield prediction methodology contains two phases- training phase (data is collected and pre-processed) and test phase (rules are generated which result in the prediction of yield as output) (Lata and Chaudary 2019). The crop yield prediction process is highlighted in Figure 1.

Collection of dataset: The first step in crop prediction is to feed the raw information. Crop yield is affected by agro-climatic factors which are further dependent on the field under study and agricultural practices. In India, climatic information of different places is collected by Indian Meteorological Department. The data is accessible without any charge.

Database pre-processing: The collection of data is followed by pre-processing the dataset for junk or noise removal. This includes arranging the data in a single file. The standard pattern includes columns with information of year, area, production, yield (production/area), monthly mean temperature, monthly mean rainfall, soil moisture, pH, etc. The data file is usually saved in .csv format.

Classification of data: The third step is to divide the data information into training and testing datasets. The splitting of data is done by train test split (scikit-learn). The training dataset contains useful information for training datasets to predict yield while the testing dataset employs the rest of the information for analyzing the performance of the system.

Crop yield prediction models used in India: Data mining tools used in agriculture are mainly of predictive type. A lot of data mining tools are currently being used for better interpretation, comprehension and making successful prediction based on large input data.The most common data mining tools used particularly in crop yield prediction in India are artificial neural network, bayesian belief network, support vector machine, decision tree, regression analysis, least absolute shrinkage regression operator (LASSO), elastic net (ENET) and random forest.

Artificial neural network: An artificial neural network (ANN) is an information processing model based on the working of the brain where a network of interconnected neurons processes the information (Fente and Singh 2018). ANN comprises a large number of simple processing units connected to form a complex network. Each of the units is capable of receiving and sending signals efficiently and has a standard topology in which one layer receives inputs, the other generates outputs and there are a lot of hidden layers in between. ANN works on supervised learning and is trained once to predict future patterns based on the pattern recognition of previous data used as input (Mahto et al 2021). This is the same as the human brain learning by examples. The accuracy of ANN increases with the amount of raw data provided. The mathematical model of ANN includes information about inputs, processing functions, and outputs.ANN is proving to be an important tool for crop production prediction. Using yield history and the responsible factors as input, the model can be configured for automatic learning of the pattern. The accuracy of ANN increases with the amount of raw data provided. The mathematical model of ANN includes information about inputs, processing functions, and outputs. ANN is proving to be an important tool for crop production prediction. Using yield history and the responsible factors as input, the model can be configured for automatic learning of the pattern. ANN efficiently resolves the nonlinear relation complexity existing between crop production and various predictor parameters provided as input. This can be used to generate predictions of the flood, pest attack, and rainfall patterns. Rice yield in Maharashtra was predicted using ANN with the accuracy of 97.5% and specificity of 98.1 (Gandhi et al 2016a).

Regression analysis: Regression modelling is based on evaluating the dependence of a dependent variable (predictant) on one or more independent variables (predictors) (Gonzalez-Sanchez et al 2014 Kumari et al 2016, Champaneri et al 2020). In crop yield prediction, yield is the dependent variable and all other agro climatic factors like temperature, rainfall, relative humidity, soil characteristics are considered as independent variables. Multiple regressions are employed when more than one independent variable is used as input. Stepwise multiple linear regressions (SMLR) is a regression technique where potential variables are added and weakly correlated variables are removed at each step based on the p-value and checked for statistical significance. Kadbhane and Manekar (2020) developed Agro-Climatic Grape Yield (ACGY) model based on multi regression analysis. Climatic factors for every month were used as input parameters. The performance of the statistical model was tested in the terms of discrepancy ratio (1.03), the standard deviation of discrepancy ratio (0.19), mean percentage error (0.03%), and standard deviation of mean percentage error (0.19). The model showed an increase in grape yield in the year 2050 in comparison to the current yield.

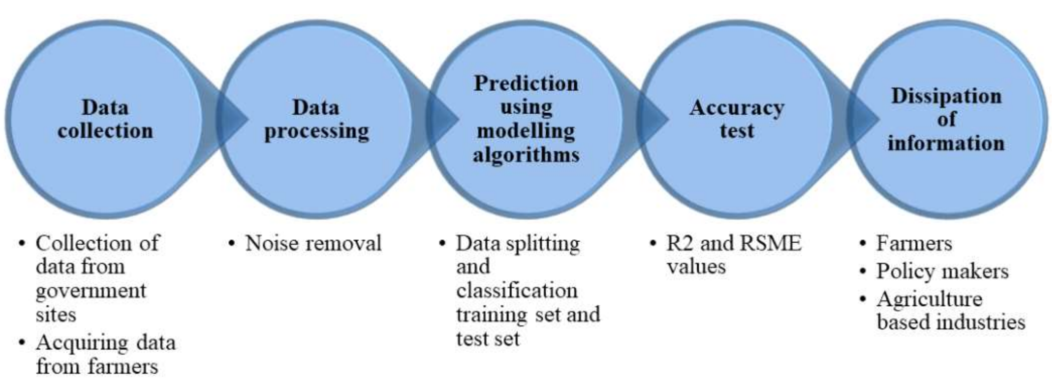

Fig. 1. Flow chart representing crop yield prediction process

Different models based on regression analysis are used in crop yield prediction. Some of these are- shrinkage regression (supports multicollinearity by correcting the level of regression coefficients), ridge regression (maintains all predictors by imposing specific penalties), least absolute shrinkage, and selection operator (LASSO) and Elastic net regression (ENET). The LASSO and ENET models are shrinkage regression models that can manage multicollinearity, regularisation, and variable selection to increase statistical model prediction accuracy and interpretability. For a consistent regression coefficient and automatic variable selection, LASSO eliminators are used. LASSO regression creates models that are simpler and easier to understand since they use a smaller number of factors. Like RIDGE, ENET essentially decreases coefficients and sets some coefficients to zero (like in LASSO). ENET minimises the impact of many elements while not completely eliminating them. Lambda (1) and alpha (0.5) are two parameters used in both LASSO and ENET that must be optimised for the specific study. Wheat yield forecast was done using Lasso (Least absolute shrinkage and selection operator) regression technique (Kumar et al 2019). R2, RMSE, and MAPE parameters were found to be 0.95, 99.27, 2.7 which are statistical parameters for the validation of the accuracy.

Support vector machine: Support vector machine (SVM) is a classification-based regression model in which every information is plotted in a different dimension (Yang et al 2015) and creates a set of hyperplanes with more or infinite coordinates in boundless dimensional space, in which every data variable is mapped to a coordinate. The model learning training is based on linear function but for nonlinear cases, the model employs kernel functions to plot datasets to more dimensional coordinates. SVM is a simple technique where only a few parameters are to be adjusted for the optimization of the model. The model's classifier feature is capable to differentiate between crop and weed plants. Prediction of rice yield in India was performed using SVM-based classification models (Kumar et al 2019). The study employed one against-one multi classification process, training based on kernel function, and cross-validation using k-fold. The dataset used for the modelling included rice yield from 1950 to 2014 year in India and was obtained from the Directorate of Economics and Statistics, Ministry of Agriculture, Government of India. The accuracy of the model for 4-year relative average was obtained when 4-fold cross validation (75.06%) method was used. The accuracy of the model can be further enhanced by revising the training patterns used in the study.

Decision tree: The decision tree is a technique structured to learn a rule common to previous observations. It is a classification-based data mining technique. The model contains nodes (3 kinds), branches (2 kinds), terminal values, strategy, payoff distribution, and the rollback method. The decision node describes a point where a choice is made and is expressed as square. The decision node further extends to a sequence of decision branches and the result of these sequences is represented by each terminal value. The decision tree algorithm includes the following steps: growth of large decision tree followed by reduction (over fitting of data) and finally the tree is pruned (also known as classification tree described) that is used as the base for classification of the datasets. J48 is an open-source algorithm that is a java based implementation and advanced version of C4.5. J48 is designed to build a decision tree on continuous data in the Weka data mining tool. The decision tree technique was used to predict soybean yield in Bhopal district. The productivity was found to be regulated by relative humidity followed by temperature and rainfall (Veenadhar et al 2011).

Random forest: Random forest is a classification data mining algorithm and can build decision trees from both huge and small data to give an efficient prediction (Goel and Abhilasha 2017). The model scans how many generated trees give the same prediction result. The result which gets the maximum score will be shown as output. This algorithm has high versatility and precision in predicting results. Random forest algorithm was used to predict cotton yield in Maharashtra using the R package (Prasad et al 2021). Agromet spectral variables and crop yield from 2001 to 2017 were used as input datasets to predict the yield before actual harvest. The model was found to be faster and reliable with a coefficient of determination (R2) value of 69%, 60%, and 39% for September, December, and February months yield. The model was capable of processing large datasets.

Bayesian belief network: Bayesian network is a powerful statistical model which is a clan of algorithmic rules. It deals with uncertain data and the data includes both qualitative and quantitative variables. Bayesian Belief Network is widely used in agricultural datasets.The model is best suited to assess the crop yield taking into consideration the uncertainty of future climate change based on previous climate parameters including temperature, rainfall, and other factors.

Prediction of rice yield in 27 districts of Maharashtra was done using the WEKA tool employing the Bayesian Networks model (Gandhi et al 2016b). In the report, input datasets used for prediction include precipitation, temperature (minimum, average, and maximum), plant's evapotranspiration, area, production, and yield for the Kharif season collected from accessible records of the Government of India.

Comparison of prediction techniques: The present section focuses on some of the earlier studies associated with comparative study of different data mining tools in the area of crop yield prediction in India. The comparison is based onvarious statistical accuracy parameters including coefficient of determination (R2), root-mean-square error (RSME) or F measure (f-score). Different prediction models based on artificial neural network (ANN), stepwise multiple linear regression (SMLR), principal component analysis together with ANN (PCA-ANN), principal component analysis together with SMLR (PCA-SMLR), least absolute shrinkage and selection operator (LASSO), and elastic net (ELNET) were used to predict coconut yield in the west coast of India (Das et al 2019). Weather data (maximum and minimum temperature, relative humidity, wind speed, and solar radiation) and annual coconut yield for the period 2000-2015 were used as input data. Performance of ELNET was found to be best for coconut prediction based on R2 of calibration (2.08) and RSME (2.36). The order of performance of different models was ELNET > LASSO > ANN > SMLR > PCASMLR > PCA-ANN. Among the weather conditions, relative humidity and solar radiation were the major determinants of coconut yield. Another study used five machine learning techniques namely K-Nearest Neighbour (KNN), Naïve Bayes, Multinomial Logistic Regression, Artificial Neural Network (ANN), and Random Forest to predict mustard crop yield in Jammu (Pandith et al 2020). The input data included soil characteristics and yield. Accuracy, recall, precision, specificity, and f-score parameters were analyzed to evaluate the performance of these models. KNN and ANN were found

Table 1. Different techniques used for crop yield prediction in India

Modeling software	Basis of software	Crops	Interaction/Data sets	References
Waikato Environment for Knowledge Analysis (WEKA)	SVM	Rice	Precipitation, minimum temperature, average temperature, maximum temperature	Gandhi et al 2016
	ANN	Rice	Precipitation, Minimum, average and maximum temperature,	Gandhiet al 2016 a, b
	SVM, NaiveBayes	Rice paddy, cotton, sugarcane, groundnut, black gram	Climate variables	Balakrishna et al 2016
	SVM, Naive Bayes, AdaSVM AdaNaive	Crop growing factor	Soil pH, nitrogen, soil depth, temperature	Balar and Patel 2019
	ANN	Cropyield	Minimum and maximum temperature h	Sivanandhini and Prakash 2020
	ANN	Rice	Precipitation, minimum temperature, average temperature	Kulkarni 2018
	LASSO, ENET, PCA, PCA – SMLRANN	Sorghum	Weather (Karnataka)	Sridhara 2020
R package	RF	Cotton	Rainfall, vegetation condition index, standardized precipitation index	Prasad et al 2021
Decision Support System for Agrotechnology Transfer (DSSATT)	SMLR, PCA-SMLR, LASSO,ELNET, ANN, PCA-ANN	Coconut	Maximum and minimum temperature, relative humidity, wind speed and solar radiation	Das et al 2020
SPSS, MS-EXCEL		Potato	Minimum Temperature, Maximum Temperature, Relative humidity, Relative humidity and Wind-Velocity (U.P)	Snehdeep et al 2018
	C 4.5 algorithm	Paddy	Rainfall, Maximum temperature, Minimum temperature, Potential Evapotranspiration	Veenadhari et al 2014
	ANN, SVM, Recursive Partitioning and Regression Tree, Random Forest, Generalized Linear Model	Wheat	Area, Rainfall and Soil type	Gahoi 2019

ANN; Artificial neural network, MLR; Multiple and Stepwise Linear Regression, SLR; Stepwise linear regression, RR; Ridge regression, RF; Random forest, SVM; support vector machine, DSSATT: Decision Support System for Agro technology Transfer to be the best techniques for mustard crop yield predictionwith 0.8405 and 0.8405 f-score, respectively. Naïve Bayes was found to have the lowest accuracy (72.33%) in prediction in the concerned study. Sorghum yield prediction for different districts of Karnataka was done using six multivariate weather-based models viz., least absolute shrinkage and selection operator (LASSO), elastic net (ENET), principal component analysis (PCA) in combination with stepwise multiple linear regression (SMLR), artificial neural network (ANN) alone and in combination with PCA and ridge regression model (Sridhara et al 2020). The datasets included maximum and minimum temperature (Tmax and Tmin °C), relative humidity (RH %), actual evapotranspiration (AET), and rainfall (mm). The study concluded LASSO and ENET were the best models the prediction of sorghum with RSME values varying from 88.99 kg ha^{-1} to 863.87 kg ha^{-1} and 96.89 to 870.98 kg ha^{-1} respectively.

Random forest technique was found to be more accurate to predict wheat prediction in Madhya Pradesh with 94.33% accuracy in comparison to Recursive Partitioning and Regression Tree (93.39%), Generalized Linear Model (91.5%), Neural Network (92.45%) and Support Vector Machine (81.13%) (Gahoi 2019). The studied parameters included area harvested, rainfall, and soil type (Deep Medium Black, Shallow &Medium Black, Alluvial Soil. Mixed Red & Black).

Challenges in the prediction of crop yield: Machine learning techniques are getting more attention in predicting crop yield in the present scenario. But they are associated with some hard challenges (Mayuri and Priya 2018).

Accuracy: The basic hindrance is the requirement of huge accurate previous data as the prediction is based on it. India faces challenges in obtaining and maintaining data from remote agricultural lands. Most of these lands are abandoned during the survey as they fail to meet the minimum hectare of land criteria. To model crop yield, existing methods rely on survey data and other variables linked to crop growth (such as weather and soil conditions). In the United States, where data is copious and of relatively high quality, these approaches have been quite successful. Comprehensive surveys of meteorological factors like the Daymet (Thornton et al 2014) and land cover types like the Cropland Data Layer (Boryan et al 2011) are publically available and considerably aid agricultural production forecast. However, in underdeveloped nations, where accurate yield projections are most needed, weather, soil attributes, and precise land cover data are generally unavailable. On the other hand, remote sensing data is widely available and relatively inexpensive. Existing methods are costly and difficult to expand since they rely on locally gathered survey data. Approaches based on remotely sensed data, such as satellite imaging, have the potential to be a low-cost, high-effective alternative.

Associated factors: The prediction results are not universal. The results would differ based on the seed type, use of fertilizer, and other farmer-driven agricultural practices. The other major challenge is unpredictable arrival of pests and diseases. These may drastically affect the yield due to the absence of enough protection measures in place. So, integration of different factors as input while making prediction is an important aspect.

Limitations in modelling approaches: There are some prediction model-based challenges. The basis of prediction used in the machine learning techniques lacks transparency and interpretability. The recent advancement in the technology of Explainable Artificial Intelligence is helping to overcome the issue. ANN has shortcomings in learning patterns as crop yield is a function of many factors and has inconsistency and unpredictability. Back-propagation neural networks have limitations in selecting large numbers of input variables, hidden layer size, and learning rate. Regression models are widely used in crop prediction and work accurately for linear data but they do not fit fine for complex nonlinear data.

CONCLUSION

Various crop yield modelling techniques are proving promising in agriculture, especially in crop yield prediction. The present study puts together accuracy of different data mining tools used in crop yield prediction and can have future wide applicability. ELNET, LASSO and ANN are some of the best tools for crop yield prediction as concluded from various comparison studies. The prediction is useful for farmers to make a lot of decisions about the best time to sow and harvest seeds, and other decisions such as domestic sustenance and export of crop products. The application of machine learning in yield prediction is expected to grow. An important factor to be considered for using these technologies in agriculture is increasing efficiency and accuracy of the model which can be achieved by integrating ensemble learning algorithms, increasing the input data set and parameter tuning. In the future, we need to develop methodologies focused on models for pre-harvest forecasting, real-time weather parameters and complex agricultural datasets. There is scope for developing tools for soil identification and pest control.

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Received 16 January, 2022; Accepted 23 May, 2022

Indian Journal of Ecology (2022) 49(3) (SI): 1011-1022
DOI: https://doi.org/10.55362/IJE/2022/3629

Manuscript Number: 3629
NAAS Rating: 5.79

Agriculture Food Crops Diversity of India: A Scenario

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Abstract: Agriculture 'the life line of India' have broad diversity of food crops which are cultivated in the rural crop fields of country. It plays a significant role in the development of India and continues to be a major driver of economy with 16-17% national GDP and largest employment providing sector (59% employment to national workforce). Various types of crops are native to the country and have been cultivated since ancient times. Agriculture diversity includes various types of indigenous varieties of Rice (*Oryza sativa* L.) Millets- Finger Millet [*Eleusine coracana* (L.) Gaertn.], Foxtail millets [*Setaria italica* (L.) P. Beauv.], Sorghum [*Sorghum bicolor* (L.) Moench], Pear millet [*Cenchrus americanus* (L.) Morrone], Banyard millet [*Echinochloa crus-galli* subsp. *utilis* (Ohwi & Yabuno) T. Koyama], Wheat (*Triticum aestivum* L.), Barley (*Hordeum vulgare* L.), and Maize (*Zea mays* L.), Chickpea (*Cicer arietinum* L.) and Moth bean [*Vigna aconitifolia* (Jacq.) Maréchal]. This paper discussed the consequences of the green revolution in agriculture production and impacts on indigenous crop varieties with their conservation needs.

Keywords: Agriculture, Crop diversity, Agriculture produces

India is the second largest country from the sight of population in the world and has wide diversity of climate, topography, land use, flora & fauna with socio-economic conditions. By the largest land use in agriculture India became one of the largest producing countries in agriculture supplies worldwide (Hinz et al 2020). In India, Agriculture is the most important sector and it is the life line of Indian economy. One-third of the population of India is dependent upon agriculture to sustain livelihood. More than half number of jobs from agriculture sector are available in India. By sharing in national income, being biggest employment providing sector, providing raw material to industries and market for industrial products, agriculture shows the importance in Indian economy. This sector shares 16-17% of national GDP with 10% total export and 59% employment to national workforce (Arjun 2013, Goyal et al 2016, Hand book of Agriculture 2017, Hinz et al 2020).

Agriculture biodiversity: India has rich agriculture biodiversity that's why it is the backbone of sustainable agricultural growth that includes different types of farming systems. Agro-biodiversity includes the variability of many economically important plant and animals with agroforestry, crops and cropping systems, orchards, live-stock, fisheries, poultry etc. These systems provide food, fodder, fibre, shelter, fuel, medicines, income and livelihood. It plays an essential role for sustainable improvement in Food and Nutrition Security (Hand book of Agriculture 2017, Natarajan et al 2018). It is most significant component of biodiversity which holds a key to the foundation of agriculture and food and nutritional security. The genetic diversity of kingdom and species increase the productivity of farming system. The management of genetic resource includes some actions like collection and exploration of plants, characterization & evaluation, conservation, germplasm exchange and genetic enhancement (Natarajan et al 2018).

Indian gene center is one of the 17 megadiverse countries in the world which includes more than 8% identified plants and nearly 2.5% global land mass. Approximately 17500 higher plant species were estimated and occurs in 16 vegetation types. There are more than 380 cultivated/ semi-cultivated crop species and 130 breeds of domesticated animals and poultry in the country (Hand book of Agriculture 2017). It is crucial in the conservation of different inherited traits of cultivated plants, wild species of cultivated crop plants and domesticated farm animals (Chaudhuri 2005, Natarajan et al 2018).

Field crops of India: Agrobiodiversity is a vital subset of biodiversity which includes agro-ecosystems, crops varieties/ species, livestock and fish species, plant and animal germplasm, soil micro-organisms and cultivated fields, wild species, traditional knowledge and bio-control agents for crops/ livestock pest (Natarajan et al 2018) (Fig. 1). At the time of independence, India faced the shortage of food grains due to low farm productivity. The area for food grains was 97.32 M ha in which only 18% were irrigated in 1950-51. After green revolution, when agriculture adapted modern methods and technology, it improved and increased the growth of food grains production. Consequently, India has become self-sufficient in food grains. Cereals occupied largest crop area than other crops in India. In India, rice (*Oryza sativa* L.), maize (*Zea mays* L.), wheat (*Triticum sps.* L.), barley (*Hordeum vulgare* L.), pulses and oilseeds are major crops grown in cereal-based production system in India which supports the Indian economy. These crops are cultivated in different states of India viz. Andhra Pradesh, Bihar, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Odisha, Punjab, Rajasthan, Tamil Nadu, Uttarakhand, Uttar Pradesh and West Bengal. India is the second largest producer of rice, wheat and millets in the world. Rice is the third important crop of the world and staple food crop of India followed by wheat and other cereals. In India, cereals play the dominant role in Indian diets as an energy source and more than half population depended on these crops for their survival (Hand book of Agriculture 2017).

Introduced and naturalized crop diversity: A unique combination of living species, habitats and ecosystems which make rich and fascinating diversity of India. This diversity includes various Agro-Climatic Zone of India, types of forest plant species herbs, grasses, shrubs, forages and ornamental plants. Presently cultivated plants in the country have been derived from two sources, viz. indigenous and introduced. The later have come from various continents and countries like Asia, Africa, China, North and South America, Southeast Asia and Pacific Islands, and the Europe. Over the past few centuries some new crops were introduced in the country by Moughals, Spanish, Portuguese and British explorers. These crops are apple, peach, pear, grape, pine apple, papaya, almond, date palm, apricot, tomato, potato, sweet potato, beans, onion, garlic, chilies, maize and lentil etc. (Hand book of Agriculture 2017).

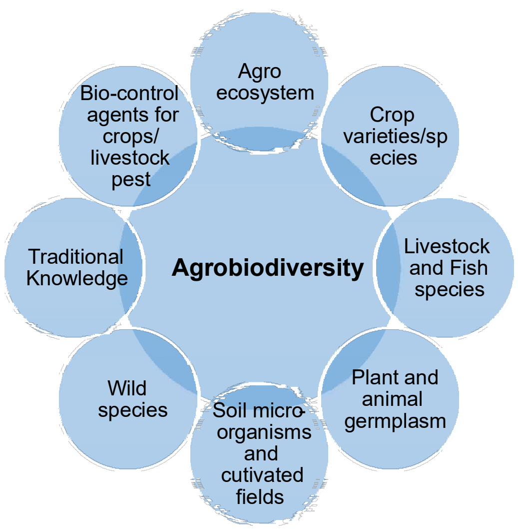

Fig. 1. Agro-biodiversity-a subsets of biodiversity

Indigenous crop: In India, approximately 49 major and minor crops are estimated which includes rice, wheat, maize, minor millets, pulses, Indian mustard, tuber crops, vegetables, fruits, spices, sugar crops, fiber crops and many medicinal plants. The advantage of cultivation of indigenous crops is that, they are highly adapted to environmental condition, makes the agriculture genetically diverse and sustainable and consumption reduces the dependency on imports and maintain the food varieties and micro-nutrient in diet (Nelson et al 2019). Some cultivated food crops are listed on the basis of Indian origin, which are as follow-

Rice (*Oryza sativa* L.), Finger millets [*Eleusine coracana* (L.) Gaertn.], Chickpea (*Cicer arietinum* L.), Moth bean [*Vigna aconitifolia* (Jacq.) Maréchal], Rice bean [*Vigna umbellata* (Thunb.) Ohwi & H.Ohashi], Horse gram [*Macrotyloma uniflorum* (Lam.) Verdc.], Asparagus bean [*Vigna unguiculata* (L.) Walp.], Eggplant (*Solanum melongena* L.), Rat's tail radish [*Raphanus raphanistrum* subsp. *sativus* (L.) Domin], Taro yam [*Colocasia esculenta* (L.) Schott], Cucumber (*Cucumis sativus* L.), Tree cotton (*Gossypium arboreum* L.), Jute (*Corchorus olitorium* L.), Pepper (*Piper nigrum* L.), Tea [*Camellia sinensis* (L.)

Table 1. Area and production of all major crops of the country 1950-2020

Major crops of India	Area in MHa					Production in MT				
	1950-51	1990-91	2012- 13	2016-17	2019-20	1950-51	1990-91	2012-13	2016-17	2019-20
Rice	30.81	42.69	42.75	43.19	43.78	20.58	74.29	105.23	110.15	118.43
Wheat	9.75	24.17	30.00	30.60	31.45	6.46	55.14	93.51	98.38	107.6
Nutri/Coarse cereals	37.67	36.32	24.76	24.77	24.02	15.38	32.70	40.04	44.19	47.5
Pulses	19.09	24.66	23.26	29.46	28.34	8.41	14.26	18.34	22.95	23.2
Oilseeds	10.73	24.15	26.48	26.20	27.04	5.16	18.61	30.94	32.10	33.4
Sugarcane	1.71	3.69	5.00	4.38	4.57	57.05	241.05	341.20	306.72	355.7
Cotton	5.88	7.44	11.98	10.84	13.37	3.04	9.84	34.22	33.09	35.5
Jute & Mesta	0.57	1.02	0.86	0.76	0.68	3.31	9.23	10.93	10.60	9.9

Source: *Pocket Book of agricultural statistics 2017*- Ministry of Agriculture & Farmers Welfare Department of Agriculture, Cooperation & Farmers Welfare Directorate of Economics & Statistics New Delhi https://agricoop.nic.in/sites/default/files/pocketbook_0.pdf
Abbreviation: MT: Million Tons; MHa: Million Hectare

Table 2. Status of agro-climatic zone of India with sub-regions and crop distribution

Agro-climatic zone	Sub-regions	Climate type	Rainfall (mm)	Soil type	Agriculture produces
Western Himalayas Region	High altitude temperate	Humid to cold arid	165	Hill soils, mountain, meadow skeletal, tarai	Rice, wheat, barley, maize, oats, ragi, sugarcane and potato etc. Fruits: almond, apricot, cherry, litchis, peaches, pears, walnut, saffron etc.
	Valley temperate	Sub-humid	400	Sub-mountain, mountain skeletal, meadow	
	Sub-tropical	Semi-arid to humid	1030	Alluvial (Recent), brown hills	
	Hill temperate	Humid	2000	Brown hill	
Eastern Himalayas Region	Lower Brahmaputra	Per humid to humid	1840	Alluvial, red loamy, tarai soils	Rice, wheat, maize, ragi, rapeseed, sesame, sugarcane, potato, tea and jute. Fruits: pineapple, litchi, oranges and lime etc.
	Himalayan Hills	Per humid to Humid	2641	Brown Hills	
	Southern Hills	Per humid to humid	2052	Acidic soils	
	Upper Brahmputra	Humid to per humid	2809	Alluvial, red loamy	
	North-East Hills	Per humid to humid	3528	Red sandy laterite	
Lower Gangetic Plains Region	Rarh Plains	Most sub-humid to dry sub-humid	1302	Red and yellow red loamy	Rice, wheat, maize, rapeseed, sesame, jute, potato and pulses
	Central Alluvial Plains	Most sub-humid to dry sub-humid	1449	Red and yellow, Deltaic, alluvium, red loamy	
	Barind Plains	Most sub-humid & dry sub humid	1587	Red and yellow alluvial (Recent)	
	Alluvial Coastal Saline Plains	Dry sub-humid to moist sub-humid	1607	Red and yellow deltaic, alluvial	
Middle Gangetic Plains Region	North-West Alluvial	Moist sub-humid to dry sub-humid	1211	Alluvial (Recent), Calcareous	Rice, wheat, maize, barley, millets, sugarcane, peas, gram, mustard and potato
	North-East Alluvial	Dry sub-humid to moist sub-humid	1470	Alluvial, Tarai	
Upper Gangetic Plains Region	South-Western Plains	Semi-arid	721	Alluvial	Rice, wheat, bajra, sugarcane, maize, potato, pulses and oils seed.
	North-Western Plains	Dry sub-humid to semi-arid	907	Alluvial, Tarai	
	Central Plains	Dry sub-humid to semi-arid	979	Alluvial	
Trans-Gangetic Plains Region	Scarce Rainfall arid region	Arid and Extreme arid	360	Calcareous, Sierozemic, Alluvial (Recent), desert	Rice, wheat, sugarcane, maize, millets, cotton, pulses and oilseeds.
	Plains	Semi-arid to Dry sub-humid	561	Alluvial (Recent) calcareous	
	Foothills of Shivalik & Himalayas	Semi-arid to Dry sub-humid	890	Alluvial (Recent) calcareous	
Eastern Plateau and Hills Region	Eastern Plain	Dry sub-humid	1271	Medium to deep black red and yellow	Rice, maize, ragi, millet, potato, groundnut, gram, tur, urd, soyabean, castor, niger and oilseeds etc.
	North Central Plateau	Moist sub-humid to dry sub-humid	1296	Red sandy, red and yellow	
	Tribal	Moist sub-humid to dry sub-humid	1338	Red sandy, red and yellow, red loamy laterite	
	Eastern Plateau	Moist sub-humid to dry sub-humid	1369	Red & yellow, Red loamy	
	Eastern Highland	Moist sub-humid to dry sub-humid	1436	Red sandy, red and yellow	
Central Plateau and Hills Region	Transitional Plain	Semi-arid (Wetter half)	490	Desert soil, grey brown	Rice, wheat, maize, linseed, sorghum & other millets, gram, pigeon pea, cotton, groundnut, rapeseeds, sunflower, niger, soybean and other oilseed crops.
	Southern Plains & Aravalli Hills	Semi-arid (Wetter half)	500	Red and yellow, grey brown	
	Semi-arid Eastern Plains	Semi-arid (Drier half)	500	Alluvial	

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Table 2. Status of agro-climatic zone of India with sub-regions and crop distribution

Agro-climatic zone	Sub-regions	Climate type	Rainfall (mm)	Soil type	Agriculture produces
	Flood Prone Eastern Plain	Semi-arid (drier half)	500	Alluvial (Recent)	
	Gird	Semi-arid (half drier & wetter half)	670	Medium black, Alluvial	
	Bundelkhand (MP)	Dry sub-humid to semi-arid	700	Mixed red & black	
	South Eastern Plains	Semi-arid (wetter half)	760	Medium black	
	Southern Plains	Semi-arid to arid	760	Medium red and black, grey brown	
	Bundelkhand (UP)	Dry sub-humid to arid	780	Dry sub-humid to arid	
	Kymore Plateau Satpura hills	Dry sub-humid	1100	Dry sub-humid	
	Vindhya Plateau	Dry sub-humid	1130	Dry sub-humid	
	Satpura Plateau	Dry sub-humid	1220	Dry sub-humid	
	Central Narmada Valley	Dry sub-humid	1300	Dry sub-humid	
	North Hills	Moist sub-humid to dry sub-humid	1570	Moist sub-humid to dry sub-humid	
Western Plateau and Hills Region	Scarcity region	Semi-arid	602	Medium black, deep black	Rice, wheat, sorghum & millets, sugarcane, gram, cotton, groundnut oilseeds etc. Fruits: oranges, grapes and bananas.
	Plateau region	Semi-arid (wetter half)	874	Medium black, deep black and mixed red	
	Hill region	Semi-arid	988	Medium to deep, Black shallow red and red loamy	
	Plateau region south	Semi-arid to dry sub-humid	1040	Medium black and shallow black	
Southern Plateau and Hills Region	Sub-region-1	Semi-arid	677	Red loamy, medium black, red sandy, coastal alluvium, laterite	Rice, wheat, maize, sorghum & millets, cotton, pulses, coffee, tea, cardamom and castor, groundnut & oilseeds and spices crops
	Sub-region-2	Semi-arid & arid	725	Red sandy, medium to deep black	
	Sub-region-3	Semi-arid to Dry sub-humid	841	Mixed red and black red loamy, deltaic alluvium	
	Sub-region-4	Semi-arid	865	Red loamy, red sandy	
	Sub-region-6	Semi-arid (wetter half)	1001	Deep black, medium black	
East Coast Plains & Hills Region	South Coastal Tamil Nadu	Semi-arid (drier half)	780	Mixed Red & Black, coastal alluvium	Rice, bajra, ragi, sorghum, jute, tobacco, maize, sugarcane, sesame, groundnut, cotton and tobacco.
	South coastal Andhra Pradesh	Semi-arid	996	Deltaic alluvium, deep black, red, sandy, red & black	
	North Coastal Tamil Nadu	Semi-arid	1036	Red loamy, red sandy, Coastal alluvium	
	Tanjavur	Semi-arid to dry sub-humid	1113	Deltaic alluvium, red loamy	
	North coastal Andhra	Dry sub-humid	1128	Red loamy, laterite medium black, red, sandy, coastal alluvial	
	North Odisha Coast	Moist sub-humid	1287	Deltaic alluvial, coastal alluvial, laterite, red loamy	
West Coast Plains & Ghats Region	Hilly	Per Humid	226	Laterite, red loamy, Coastal alluvium	Rice, ragi, coconut, sesame, groundnut, niger oilseeds, sugarcane, tapioca, pulses and cotton. Fruits: Mango, banana, pineapple and jack fruit etc.

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Table 2. Status of agro-climatic zone of India with sub-regions and crop distribution

Agro-climatic zone	Sub-regions	Climate type	Rainfall (mm)	Soil type	Agriculture produces
Gujarat Plains & Hills Region	North-West arid	Arid to semi-arid	340	Grey brown, deltaic alluvium	Rice, wheat, maize, bajra, sorghum, sugarcane, arhar, groundnut, cotton and tobacco.
	North Saurashtra	Dry sub-humid	537	Medium black	
	North Gujarat	Arid to semi-arid	735	Grey brown, Coastal alluvium	
	South Saurashtra	Dry sub-humid	844	Coastal alluvium, medium black	
	Middle Gujarat	Semi-arid	904	Medium black	
	South Gujarat	Semi-arid to dry humid	974	Deep black, Coastal alluvium	
	South Gujarat (Heavy rainfall)	Semi-arid to dry sub-humid	1793	Coastal alluvium, medium black	
Western Dry Region	Western Dry	Arid to extremely arid	395	Dessert soil, grey brown	Bajra, jowar, moth bean, wheat and gram
Island Region (Sub-regions not delineated)	Andaman-Nicobar (including region)	---	3,000	Medium to very deep red loamy soils and including marine alluvium derived soils along the coast	Rice, maize, millets, pulses, arecanut, turmeric and cassava
	Lakshadweep (including regions)	---	1,600	highly calcareous and sandy in nature	

***Source*:** Planning Commission (Khanna 1989) has identified 15 resource development regions in the country, 14 in the main land and remaining one in the islands of Bay of Bengal and Arabian Sea.
Abbreviation: mm: Milimeter

Kuntze], Pigeon pea [*Cajanus cajan* (L.) Huth], Sesame (*Sesamum indicum* L.), Cardamomum [*Elettaria cardamomum* (L.) Maton] and Lemon [*Citrus* × *limon* (L.) Osbeck] (Hand book of Agriculture 2017).

Effect of green revolution in indigenous crop: In the past, India faced the era of chronic food shortage due to population explosion and low farm activity. At that time Indian annual food imports were 8-10 MT. After independence, to overcome the shortage of food and self-sufficiency in food-grains was the first or foremost challenge for India. This could be accomplished only by the increasing agricultural production and minimizing dependence on food imports (Hand book of Agriculture 2017). In 1960, Green Revolution was initiated in India with major outcome. Many technologies were developed with great outcomes in the agriculture sector which improved farm productivity. The introduction of high yield varieties, fertilizer use and water & pest management techniques increased the agriculture production. Specially rice and wheat varieties, which made India self-sufficient in food grains. These genetically improved varieties were developed by the contribution of many research centers viz. International Maize and Wheat Improvement Centre (CIMMYT), Mexico, and the International Rice Research Institute (IRRI), Philippines, respectively. These high yielding varieties are more grain-producing and highly fertilizer responsive than earlier varieties. Consequently, between 1950 and 1990, the global production of cereals increased 174% (Nelson et al 2019). On the other hand, the green revolution's effect on indigenous crop varieties is the loss of local varieties and species due to preference of high yielding varieties for better production. Actions initiated by government for increasing the grain production is very beneficial but also destroyed the gene pool diversity. Maximum use of chemical fertilizer, pesticide and lack of crop rotation make the soil infertile (Nelson et al 2019).

Production scenario (1950-2020): According to the 4th Advance Estimates for 1950-51, total food grain production was 50.82 MT and new estimate for 2019-20, total food gran production is 296.65 MT. The estimate of 2019-20 in higher than all previous years (1950-51 to 2018-19) which shows the growth in agriculture production of the country. Report shows the estimated area and production of crops (Table 1) with comparison of other major crops. In which, total rice production in 1950 was 20.58 MT which increased year by year and reached at 118.43 MT in 2019-20. Like rice, other crops show changes in area and production (*Pocket Book of agricultural statistics* 2017, Annual report 2020-21).

Agro-Climatic zone of India: The extension of climate for suitability to agriculture or the land unit in terms of climate which is suitable for certain crop and cultivar is known as Agro-Climatic Zone of India. It is characterized by agro-ecological diversities in soil, rainfall, temperature and cropping system. India has divided into fifteen (15) major agro-climatic zones by Planning Commission of India. These agriculture zones are based on many agro-climatic features like soil type, geological formation, climate, irrigation, cropping pattern and mineral resources (Alagh 1990, Singh 2006, Balasubramanian 2013). The 15 Agro-climatic zones in India in which different Cereal & Millet Crops, Pulses crops, Oilseed crops and sugar crop are found is described as follows (Table 2 and 3).

Table 3. Food grain crops of India with their performance in cultivation states

Cereal & millet crops	Common name	Native range	Ranking among growing countries in the world	Highest producing state of India	Composition of Nutrient (gm)	Economic aspects
Rice (*Oryza sativa* L.)	Hindi: Dhan English: Rice, Chaval Sanskrit: Dhanya, Dhanyah, Garuda	China (China North-Central, China South-Central, China Southeast)	China, India, Bangladesh, Indonesia, Thailand, Vietnam, Myanmar, Philippines, Brazil, Japan, Pakistan, United states and Egypt	West Bengal, Uttar Pradesh, Andhra Pradesh, Punjab, Tamil Nadu, Bihar, Chhattisgarh, Odisha, Assam, Karnataka	Carbohydrate: 28.73-81.63g Protein (g): 6.8-7.5 Fiber (g): 3.4-4.1 Crude Fat (g): 0.5-2.7 Energy (kcal): 384 Moisture %: 14.0 (Das et al 2011, Kumar et al 2016, Chaudhari et al 2018)	Used as staple food; in making bread, snacks, cookies and biscuits; livestock feed and organic fertilizer (compost); manufacturing in fatty acids and medicines.
Maize (*Zea mays* L.)	Hindi: Makka English: Maize, Corn Sanskrit: --	Guatemala , Mexico	United states, China, Brazil, Argentina, Ukraine, India	Karnataka, Madhya Pradesh, Bihar, Andhra Pradesh, Telangana & Bihar, T. N., Maharashtra, U. P and Rajasthan	Carbohydrate (g): 60.9-74.3 Protein (g): 9.4- 9.8 Fiber (g): 9.0 Crude Fat (g): 4.9 Energy (kcal): 396 Moisture %: 14.0 Starch: 65% (Das et al 2011, Kumar et al 2016, Kaul et al 2017, Chaudhari et al 2018, Huma et al 2019)	Dry milling used for flour, livestock feed; fermentation and many pharmaceutical and cosmetic industrial uses; syrup used in manufacturing of jams, jellies, and other sweets and as an additive for cane sugar and maple syrup
Wheat (*Triticum aestivum* L.)	Hindi: Gehun English: Wheat Sanskrit: arupa, bahudugdha, godhuma	Medit. to Central Asia and NW. India, Ethiopia.	China, India, Russia, United States	Uttar Pradesh, Punjab, Haryana, Rajasthan, Bihar, West Bengal, Assam, Parts of Madhya Pradesh, Himachal Pradesh, Jammu & Kashmir	Carbohydrate (g): 61.6-71.2 Protein (g): 10.6- 11.8 Fiber (g): 12.5 Crude Fat (g): 1.9 Energy (kcal):375 Moisture %: 14.0 (Das et al 2011, Kumar et al 2016, Chaudhari et al 2018)	Staple food; flour for making chapatti, bread biscuits, cookies; used in preparation of starch, gluten, malt, and distilled spirit; manufacturing of beer and other alcoholic beverages
Sorghum (*Sorghum bicolor* (L.) Moench)	Hindi: Jowar English: Sudan Grass Sanskrit: Devadhanya	Africa	United States, India, Nigeria, Mexico, Sudan and Argentina	Maharashtra, Karnataka, Madhya Pradesh, Andhra Pradesh, Rajasthan, Tamil Nadu and Gujarat	Carbohydrate (g): 72.1 Protein (g): 8.3-10.6 Fiber (g): 13.8 Crude Fat (g): 3.9 Energy (kcal): 384 Moisture %: 14.0 (Das et al 2011, Kumar et al 2016, Chaudhari et al 2018)	Used as in the production of sugar, alcohol, syrup, fodder, fuel, bedding, roofing, fencing, and paper; in production of starch, glucose and liquid glucose used as pasture, hay, green chop, or silage for livestock
Barley (*Hordeum vulgare* L.)	Hindi: Jav. English: Barley Sanskrit: Aksata, Akshata, Dhanyaraja	Israel	Russia, Canada, Ukraine, Australia and Turkey	Uttar Pradesh, Rajasthan, Punjab, Madhya Pradesh, Haryana, Bihar, Himachal Pradesh, West Bengal and Jammu Kashmir	Carbohydrate (g): 77.7 Protein (g): 9.9 Fiber (g): 15.6 Crude Fat (g): 1.2 Energy (kcal): 352 Moisture %: 10.1 (Das et al 2011, Kumar et al 2016, Chaudhari et al 2018)	Fodder crop & large use in animal feed and; hull less barley grain is preferred for chapatti used in malting Industry for bear, whisky and other products

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Table 3. Food grain crops of India with their performance in cultivation states

Cereal & millet crops	Common name	Native range	Ranking among growing countries in the world	Highest producing state of India	Composition of Nutrient (gm)	Economic aspects
Oats (*Avena sativa* L.)	Hindi: Jav English: Oat Sanskrit:-karambhaka or karambha	Iran and Iraq	Russia	Uttar Pradesh, Punjab, Madhya Pradesh, Haryana, Rajasthan, Bihar, Gujarat, Maharashtra, Uttarakhand and H.P	Carbohydrate (g): 63.0 Protein (g): 9.3-16.9 Fiber (g): 5.5 Crude Fat (g): 5.9 Energy (kcal): 389 Moisture %: 8.2 (Das et al 2011, Kumar et al 2016, Chaudhari et al 2018)	Whole grain consumed as human food; forage and fodder; straw for bedding, hay, haylage, silage and chaff; in bakery industry.
Pearl millet (*Cenchrus americanus* (L.) Morrone)	Hindi: Bajra English: Pearl millet Sanskrit: --	Central tropical Africa	India, Nigeria, Chad, Tanzania, Mali, Niger, Ethiopia, China and Russia	Rajasthan, Maharashtra, Uttar Pradesh, Gujarat, Haryana, Karnataka, Madhya Pradesh and Tamil Nadu	Carbohydrate (g): 67.5 Protein (g): 11.6 Fiber (g): 11.3 Crude Fat (g): 5 Energy (kcal): 361 Moisture %: 12.4 (Das et al 2011, Kumar et al 2016, Chaudhari et al 2018)	Used as staple food and cooked like rice, porridges, boiled or steamed foods; livestock producers for grazing, silage, hay, and green chop; in manufacturing of alcoholic beverages
Finger millet (*Eleusine coracana* (L.) Gaertn.)	Hindi: mandwa English: Finger Millet/ African millet Sanskrit: Madhulika	Ethiopia	India, Nigeria, Niger, China	Karnataka, Tamil Nadu, Uttarakhand, Andhra Pradesh, Odisha, Gujarat, West Bengal and Bihar	Carbohydrate (g): 72.6 Protein (g): 7.7 Fiber (g): 11.3 Crude Fat (g): 1.5 Energy (kcal): 336 Moisture %: 13.1 (Das et al 2011, Adhikari 2012, Kumar et al 2016, Chaudhari et al 2018)	Used for foods (roti or unleavened breads, ambali or thin porridge and mudde); Manufacturing of wine
Foxtail Millet (*Setaria italica* (L.) P.Beauv.)	Hindi: Kangani English: Green Foxtail Sanskrit:	China	China and India	Telangana, Andhra Pradesh., Karnataka, Rajasthan, Madhya Pradesh	Carbohydrate (g): 60.9 Protein (g): 12.3 Fiber (g): 2.4 Crude Fat (g): 4.3 Energy (kcal): 331 Moisture %: 11.2 (Das et al 2011, Kumar et al 2016, Chaudhari et al 2018)	Used for human food; fodder for animal & birds feeding; mixed with cake, cookies, bread, and biscuits to provide proteins and micro-nutrients
Proso millet (*Panicum miliaceum* L.)	Hindi: English: Sanskrit:	China	India and China	Bihar, North East, Tamil Nadu, Karnataka and Maharashtra	Carbohydrate (g): 70.4 Protein (g): 12.5 Fiber (g): -- Crude Fat (g): 1.1 Energy (kcal): 341 Moisture %: 11.9 (Das et al 2011, Kumar et al 2016, Chaudhari et al 2018)	Consumed as human food; Livestock feed, forage and fuel
Kodo millet (*Paspalum scrobiculatum* L.)	Hindi: English: Sanskrit:	India	India, Nigeria, Niger, China	Madhya Pradesh, Chhattisgarh, Maharashtra, Tamil Nadu, Karnataka	Carbohydrate (g): 66.6 Protein (g): 10.6 Fiber (g): 10.2 Crude Fat (g): 4.2 Energy (kcal): 353 Moisture %: 11.6 (Deshpande et al 2015, Bunker et al 2021)	Used as staple food in south India & used in recipes by tribal populations; Livestock feed and poultry.

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Table 3. Food grain crops of India with their performance in cultivation states

Cereal & millet crops	Common name	Native range	Ranking among growing countries in the	Highest producing state of India	Composition of Nutrient (gm)	Economic aspects
Barnyard millet (*Echinochloa crus-galli* subsp. *utilis* (Ohwi & Yabuno) T.Koyama)	Hindi: Sanwa and Jhangora English: Barnyard millet Sanskrit: Shyama	Japan	India, Niger, and China	Uttarakhand, Uttar Pradesh, Karnataka, Madhya Pradesh., North East and Tamil Nadu	Carbohydrate (g): 68.8 Protein (g): 10.5 Fiber (g): 6.6 Crude Fat (g): 3.6 Energy (kcal): 398 Moisture %: 8.7 (Kaur, and Sharma 2020).	Used for food, snacks and porridge.
Little millet (*Panicum sumatrense* Roth)	Hindi: Shavan English: Indian Millet Sanskrit:	Tropical & Subtropical Asia	India, Niger, and China	Karnataka, Maharashtra, Tamil Nadu, Andhra Pradesh, Madhya Pradesh, Jharkhand, Orissa, Gujarat and Chhattisgarh	Carbohydrate (g): 74.75 Protein (g): 8.42 Fiber (g): 12.51 Crude Fat (g): 2.10 Energy (kcal): 351.65 Moisture %: 14.23 (Kalal et al 2019, Maitra and shankar, 2019)	Grains flour used for food; Used as sole forage crops
Buck Wheat (*Fagopyrum esculentum* Moench)	Hindi: Kotu, Kuktu, English: Buck Wheat Sanskrit:	China	Russia, China, Ukraine, France	Jammu and Kashmir, Himachal Pradesh, Uttarakhand, West Bengal, Sikkim, Meghalaya, Arunachal Pradesh and Manipur	Carbohydrate (g): 33.5 Protein (g): 5.68 Fiber (g): --- Crude Fat (g): --- Energy (kcal): --- Moisture %: ---	Used in food and bakery product

Status of Pulses crop

Pulses	Common name	Native range	Ranking among growing countries in the world	Highest producing state of India	Composition of Nutrient (gm)	Economic note
Green Gram (*Vigna radiata* L.)	Hindi: Moong English: Moong Bean Sanskrit: Mudga	India	India, Burma, Sri-lanka, Pakistan, China	Maharashtra, Uttar Pradesh, Madhya Pradesh, Andhra Pradesh, Gujarat and Karnataka	Carbohydrate (g): 60 Protein (g): 24 Fiber (g): 1 Fat (g): 1 Energy (kcal): 348 Moisture %: 10 Calcium (mg): 75 Phosphorus (mg): 405 Iron (mg): 4 (Asif et al 2013, Singh et al 2016)	Used as food, splited or whole seed eaten as snack and dhal; Bread and bakery; Livestock feed
Horse Gram (*Macrotyloma uniflorum* L.)	Hindi: Gaheth, Kulat English: Horse Gram, Madras Gram Sanskrit: Kulatthah	India	India, --- Myanmar, Nepal, Malaysia, Mauritius and Sri Lanka	Karnataka, Andhra Pradesh, Orissa, Tamil Nadu, M.P., Chhattisgarh, Bihar, W.B., Jharkhand, and in foot hills of Uttarakhand	Carbohydrate (g): 57 Protein (g): 22 Fiber (g): 5 Fat (g): 0 Energy (kcal): 321 Moisture %: 12 Calcium (mg): 287 Phosphorus (mg): 311 Iron (mg): 7 (Asif et al 2013, Singh et al 2016)	Used as food; splited or whole seed eaten as snack and dhal; Bread and bakery; Livestock feed
Black Gram (*Vigna mungo* (L.) Hepper)	Hindi: Urad English: black gram Sanskrit: Mashah	India	India, Myanmar and Pakistan	Madhya Pradesh (16.50 lakh ha), Uttar Pradesh (7.01 lakh ha), Rajasthan (4.56 lakh ha), Maharashtra (2.87 lakh ha), Karnataka (0.687 lakh ha) and Andhra Pradesh (0.11 lakh ha)	Carbohydrate (g): 60 Protein (g): 24 Fiber (g): 1 Fat (g): 1 Energy (kcal): 347 Moisture %: 11 Calcium (mg): 154 Phosphorus (mg): 385 Iron (mg): 4 (Asif et al 2013, Singh et al 2016)	Used as food; splited or whole seed eaten as snack and dhal; Bread and bakery; Livestock feed

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Status of Pulses crop

Pulses	Common name	Native range	Ranking among growing countries in the world	Highest producing state of India	Composition of Nutrient (gm)	Economic note
Bengal Gram (*Cicer arietinum* L.)	Hindi: Chana English: Chickpea, Bengal gram Sanskrit: Jivana, Chanakah	Iran, Iraq	India, Pakistan, Turkey and Iran	Madhya Pradesh, Uttar Pradesh, Rajasthan, Maharashtra, Andhra. Pradesh and Karnataka	Carbohydrate (g): 61 Protein (g): 17 Fiber (g): 1 Fat (g): 5 Energy (kcal): 360 Moisture %: 10 Calcium (mg): 202 Phosphorus (mg): 312 Iron (mg): 5 (Asif et al 2013)	Used as food; splited or whole seed eaten as dal, snack, sweets, and namkeen; Leaves are used as vegetable; Livestock feed
Cowpea (*Vigna unguiculata* (L.) Walp.)	Hindi: Lobiya English: Blackeyed Pea; Cowpea Sanskrit: Mahamasah, rajamasah	Centra l Africa	Nigeria	Punjab, Haryana, Delhi, West U.P and Rajasthan, Karnataka, Kerala, Tamil Nadu, Maharashtra and Gujarat	Carbohydrate (g): 54 Protein (g): 24 Fiber (g): 3 Fat (g): 1 Energy (kcal): 323 Moisture %: 13 Calcium (mg): 77 Phosphorus (mg): 414 Iron (mg): 9 (Ezeagu, 2009, Asif et al 2013, Singh et al 2016)	Used as feed, forage, hay, and silage for livestock, and green manure
Lentil (*Vicia lens* (L.) Coss. & Germ.)	Hindi: Masur English: Lentil Sanskrit: Masura, mangalaya	Turkey to South Iran	Canada, India, Australia, Turkey, United States, Nepal, Ethiopia, China	Bihar, W.B. Jharkhand	Carbohydrate (g): 59 Protein (g): 25 Fiber (g): 1 Fat (g): 1 Energy (kcal): 293 Moisture %: 12 Calcium (mg): 69 Phosphorus (mg): 293 Iron (mg): 7 (Asif et al 2013, Singh et al 2016)	Splited or whole seeds are used as dal and curry; flour used to make bread, cake and baby foods
Kidney Bean (*Phaseolus vulgaris* L.)	Hindi: Rajma, Rajmah English: Kidney Bean, Common Bean Sanskrit:	Centra l and South Ameri ca	India, Myanmar, Brazil	Gujarat, Jharkhand, Tamil Nadu, Karnataka, Uttar Pradesh, Andhra Pradesh, West Bengal, Bihar, Madhya Pradesh	Carbohydrate (g): 61 Protein (g): 23 Fiber (g): 5 Fat (g): 1 Energy (kcal): 346 Moisture %: 12 Calcium (mg): 260 Phosphorus (mg): 410 Iron (mg): 5 (Asif et al 2013, Singh et al 2016)	Staple food; dry seeds used as Dal; Bakery and livestock feed
Pigeon Pea (*Cajanus cajan (L.) Huth*.)	Hindi: Arhar, toor dal English: Red gram, Pigeon pea Sanskrit: Adhaki, Kakshi, Tuvari	India, West Himal aya	India, Myanmar, China, Nepal	Maharashtra, Karnataka, Andhra Pradesh, Uttar Pradesh, Madhya Pradesh, Gujarat, Odisha, Tamil Nadu, Chhattisgarh and Bihar	Carbohydrate (g): 58 Protein (g): 22 Fiber (g): 1 Fat (g): 2 Energy (kcal): 335 Moisture %: 13 Calcium (mg): 73 Phosphorus (mg): 304 Iron (mg): 2 (Asif et al 2013, Singh et al 2016)	Split or whole seeds used as Dal; Green seeds & pods used as vegetable; livestock feed (Handbook of Agriculture; Joshi et al 2001)
Garden pea (*Pisum sativum* L.)	Hindi: Matar English: Garden pea, English pea Sanskrit: Renuka, Satila	Weste rn Asia	China, Ethiopia and Australia		Carbohydrate (g): 16 Protein (g): 7 Fiber (g): 4 Fat (g): 0 Energy (kcal): 93 Moisture %: 73 Calcium (mg): 20 Phosphorus (mg): 139 Iron (mg): 1 (Asif et al 2013, Singh et al 2016)	Split or whole seeds used as Dal, salad and soup; Roasted seeds used as coffee; Green seeds used as vegetable; livestock feed
Indian Bean (*Lablab purpureus* (L.) Sweet)	Hindi: Bhatvas, Shimi, Sem English: Indian bean Sanskrit: Nispavah	India or South-East Asia	----	Karnataka, Tamil Nadu, Andhra Pradesh and Maharashtra	Carbohydrate (g): - Protein (g): 20-35%. Fiber (g): Fat (g): - Energy (kcal): - Moisture %: - Calcium (mg): - Phosphorus (mg): - Iron (mg): -	Pulse, vegetable, and forage

Status of Oilseed crop

Linseed (*Linum usitatissimum* L.)	Hindi: Alsi English: Flax seed, linseed Sanskrit: Atasi	Fertile Crescent, 'an area east to Mediterranean Sea towards India'	Canada, India, China, USA	Madhya Pradesh, Maharashtra, Chhattisgarh, Uttar Pradesh, Jharkhand, Bihar, Odisha, Karnataka, Nagaland, Assam, West Bengal, Himachal Pradesh, and Rajasthan	Oil content (%): 38 Carbohydrate (g): 28.8 Protein (g): 18.3 Fiber (g): 27.3 Fat (g): 42.16 Energy (kcal): 534 Kcal Moisture %: - Calcium (mg): 255 Phosphorus (mg): 622 mg Iron (mg): 5.73 (Sonawane and Arya 2012), Goyal et al 2014, Saini et al 2020)	Rich oil source; used in snack and as topping in corn snack, cake, tortilla, ice cream, yogurt and fibre textile
Soybean (*Glycine max* (L.) Merr.	Hindi: Soya bean English: Bhat, Bhatwar, Bhetmas Sanskrit: ---	Russian Far East to China and Temp. E. Asia.	United States, Brazil, Argentina, and China, India	Madhya Pradesh, Maharashtra, Rajasthan, Karnataka, and Telangana.	Oil content (%): 20% Carbohydrate (g): 19.8 Protein (g): 42.9 Fiber (g): 21.77–30.31 Fat (g): 19.8 Energy (kcal): --- Moisture %: 6.9 Calcium (mg): 245 Phosphorus (mg): 131-205 Iron (mg): 9.6 (Ezeagu 2009, Sharma et al 2014, Bhartiya et al 2020, Saini et al 2020)	Human food beverages; oil sources; industrial uses; biodiesel
Niger (*Guizotia abyssinica* (L.f.) Cass.)	Hindi: Ramtil English: Niger Sanskrit: ---	North East Tropical Africa.	South India, Ethiopia	Madhya Pradesh, Odisha, Maharashtra, Karnataka and Chhattisgarh	Oil content: 30-40% Protein (%):10-25 Fiber (%):10-20 (crude) Fat (%):20-31 Energy (kcal): - Moisture %: 10-11 Calcium (mg): 50-587 Phosphorus (mg): 180-800 Iron (mg): 56.7 mg (Jagtap 2015, Jain and Singla 2016)	Oil source; animal's and bird's feed; Biofuel
Safflower (*Carthamus tinctorius* L.)	Hindi: Kusum or Kardi English: Safflower Sanskrit:---	Asia, the Middle East, and Africa	India, USA, Mexico and China	Maharashtra, Karnataka and parts of Andhra Pradesh, Madhya Pradesh, Odisha, Bihar	Oil content (%): 33 Protein (%): 17.9 (crude) Fiber (%):16.4 Calcium (mg): 59.00-101.50 Phosphor (Mg): 663.00-770.40 Potassium (K): 156.15-203.60 (Mahdi and Hassanabadi 2010, Al Surmi NY et al 2016)	Vegetable oil; in coloring food and cosmetics; biofuel and in medicines
Sunflower (*Helianthus annus* L.)	Hindi: Surajmukhi English: Sunflower Sanskrit: ---	North America	Ukraine, Russia, European union, Argentina, Turkey	Karnataka, Andhra Pradesh and Maharashtra	Oil content %: 29 Carbohydrate (g): 18.72 Protein (g): 19.69 Fiber (g): 0.96 Fat (g): 53 Energy (kcal): 534 Moisture %: 3.1 Calcium (mg): 277 Phosphorus (mg): 667.66 Iron (mg): 4.9 (Aishwarya and Anisha 2014, Saini et al 2020)	Vegetable oil; used to create biodiesel; livestock and poultry feeds
Sesame (*Sesamum indicum* L.)	Hindi: Safed til English: Sesame Sanskrit: ---	Tropical & Subtropical Old World	India, Tanzania, Nigeria, China	Gujarat, Tamil Nadu, West Bengal, Karnataka and Madhya Pradesh.	Oil content: 50% Carbohydrate (g): 24-35 Protein (g): 18.08 Fiber (g): 5.5 Fat (g): 50.87 Moisture %: 3.1 Calcium (mg): 960 Phosphorus (mg): 659 Iron (mg): 19.2 (Prasad et al 2012; Kumar et al 2010)	Oil source; food and confectionery & biscuit; Livestock and poultry feed; Used in pharmaceutical
Coconut (*Cocos nucifera* L.)	Hindi: Nariyal English: Coconut Sanskrit: Kalpa vriksha	Central Malesia to SW. Pacific	Indonesia, Philippines, India, Sri Lanka, Vietnam, Mexico, Thailand and Malaysia.	Kerala, Karnataka, Tamil Nadu, Andhra Pradesh, West Bengal, Odisha, Gujarat, Assam, Maharashtra and Bihar	Oil content: 50% Carbohydrate (g): 87.10(juice)- 88.65(milk) Protein (g): 7.50 (milk); 3.05(juice) Fiber (g): 3.35 (milk); 2.35(juice) Fat (g): 50.87 Energy (kcal): 304(milk); 334.21 (juice) Moisture %: 8.33 Calcium (mg): 26 Phosphorus (mg): 36 Iron (mg): 0.7 (DebMandal and Mandal 2011, Belewu et al 2014)	

Status of sugare crop

Sugarcane (*Saccharum officinarum* L.)	Hindi: Ganna, Ikh, English: Sugarcane Sanskrit: Ikshu	Central and E. U.S.A. and Central and E. Asia to Tropical and Subtropical	India, Brazil, EU-28, Thailand, China, USA, Russian, Mexico, Pakistan	Tamil Nadu, Kerala, Karnataka, Andhra Pradesh, Maharashtra and Gujrat	Carbohydrate (g): 58.55 Protein (g): 3.20 (crude) Fiber (g): 29.88 (crude) Fat (g): 1.68 Moisture: 82.91% Total Sugar(g): 16.32% Calcium (mg): 18 (Sankhla et al 2012, Williams et al 2016)	Use in making sugar jaggery; manufacturing in alcohols and beverages and leaves used as livestock feed.
Sugar beet (*Beta vulgaris* L.)	Hindi: Chukander English: Beet root Sanskrit: Palanki	Middle East	Russia, France, the United States, Germany, and Turkey	Haryana, Uttar Pradesh, Himachal Pradesh, West Bengal and Maharashtra	Carbohydrate (g): 9.96 Protein (g): 1.68 Fiber (g): 2.0 (dietary) Fat (g): 0.18 Energy (kcal): 43 Sugar(g): 9.2 Calcium (mg): 16 Phosphorus (mg): 38 Potassium (mg): 305 Iron (mg): 0.79 (Yashwant, 2015; Neha et al 2018)	Alcohol, pharmaceuticals and baker yeast industries
Tapioca (*Manihot esculenta* Crantz)	Hindi: Shakarkand English: Cassava, Tapioca Sanskrit: Tarukandah	W. South America to Brazil	Nigeria, Brazil, Thailand and Indonesia	Tamil Nadu, Kerala, Andhra Pradesh, Nagaland and Assam	Carbohydrate (g): 39.06 Protein (g): 1.36 Fiber (g): 0.28 (dietary) Fat (g): 0.18 Moisture %: 59.68 Energy (kcal): 160 Calcium (mg): 16 Phosphorus (mg): 27 Iron (mg): 0.27 (Salvador et al 2014)	Human food; bakery and biofuel.

Abbreviations: g: gram; mg: milligram; Kcal: Kilocalorie

CONCLUSION

India is a population rich country where more than half people belongs to rural areas which are totally dependent on the agriculture farming for livelihood. In the past farm productivity was low and depended on imports for domestic need of food items. In 1950-51, the total irrigated area was 18% and food grains cultivation was 97.32 Mha. The productivity was 522 kg/ha and production stood 51 MT with 361.1 million populations which increased to 439.2 MT in 1961 at growth rate of 1.96%. The demand of food-grains was increased due to high population. After 1960, Green revolution efforts in research and development resulted in the introduction of high yielding seeds of wheat and rice which were called as miracle seeds. Many technologies were developed which increased the farm productivity and made India self-sufficient in food grains. The use of pesticide, fertilizer and irrigation methods solved many problems like disease, nutrition and drought. In addition to being produced, many crops were introduced from other countries. Many indigenous crops which are discussed in this paper were cultivated from ancient times. Consequently, agriculture becomes one of the largest contributors in national Gross Domestic Product (GDP).

The disadvantage of the modern management techniques of agriculture are loss of indigenous varieties due to focusing on high yield producing plants which destroyed the diversified gene pool. The maximum use of chemical fertilizer and pesticides make soil infertile and loss of nutrients from grains. It also reduced the organic trend of farming by the dependency on chemicals and pesticides for the resistant of diseases. These grains affect the human health. So, the intensive research work with a proper planning should be initiated for the conservation of the traditional varieties because of their nutritional benefits, these kinds and techniques should be included in the nation's food and nutrition security strategies.

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Received 30 January, 2022; Accepted 04 June, 2022

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Indian Journal of Ecology (2022) 49(3) (SI): 1023-1035
DOI: https://doi.org/10.55362/IJE/2022/3630

Manuscript Number: 3630
NAAS Rating: 5.79

Situational Analysis of Government Initiatives for the Welfare of Farmers in India: Impact and Futuristic Insights

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***Abstract*:** Agriculture in India has been continuously progressing, however, rural inhabitants and arable farmland per person is decreasing. In this context, every Indian farmer must adopt new and modern technologies and practices to balance food demand and supply problems. The Indian government implemented various missions and schemes for uplifting the agriculture sector and farmers, but due to varied geographical environments, and other loopholes like planning, execution issues, lack of awareness, integration failure of schemes, needs to be addressed to improve the existing condition of farmers as well as the agriculture sector. In this regard, this review sheds light on various impacts and gaps associated with the implementation of schemes. The mission for integrated development of horticulture was found to be the most successful scheme that increased farmer's income by 40%, and National food security mission is also associated with bumper production, but in some states where this mission is not integrated with irrigation schemes, the production is low. Further, when we applied the exponential model for the futuristic projections of production, area expansion, an increase was observed. Overall, the information about various factors influencing yield as well as production predictions can be efficiently managed using data-based digitalized agriculture approach.

Keywords: Indian agriculture, Schemes, Gaps, Digitalized agriculture, Exponential model

The agriculture sector is one of the prime contributors to India's economy, offering approximately 17.8% of the country's gross value added (GVA) during FY 2019-20 (PIB-MOF 2021). The Indian agriculture sector has been found successful in alleviating poverty (90 to 15%), with just 48.9% of India's workforce as compared to 75% at the time of independence (Acharya 2020). There is a hike in agricultural production which has made us self-sufficient and uplifted our condition after independence from begging bowl for food to a net exporter of agriculture and other allied products. Although the country has reached a good position still adequate efforts are required to reach the remarkable milestone. But the irony is despite this, neither the farmers can achieve economic satisfaction, nor there is any food or nutrition security for the malnourished population (14.8%) including 38.4% of children (FAO 2020, Babu et al 2021). Therefore, leaving India to rank 71 out of 113 countries in the Global Food Security Index (GFSI 2020).

Although, India is gifted with a handful of arable land with 15 agro-climatic zones, which is having almost all types of weather conditions, soil types and is thus capable of growing a variety of crops (Department of Water Resources, RD and GR 2021). Regardless of all these facts, the average productivity of many crops in India is quite low. The Indian government is always working restlessly for the welfare of farmers through the implementation of various schemes by rectifying various loopholes of the existing system. The farmers are finding it more difficult to estimate rainfall, soil conditions, and even groundwater levels based on current environmental factors. In continuation, the financial condition of farmers remains the same due to high input cost, weather variability, and low price (Chandel et al 2021). The objective of doubling farmers' income by 2022, according to the Indian government's vision, appears to be a difficult task. To achieve this goal, a large number of veterans across the globe suggested that increased access to Big Data could be extremely beneficial to the agricultural sector and by adopting digitalized smart farming (Saiz-Rubio and Rovira-Más 2020, Shankarnarayan and Ramakrishna 2020).

In this review, compiled data about various agriculture-related schemes implemented by the Indian government, their impact, gaps, and solution to the existing problems, along with their evaluation reports by Indian authorities like The Comptroller and Auditor General of India (CAG) and NITI Aayog. Further, the futuristic projections for the Mission for Integrated Development of Horticulture and National food security mission are also highlighted. In addition, the role of big data and digitalized agriculture approaches for the improvement of the agriculture sector are also discussed.

Inclusion Criteria and Statistical analysis

In this study, for data compilation, various research, review articles, and different websites like NITI Aayog, CAG (Comptroller and Auditor General of India), Ministry of Agriculture and Farmers Welfare, were utilized using various keywords like Indian agriculture, policies, beneficiaries, schemes, Digitalized agriculture, and Big data analytics, etc. Time series forecasting is a technique for predicting future values based on existing data in two successful schemes (Mission for integrated development of horticulture and National food security mission). Time series analysis is employed against non-stationary data, like economic data, weather, stock price, demand and supply, retail sales, etc. (Sharma et al 2020). The most advanced type of forecasting tool is a causal model. It expresses the relevant causal links analytically and may include pipeline considerations (i.e., inventories) as well as market survey data. It may also include the findings of a time series analysis directly. One of the most essential functions in mathematics is the exponential function. It is one of the most popular forecasting methods that use the weighted moving average of past data as the basis for a forecast. The procedure gives the heaviest weight to more recent observations and a smaller weight to observations in the more distant past (Ostertagova and Ostertay 2012). Exponential functions are used in a variety of scientific fields, including population expansion and radioactive decay. Further, they are also employed in finance, credit schemes, etc.

The exponential equation is:

$$Y = AB^t$$

where, t is the time period and Y is the observation at time t. This implies that the series is changing by a constant ratio of B per unit time.

$$Y = AB^t$$

$$\log Y = \log A + t \log B$$

i.e. $y = a + b\,t$

where, $y = \log Y$,

$a = \log A$ and

$b = \log B$

Normal equations of this model are:

$$\sum y = n\,a + b \sum t$$

$$\sum t\,y = a \sum t + b \sum t^2$$

The above-normal equations were solved to get a and b constant values.

$$a = \bar{y} - b\bar{t}$$

$$b = \frac{\Sigma(t-\bar{t})(y-\bar{y})}{\Sigma(t-\bar{t})^2}$$

These values are put in the equation of exponential model to get the estimated and prediction values in horticulture and the National food security mission.

Government Initiatives

The agricultural sector provides a livelihood for 58 percent of the Indian population (IBEF 2019). Agriculture is beset by issues, particularly in developing nations where people can't afford contemporary agricultural methods (Shankarnarayan and Ramakrishna 2020). The Indian government took a favourable stance and was instrumental in the expansion of the agriculture sector. For the welfare of farmers, the Ministry of Agriculture has implemented several programs such as subsidies (food, fertilizer, petroleum, and other commodities), crop insurance, around 20 national schemes, and plenty of others at the state level (Balkrishna et al 2020). In Figure 1, various schemes initiated by the Indian government for farmer's welfare are highlighted.

Subsidies: The government of India began a plan of subsidies on the purchase of various agriculture inputs to assist farmers due to the high cost of inputs (Singh 1994). Agriculture subsidies are a significant aspect of the farmers' lives in India, and they are critical for their growth and the country's general agricultural development. The entire expenditure on subsidies (food, fertilizer, petroleum, and others) is expected to reach Rs 3,69,899 crore in 2021-22, representing a 19% annual increase over 2019-20. This is partly due to a greater food subsidy grant of Rs 2,42,836 crore (Union Budget 2021). Jain (2006) reported that the provision of electrical subsidies has harmed agriculture's long-term viability, as it has resulted in the depletion of subsurface water. Despite their substantial impact in previous decades, input subsidies (such as fertilizer, energy, finance, and irrigation) resulted in very poor marginal returns in terms of agricultural growth as well as poverty reduction (Fan et al 2007). Fan et al (2007) recommended that government subsidies for fertilizer, irrigation, power, and credit should be reduced, but investments in agricultural research and development, rural infrastructure, and education should be increased.

Subsidies have both beneficial and negative effects on the agriculture sector, yet the development of the sector would be extremely impossible without them. However, determining the exact impact of subsidies on the agricultural sector is difficult because the amount to which subsidies benefit agriculture is a major debate. The central government should enact some strict conditions for distributing subsidies, such as making subsidies as translucent as feasible, framing a farmer-friendly policy in subsidy distribution, using subsidies for well-defined financial goals, establishing systems for regular subsidy review, and so on (Kumar 2020).

Crop insurance: In India, 26% of agricultural land is insured (2017-2018) as compared to 69 and 89% in China and United States, respectively (Alexander 2019). Crop insurance

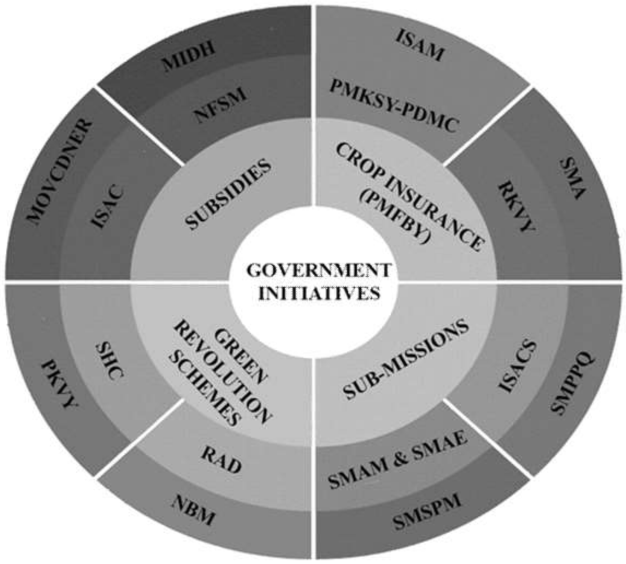

Fig. 1. Schemes implemented by the Indian Government for the welfare of farmers. PMKSY-PDMC: Pradhan Mantri Krishi Sinchayee Yojana-PDMC; RKVY: Rashtriya Krishi Vikas Yojana; MIDH: Mission for Integrated Development of Horticulture; NFSM: National Food Security Mission; SAME: Sub Mission on Agriculture Extension; SMAM: Sub Mission on Agriculture Mechanization; ISAM: Integrated Scheme for Agricultural Marketing; MOVCDNER: Mission Organic Value Chain Development for North Eastern Region; SHC: Soil Health Card; SMSPM: Sub Mission on Seed and Planting Material; RAD: Rainfed Area Development; PKVY: Paramparagat Krishi Vikas Yojana; SMPPQ: Sub Mission on Plant Protection and Plant Quarantine; SMA: Sub Mission on Agroforestry; NBM: National Bamboo Mission; ISAC: Integrated Scheme on Agricultural Cooperation; ISACS: Integrated Scheme on Agriculture Census and Statistics; PMFBY: Pradhan Mantri Fasal Bima Yojana

policies have long existed in India, but they have fallen short of covering the majority of the agriculture sector (Rajeev and Nagendran 2019). Pradhan Mantri Fasal Bima Yojana (PMFBY), the most recent crop insurance model, was introduced in 2016 (Tiwari et al 2020). Despite the introduction of PMFBY, 66% of farmers are unaware of crop insurance (Rajeev and Nagendran 2019). Crop insurance has a low distribution rate due to a lack of awareness (Rajeev and Vani 2014). Tenant farmers are not covered by crop insurance, and they account for 40% of all farmers (Rohini 2020). Although, as of January 12, 2021, the Scheme had already paid out claims for Rs. 90,000 crores (PIB-MOF 2021).

Pradhan Mantri Krishi Sinchayee Yojana-Per Drop More Crop: The Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) was inaugurated in July 1, 2015, with a five-year budget of Rs. 50,000 crores (2015-16 to 2019) to improve irrigation systems. “Har Khet Ko Pani” and “More crop per drop” are the PMKSY's mottos (Kumar and Kumar 2016). PMKSY's physical achievement (11.25 lakh hectare) fell short of the physical target in 2017-18 (12 lakh hectare). There was a significant discrepancy between the physical aim (16.0 lakh hectare) and the physical accomplishment in 2018-19 (7.57 lakh hectare) (Fig. 2). To assist micro-irrigation activities and encourage adoption among farmers, a specialized workforce at the field level is required (NITI Aayog 2020). In PMKSY, only three states, Andhra Pradesh, Gujarat, and Telangana, constitute 80% of the beneficiaries (DBTDACFW 2021)

Rashtriya Krishi Vikas Yojana: The Rashtriya Krishi Vikas Yojana-Remunerative Approaches for Agriculture and Allied Sector Rejuvenation (RKVY-RAFTAAR) was established in 2007 to ensure agriculture and related areas' interdisciplinary development by allowing states to do their development activities based on district and state agriculture strategies (RKVY-RAFTAAR 2020; NITI Aayog 2020). From 2017-18 to 2021-22, 56 projects in RKVY were de-sanctioned. Furthermore, 3302 projects were approved throughout this period, but only 235 were finished as shown in Figure 3 (RKVY 2021).

According to the Institute of Economic Growth (IEG), a comparison of average income per acre among beneficiaries and non-beneficiaries shows that RKVY had a positive influence on average household income in more than half of the states. By better engaging with the states, there is a purview for improvement in performance and maximizing the impact of the interventions being undertaken using scheme funding. (NITI Aayog 2020). The planning process was found to be weak in 24 states at the Gram Panchayat, Gram

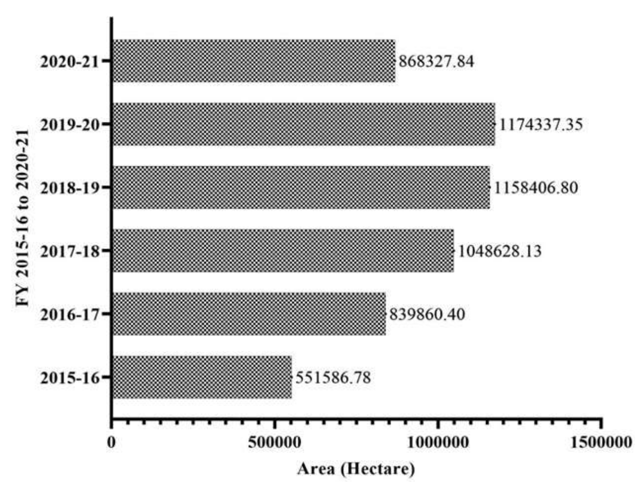

Fig. 2. Area covered (Hectare) under PMKSY from FY 2015-16 to 2020-21 (PMKSY 2021)

Sabhas, and Block level, according to the audit of RKVY. Cases of underperformance and irregularities were discovered in 150 (38%) of the 393 projects selected for audit investigation across 19 RKVY sectors (CAG report 2015).

Mission for Integrated Development of Horticulture (MIDH): National horticulture mission (NHM), Horticulture mission for North East and Himalayan States (HMNEH), National horticulture board (NHB), Coconut development board (CDB), and Central Institute for Horticulture (CIH) were all merged under MIDH in 2014-15 (NITI Aayog 2020). The fruits (5.42%), vegetables (2.51%), and flowers (1.56%) have seen a rise in the area, whereas plantation crops (0.15%), spices (0.26%), and fragrant plants have seen a modest reduction in area (0.02%) after MIDH implementation as depicted in Figure 4 (NHM and HMNEH evaluation report 2020). Before MIDH, per household average income from all sources was Rs. 4.33 lakhs, which grew to Rs. 6.06 lakhs after the scheme (Fig. 5), indicating a considerable gain of 40% (NHM and HMNEH evaluation report 2020). MIDH is the sole plan that has been found adequate at several levels of analysis such as financing, output, outcome, REESIE (Relevance, Effectiveness, Efficiency, Sustainability, Impact, Equity), and overall performance, according to the NITI Aayog report, 2020 (NITI Aayog 2020)

Futuristic projections of area and production of horticultural crops: Based on various reports, MIDH was found to be the best-implemented initiative of the Indian government. As per our investigation using the exponential model, the area, as well as production, is increasing from 2009-10 to 2034-35 (Table 1).

The exponential growth rate analysis indicated that during the study period there is positive and significant growth in area and production of horticultural crops but relative growth in the area is lower compared to that of production. The production is increased with area expansion as reported in the annual report of the Ministry of Agriculture and Farmer's welfare (Annual report 2020-21). However, there is a slight increase in the area of horticulture crops after the implementation of MIDH (NHM and HMNEH evaluation report 2020). The forecast analysis significantly indicates stagnation in the area under crops so there is a need for effective implementation of numerous programs initiated by the government to enhance the area under the crop so that the increasing demand will be met through production enhancement. This scheme might double farmer's income through area expansion and by digitalized data-based agriculture approaches.

National Food Security Mission (NFSM): NFSM was established in 2007-08 to enhance wheat, rice, and pulses production, and the country produced a record amount of

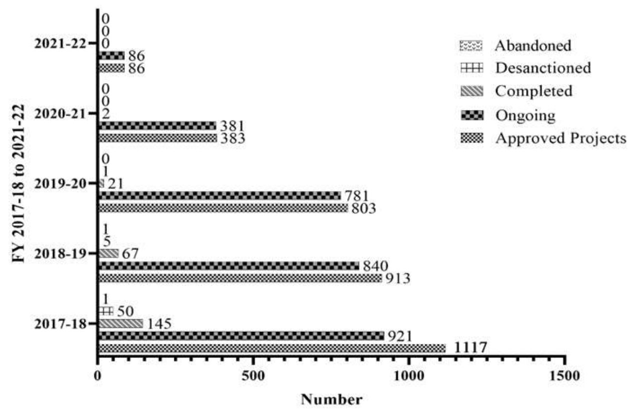

Fig. 3. Approved, ongoing, completed, de-sanctioned, and abandoned projects (RKVY 2021)

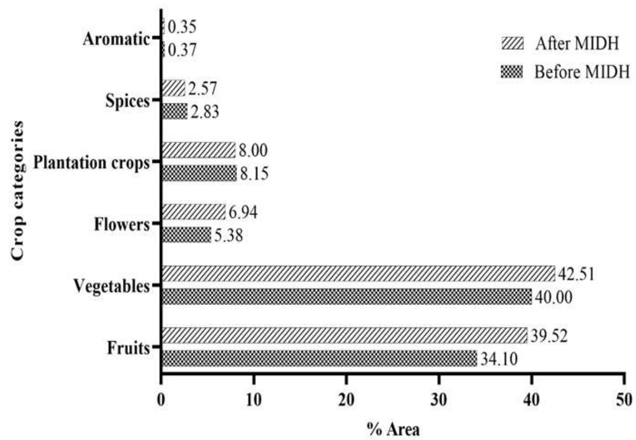

Fig. 4. Impact on area expansion after implementation of NHM and HMNEH from 2014-15 to 2018-19. NHM: National horticulture mission; HMNEH: Horticulture mission for North East and Himalayan States (NHM and HMNEH evaluation report 2020)

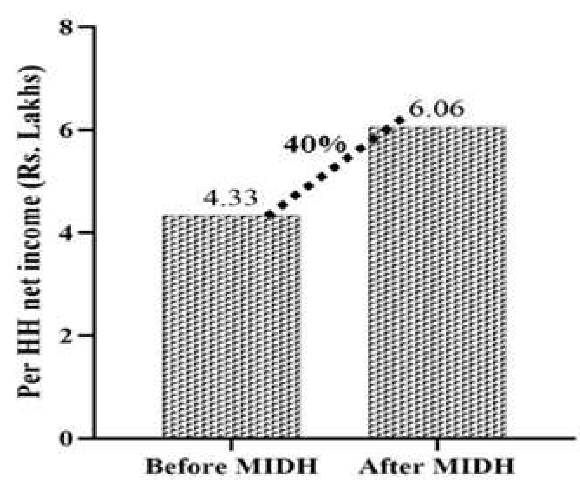

Fig. 5. Impact of NHM and HMNEH on the income of farmers from 2014-15 to 2018-19 (NHM and HMNEH evaluation report 2020)

food grains in 2017-18, totalling 285.01 million tonnes. Total food grain output in 2018-19 was 284.95 million tonnes, according to the 4th Advance Estimates. NFSM has been introduced in selected locations of 29 states across the country (PIB 2019). The Beneficiaries' earnings have increased between Rs. 3,764 and Rs. 66,763 as a result of NFSM approaches, depending on the crop. As a result, the mission has a positive impact; nevertheless, output and outcome indicators are not measured yearly (NITI Aayog 2020). In Chhattisgarh, the NFSM has benefitted merely 4% of farmers (1.38 lakh) who possess 6% of the state's cultivated land (2.76 lakh ha). Rice productivity in NFSM districts has lagged behind that of non-NFSM districts in the last five years since non-NFSM districts had more irrigation projects (25 out of 33 in the state) than NFSM districts (Fig. 6) (CAG report 2018).

To fulfill the NFSM's goal, the Department should raise awareness and educate farmers about the benefits of hybrid seeds. It should also be assured that consultants and technicians are appointed at the state as well as district level to streamline the mission's monitoring ventures (CAG report 2018). During the years 2011-12 to 2014-15, the sown area of pulses in Madhya Pradesh increased by 3%. Further, pulse production peaked in 2012-13, the first year of NFSM adoption, and then steadily declined in succeeding years (CAG report 2017).

Futuristic projections of rice, wheat and pulses production: NFSM aims to enhance the production of food grains such as rice, wheat, and pulses. We did futuristic projections of these food grains up to 2026-27, to find the gap in demand and production. As per NITI Aayog's report, the projected demand for rice, wheat, and pulses will be 119-120, 110-111, and 27-29 Million Tonnes, respectively concerning increasing population in 2028-29 (NITI Aayog's demand and Supply report 2018). The current estimates revealed the surplus production of rice, wheat, and pulses (135.57,

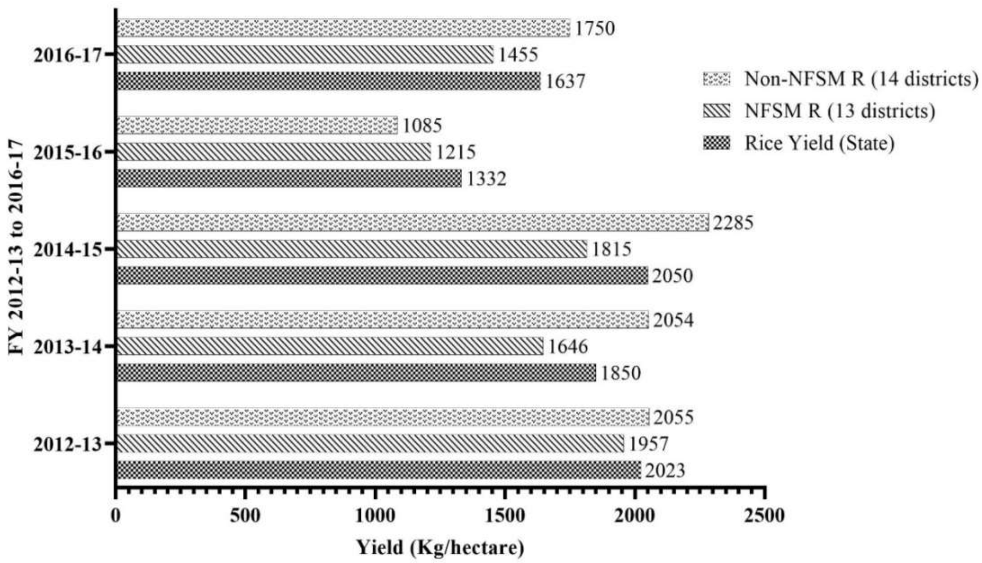

Fig. 6. Rice yield in NFSM and non-NFSM districts of Chhattisgarh (CAG report 2018)

Table 1. Futuristic area and production estimates of horticultural crops based on the exponential model

Year	Area (Million hectare)	Production (Million tonnes)	Year	Area (Million hectare)	Production (Million tonnes)
2009-2010	21.70	235.60	2018-2019	25.88	317.49
2010-2011	22.13	243.54	2019-2020	26.39	328.19
2011-2012	22.56	251.75	2020-2021	26.91	339.25
2012-2013	23.01	260.23	2021-2022	27.44	350.69
2013-2014	23.47	269.00	2022-2023	27.98	362.50
2014-2015	23.93	278.07	2023-2024	28.54	374.72
2015-2016	24.40	287.44	2024-2025	29.10	387.35
2016-2017	24.88	297.13	2025-2026	29.67	400.40
2017-2018	25.38	307.14	2026-2027	30.26	413.90

120.32, and 32.53 Million Tonnes, respectively) in 2026-27 (Table 2). The forecast analysis shows that the production of major crops shows an increasing trend in the near future, indicating a positive impact of government initiatives.

Sub Mission on Agriculture Extension (SAME): SAME trained around 4.63 crore farmers from 2016-17 to 2018-19, with 92,049 trainings conducted under the Agricultural Technology Management Agency (ATMA) scheme (NITI Aayog 2020). In SAME, on a nationwide basis, the extension personnel ratio is now less than the recommended ratio of 1:750. In comparison, India has approximately 1.2 lakh extension professionals, compared to 7.134 million local agriculture extension personnel in China (Nandi and Nedumaran 2019).

Sub Mission on Agricultural Mechanization (SMAM): More than 65% of funding in the SMAM for 2019-20 has been used as of November, indicating satisfactory progress in fund utilization (NITI Aayog 2020). In SMAM, the overall number of enrolled farmers in 2020-21 is 46677, yet only 18336 from Kerala, Tamil Nadu, and Uttarakhand has been benefitted as depicted in Figure 7 (Agri-machinery 2021).

The higher collateral, especially for loans of more than 1 lakh, higher interest rates, and comparably shorter repayment durations are some of the issues with SMAM (5-7 years). The small and marginal farm holdings account for around 85% of all farm holdings, this group of farmers must be targeted with appropriate farm machines and technologies (Tiwari et al 2019).

Integrated Scheme for Agricultural Marketing (ISAM): ISAM attempts to create competitive marketplaces and infrastructure for farmers to help them with a higher price for their produce. From 2017-18, the National agriculture market scheme, or e-NAM scheme, was integrated into ISAM (DMI 2021, NITI Aayog 2020). e-NAM has been connected with 1,000 mandis across 18 states and 3 UTs until January 24, 2021 (Lok Sabha report 2021). On the e-NAM platform, a total of 1.55 crore farmers/sellers, 68429 commission agents, and 122171 traders/buyers were registered as of March 15, 2019. On the e-NAM site, 24288397 tonnes of agri-commodities with a trade value of Rs. 64923 crores were exchanged (e-NAM 2021). ISAM must make a significant

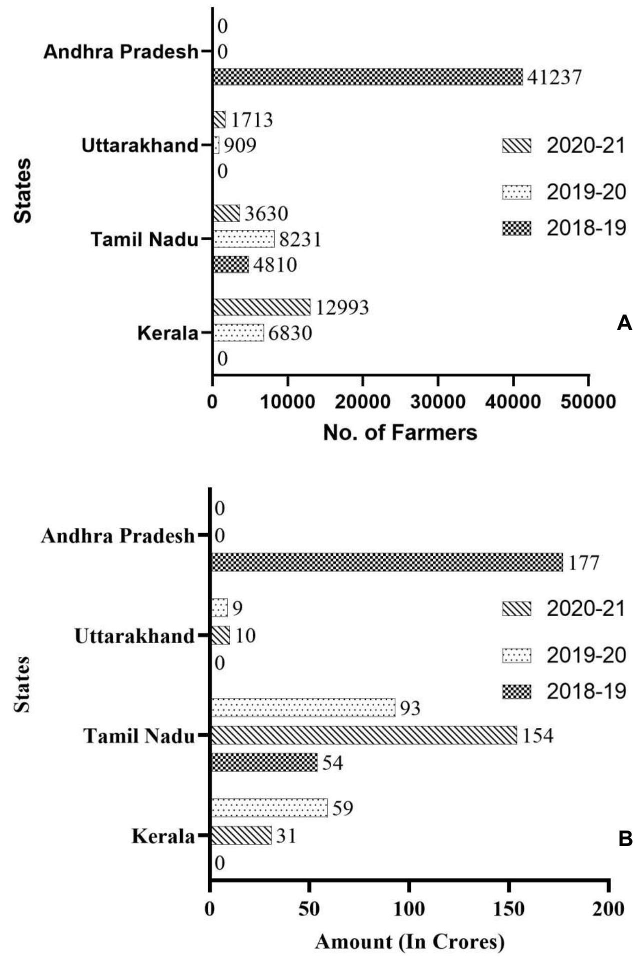

Fig. 7. Farmers benefitted (A) and subsidies allocated (B) under SMAM from FY 2018-19 to 2020-21. 0: Not available (Agri-machinery 2021)

Table 2. Futuristic production estimates of major crops based on the exponential model (million tonnes)

Year	Rice	Wheat	Pulses	Year	Rice	Wheat	Pulses
2009-2010	99.34	88.18	16.69	2018-2019	117.12	103.95	23.76
2010-2011	101.17	89.80	17.36	2019-2020	119.28	105.86	24.71
2011-2012	103.04	91.46	18.05	2020-2021	121.48	107.82	25.70
2012-2013	104.94	93.15	18.78	2021-2022	123.72	109.81	26.73
2013-2014	106.88	94.87	19.53	2022-2023	126.01	111.83	27.80
2014-2015	108.85	96.62	20.31	2023-2024	128.33	113.90	28.92
2015-2016	110.86	98.40	21.12	2024-2025	130.70	116.00	30.08
2016-2017	112.91	100.22	21.97	2025-2026	133.11	118.14	31.28
2017-2018	114.99	102.06	22.85	2026-2027	135.57	120.32	32.53

effort to overcome the sector's marketing gaps, given the extremely fragmented marketplaces, lack of marketing as well as storage infrastructure, and reduced adoption of portals like e-NAM (NITI Aayog 2020).

Mission organic value chain development for north eastern region (MOVCDNER): During the 12th Plan period, MOVCDNER is implemented in eight North-Eastern states, namely Arunachal Pradesh, Assam, Meghalaya, Manipur, Mizoram, Nagaland, Sikkim, and Tripura, to improve certified organic production by establishing a full value chain for the product (MOVCDNER 2018, NITI Aayog, 2020). In MOVCDNER, except for Mizoram, practically all of the states scored well in terms of the area covered. Tripura has performed admirably in terms of cluster/ FIG establishment, obtaining more than 100% of the target as shown in Figure 8 (NITI Aayog 2020).

Soil Health Card (SHC): SHC scheme was started in 2015 to offer farmers information about the quality of their soil. Farmers are given soil health cards that contain information such as the soil's nutrient status and the recommended dose of fertilizers to be delivered to improve its fertility (Union Budget 2021; PIB 2020; SHC 2021). In Cycle I, II, and Model village program, 22,87,14,022 SHCs were dispatched (SHC 2021). Farmers believe that soil health cards have had a substantial impact on crop yields (Padmaja and Angadi 2018). The issued SHCs must be updated regularly so that farmers are informed of the changing fertility state of their land (Chouhan et al 2017). Even though the Directorate claimed to have issued SHCs to 18% of the beneficiaries in Kerala, the study found that they had not received them (CAG report Kerala 2015).

Sub Mission on Seed and Planting Material (SMSP): SMSP was established in 2014 to increase certified seed production, farm harvested seed quality enhancement, promoting new techniques in seed production, processing, testing, and other areas, and strengthening and modernizing seed production, storage, and certification infrastructure (NITI Aayog 2020, PIB-SMSP, 2021). In SMSP, from 2014-15 to 2020-21, 4.29 lakh seed villages were established under the seed village program, with 38.01 lakh quintals of certified seeds provided at reduced costs to 170.86 lakh farmers (PIB-SMSP 2021).

The financial assistance was granted for the movement of 10.37 lakh quintals of seeds to ensure timely supply of certified/quality seeds at a reasonable cost to farmers in the North-Eastern States, J&K's UT, Ladakh, H.P., Uttarakhand, and West Bengal's hilly/remote districts under SMSP (PIB-SMSP 2021). Geo-tagging can aid in the control and tracing of scheme development in terms of asset generation in SMSP. It can also assist with traceability and certification (NITI Aayog 2020).

Rainfed Area Development (RAD): Since 2014-15, RAD has been a part of the National mission for sustainable agriculture (NMSA). For the development and conservation

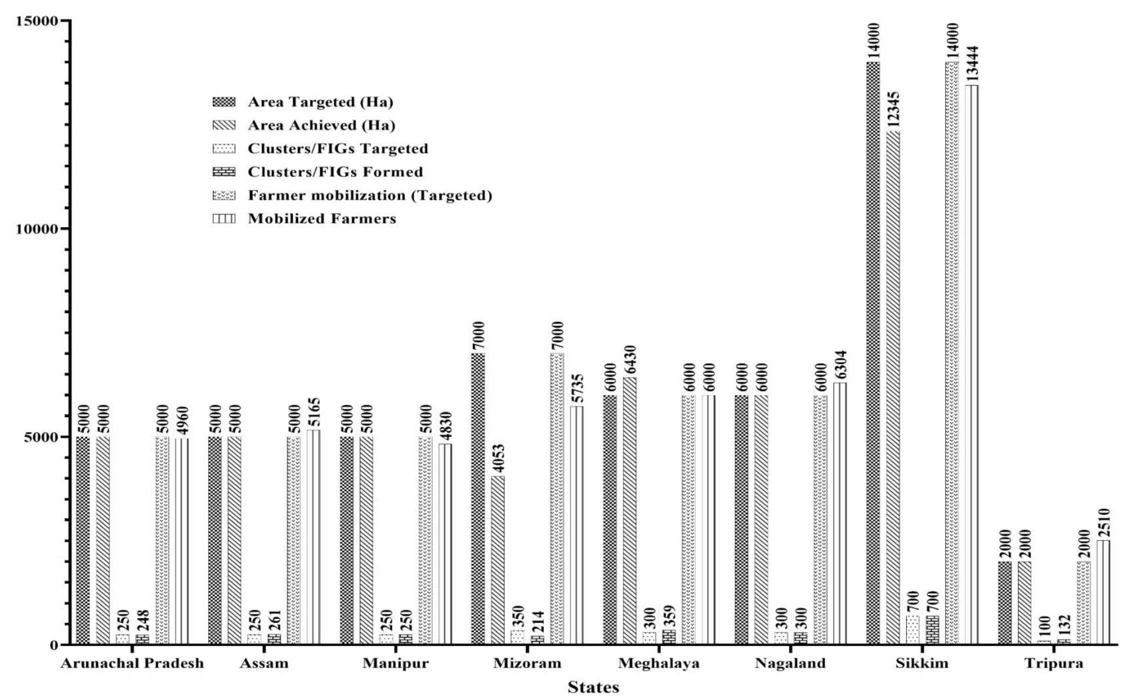

Fig. 8. Physical progress report of MOVCDNER Scheme (Phase-1) (NITI Aayog 2020).

of natural resources, as well as farming systems, RAD uses an area-based strategy. Varied systems such as integrated farming help to reduce the negative impact of crop failure (NMSA 2019, NITI Aayog 2020). From 2014 to 2019, the RAD initiative benefited around 1.5 lakh people, 45% of them were from Scheduled Castes, Tribes, and Backward Classes, and 18% were women (NITI Aayog 2020, DAFW, 2021).

RAD covers the entire country, although the states are dissatisfied with the financial scale, they can also receive assistance with interventions such as beekeeping. Furthermore, via active participation, frequent meetings, trainings, and workshops, improved coordination between farmers and implementation agencies may be developed; technical and support professionals for upgrading MIS must be rapidly hired (NITI Aayog 2020).

Paramparagat Krishi Vikas Yojana (PKVY): PKVY is an expanded component of Soil Health Management (SHM) under the NMSA, which was introduced in 2015. The goal of PKVY is to encourage and promote organic farming, which will increase soil health (PKVY 2017). The farmers' use of organic farming practices has increased year on year, according to an impact study undertaken by MANAGE after the introduction of PKVY (Reddy 2017, NITI Aayog 2020). The organic agriculture yield was 5.6%, which is less than conventional agriculture. The amount of green manure used has grown by 50%. There was a 20-50% improvement in net returns as a result of expense reductions, a positive impact of PKVY (Reddy 2017). Appointing divisional PKVY officers, separate booths for organic products at the APMC marketplace, and corporate linking are some of the gaps that need to be addressed (Reddy 2017). Due to the concentration of organic clusters in a few states, the execution of PKVY in other states such as Haryana and West Bengal should be promoted. Further, products certified by the Participatory Guarantee System (PGS) will be encouraged for increased acceptability (NITI Aayog 2020).

Sub Mission on plant protection and plant quarantine (SMPPQ): SMPPQ was launched in 2014-15 to reduce losses in agricultural crop quality and yield due to insect pests, weeds, rodents, and other pests, as well as protecting our produce from the invasion of unknown species (PIB-SMPPQ 2021). As the use of bio-pesticides/neem-based pesticides climbed from 123 MT in 1994-95 to 63540 MT in 2016-17, and the overall consumption of chemical pesticides in the country decreased, this component, SMPPQ performed admirably (NITI Aayog 2020). NITI Aayog recommended a focus on raising awareness and building capacity among private sector stakeholders, such as input distributors/handlers/distribution agents/traders/exporters, on safe chemical usage and storage for better functioning under SMPPQ (NITI Aayog 2020).

National bamboo mission: After China, India is the world's second-largest bamboo cultivator, with 136 species and 23 taxa distributed across 13.96 million hectares. India's yearly bamboo production is predicted to be 3.23 million tonnes, according to the Union Ministry of Agriculture and Farmer Welfare. Despite this, the country only accounts for 4% of the worldwide bamboo trade (Down to Earth 2021). The National Bamboo Mission (NBM) began as a Centrally Sponsored Scheme in 2006-07 and was later merged into the Mission for Integrated Development of Horticulture (MIDH) in 2014-15 (NBM Guidelines, NITI Aayog 2020). In addition, in 2018-19, a restructured National Bamboo Mission (NBM) was launched to focus on the growth of the entire bamboo value chain and connect growers with markets (PIB-NBM 2019). The business sector's involvement and participation in NBM should be promoted. The targets for scheme output and outcome metrics are not available for 2018-19. As a result, it is proposed that annual targets be set and updated regularly to aid in monitoring the scheme's performance (NITI Aayog 2020). The government has decreased GST on bamboo furniture and bamboo flooring to 12% in response to demand from bamboo-based stakeholders and to provide cheaper bamboo items to customers (PIB-NBM 2019).

Sub-Mission on agroforestry: In 2016-17, the Sub-Mission on Agroforestry (Har Medh Par Ped) scheme was launched in 20 states (PIB-SAF 2021). The scheme's goal is to encourage high-value agroforestry products while also supplementing agricultural revenue. Although one of the scheme's goals is to create jobs, it does not track how many jobs are created. The government should keep a record of entrepreneurs leveraging the scheme for self-employment (NITI Aayog 2020). The pressure on sole agriculture crops is increasing due to rapid population expansion, shrinking land holdings, and unpredictable weather conditions. Small and marginal farmers will benefit from the incorporation of trees and cattle into farmlands since it will provide them with appropriate income and employment. For instance, the Madhya Pradesh Forest and Agriculture Department, as well as NGOs, are pushing agroforestry and farm forestry on a big scale throughout the state, in conjunction with private wood-based companies (Bijalwan et al 2019).

Integrated scheme on agricultural cooperation: The fundamental goal of the Integrated Scheme on Agricultural Cooperation (ISAC) is to address concerns such as strengthening the cooperative status and eliminating regional imbalances. Another goal is to speed up the cooperatives' overall development in areas such as agriculture marketing, processing, warehousing, and digitalization (Vikaspedia 2021). Under ISAC, the scheme for marketing storage and processing activities currently supported over 17,000 cooperatives on average. Regional Institutes of Cooperative Management (RICM)/ICMs have trained over 60 thousand people. Furthermore, from 2012-13, the Integrated Cooperative Development Project has assisted nearly 3000 cooperatives in selected backward districts. NITI Aayog identified various weak areas under the cooperative sectors such as quality maintenance of inputs, link between produce and marketplace, storage, and others (NITI Aayog 2020).

Integrated scheme on agriculture census, and statistics: Integrated Scheme on Agriculture Census, and Statistics (ISACS) is also covered under green revolution (Pocket Book 2020, Vikaspedia 2021). Since 1970-71, the census released in 2015-16 is the 10th Agriculture Census. Under ISACS, the data of phase 1 have been released, phase 2 is being finalized, and for phase 3, it was compiled for 22 States/UTs. In ISACS, the major challenge is the unavailability of reliable, and comprehensive databases pertaining to land records. This can be resolved by the digitalization of records with pace and accuracy, while different plans need to be employed in states with non-land records (NITI Aayog 2020).

Other initiatives: As per the economic survey report an amount of 18000 crores have been distributed among 9 crore farmers in December 2020 under the PM-KISAN initiative. Subsequently, Minimum Support Price (MSPs) would be kept at 1.5 times of production cost as included in Union Budget 2018-19. The MSPs for Kharif and rabi crops in India have been enhanced by the Indian government in 2020-21. Recently proposed agricultural reform legislation are drafted for benefitting marginal farmers (85% of total farmers) as they suffered most from the regressive APMC regulated market regime. Moreover, under the Atma Nirbhar Bharat Abhiyan Rs. 1 lakh crore was proposed for agriculture and food management. In February 2020, with the inclusion of the livestock sector in Kisan Credit Cards (KCCs), 1.5 crores dairy farmers were targeted to provide KCC under the Atma Nirbhar Bharat Package. 44,673 KCCs have been distributed to fish farmers up to January 2021. Further, 4.04 lakh applications are in process (PIB-MOF 2021).

Impact evaluation: NITI Aayog assessed 17 schemes (16 centrally sponsored schemes under green revolution) in 2020 including the PMKSY-PDMC, RKVY, MIDH, NFSM, SMAE, SMAM, ISAM, MOVCDNER, SHC, SMSPM, RAD, PKVY, SMPPQ, SMA, NBM, ISAC, and ISACS. They account for almost 88% of overall spending (NITI Aayog 2020). The budgeted, revised, and actual estimates of these schemes and fund utilization are depicted in Figure 9 and 10, respectively. In terms of fund usage, 10 of the 17 schemes were deemed to be satisfactory (Fig. 11). Unfortunately, despite using nearly 98% of available money, only one (Mission for Integrated Development of Horticulture) was deemed to be satisfactory in terms of overall performance and two in terms of output. However, in the outcome variable progress is not available in some cases (NITI Aayog 2020).

Digitalized agriculture: A ray of hope: Under the Digital Agriculture initiative, information and communication technologies (ICT) are used to facilitate the transfer of localized information and services to make farming more socially, financially, and ecologically sustainable (Madaswamy 2020). Digital agriculture is expected to bring a significant increase in efficiency, productivity, and sustainability (Aubert et al 2012, Wolfert et al 2017). Cloud computing, the internet of things,

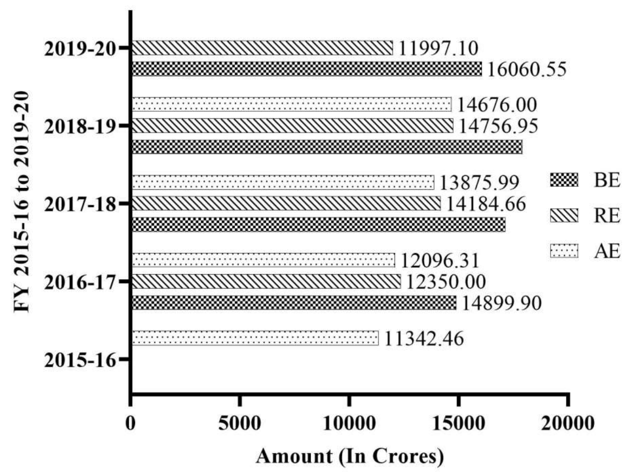

Fig. 9. Estimates for green revolution including PMKSY-PDMC. BE: Budgeted estimates; RE: Revised estimates; AE: Actual estimates (NITI Aayog 2020)

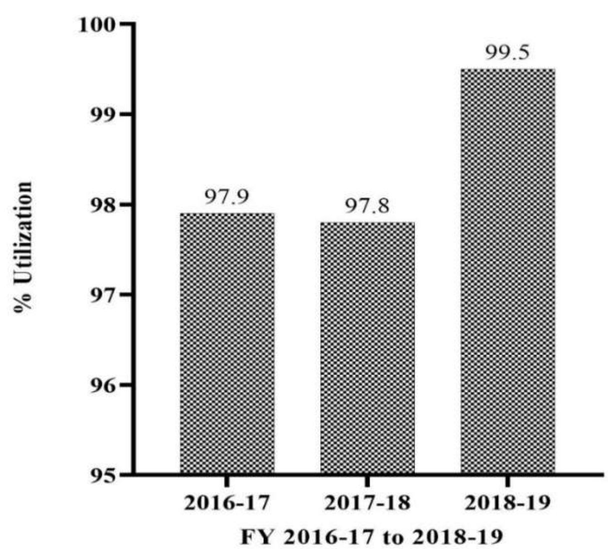

Fig. 10. Utilization of funds under green revolution including PMKSY-PDMC (NITI Aayog, 2020)

robots, and artificial intelligence are hastening the transition to smart farming to ensure agri-food sustainability (Robertson et al 2018, Ingram and Maye 2020). Moreover, crop yield forecast accuracy aids growers in developing a proper cultivation design, crop health monitoring system, effective crop yield management, and strategic objectives to reduce economic losses (Upendra et al 2020). Similarly, Shankarnarayan and Ramakrishna (2020) emphasized the value of Big Data. There is an opportunity to have access to massive amounts of satellite data, and if this information is made broadly available, it can help Indian farmers. Based on various studies, evidence is mounting that agronomic approaches such as precision farming can significantly increase farm production and income. Modern machinery, such as precision seeders, and planters, laser field levellers, and farming practices, like direct-seeded rice, rice intensification system, zero tillage, and others enable very efficient farming (Kumar 2019). Interestingly, as data has become a fundamental aspect in advanced agriculture to assist farmers with the sensible decisions, current developments in data are causing smart farming to increase dramatically. Data-driven agriculture, combined with robotic solutions that incorporate artificial intelligence approaches, lays the foundation for future sustainable agriculture (Saiz-Rubio and Rovira-Más 2020, Shankarnarayan and Ramakrishna 2020). In Figure 12, the role of data-based agriculture for the betterment of the agriculture sector is highlighted.

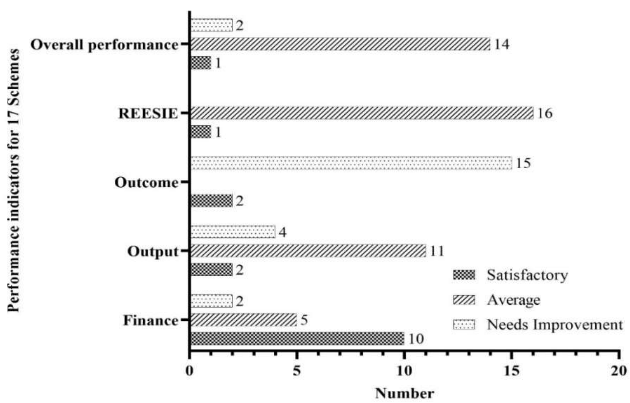

Fig. 11. Analysis of 17 schemes under Green revolution. Financial Indicators: Satisfactory: > 90%, Average: 70-90%, Needs Improvement: < 70%; Output Indicators: Satisfactory: > 80%, Average: 50-80%/physical progress, Needs Improvement: <50%;Outcome Indicators: Satisfactory: >50%, Average: <50%, Needs Improvement: Indicators need to re-aligned/not monitored/progress not available; REESIE: Relevance, Effectiveness, Efficiency, Sustainability, Impact, Equity; Overall Performance: Average of all defined parameters (NITI Aayog, 2020). Various issues, including the monitoring and planning process, are attributed to the average performance of 14 initiatives. The deployment of a digitalized agriculture approach can boost performance

The use of current data-based agriculture to make decisions can lead to more sustainable and lucrative actions to feed people in an environmentally friendly manner. Data from multiple years may be required to determine patterns in the parameters; therefore, data becomes a standard input to the farm management. Sensors are used to monitor crops and extract objective data from them. Sensing systems and analytics can provide better data to producers, users can make better real-time decisions with more obvious results while utilizing sensing technologies and machine learning to automate operations can enhance reliability. Modern farming allows for objective decision-making based on quantitative data (Big data, Internet of things, mapping GIS). People struggle to manage complex information in scenarios when several field parameters must be evaluated to make good decisions. Artificial intelligence (AI) approaches such as deep learning or neural networks, evolutionary algorithms, or expert systems can help in these situations (Saiz-Rubio and Rovira-Más 2020, Robertson et al 2018, Ingram and Maye 2020).

In India, the National e-Governance plan was first launched in seven states in 2010-11 to achieve rapid development using ICT for real-time access to agro-based information to farmers. The scheme was expanded for the remaining States and two UTs in 2014-15. Further, the program has been extended up to March 31, 2021 (PIB-February 2021). In this regard, the Indian government has signed memorandums of understanding with four groups for pilot projects. With ESRI India Pvt. Ltd. for the establishment and launch of the "National Agriculture Geo Hub," and with Amazon Web Services for the development of digital services and an agricultural value chain innovation ecosystem linked to digital agriculture. Agribazar India Pvt. Ltd. will partner with the Department of Agriculture on a pilot project to promote digital agriculture in three states (Uttar Pradesh, Madhya Pradesh, and Rajasthan). Additionally, with Patanjali Organic Research Institute for agricultural management and farmer service in Haridwar (Uttarakhand), Hamirpur (Uttar Pradesh), and Moraina (Madhya Pradesh) (PIB June 2021). On the other hand, a large number of mobile apps have been launched as a part of agro-solutions. In this regard, Balkrishna et al (2021) evaluated 73 agriculture mobile apps, which are used in different agriculture allied sectors. They found that out of these 73 apps, there are about 14% of apps are pertaining to pure agriculture, while 12% for farm management including geotagging. In the context of data-based agriculture techniques, our team at Patanjali Research Institute has developed a traceability mechanism

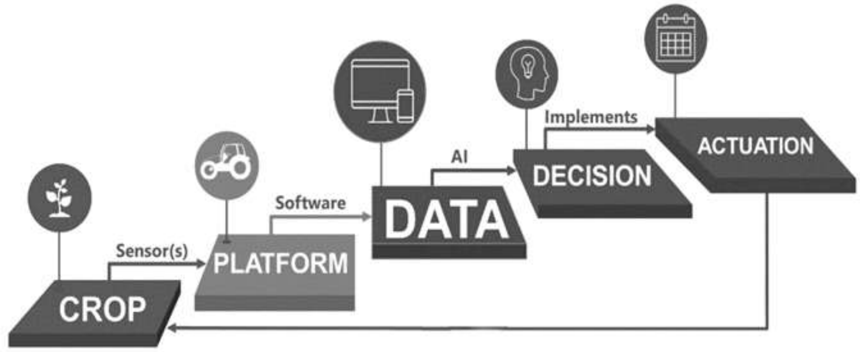

Fig. 12. Data-driven approaches for the management of agriculture(Reproduced from Saiz-Rubio and Rovira-Más 2020 under Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/)

from soil to the consumer through satellite with a digital solution. It will perform soil testing and recommend fertilizer based on soil nutrients. Along with this, an organic automotive certification program with app support accompanying it will be provided to the farmers. Parallel to this, an E-commerce portal system is also developed to reflect the farm produce along with quantitative details of both crop and other agriculture produce. This solution would be able to predict demand, shortage, and actual yield as per the commodity. A lot of work has already been done on these agro-solutions. This study will pave a new revolution in the field of digital agriculture-based initiatives in India.

CONCLUSIONS

Despite enormous efforts and a substantial proportion of the Indian economy spent on agriculture, the farmer's situation has not changed. In terms of output, Indian government efforts such as MIDH and NFSM have shown to be successful; however, several gaps in other initiatives must be addressed to improve the situation of farmers. The farming methods in India are confronted with numerous obstacles, including changing climate conditions, a diverse geographical region, traditional agricultural practices, and the country's economic and political situation. These can be overcome by implementing advanced agricultural technologies. Smart farming, digital agriculture, and Big Data Analytics are examples of these technologies that provide important information on many agricultural yield influencing elements and accurate crop production predictions. These technologies also help in the successful implementation of various government schemes.

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Received 12 January, 2022; Accepted 22 April, 2022

Indian Journal of Ecology (2022) 49(3) (SI): 1036-1043
DOI: https://doi.org/10.55362/IJE/2022/3631

Manuscript Number: 3631
NAAS Rating: 5.79

Indian Farmer and Government Initiatives: Policies, Gaps and Way Forward

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Abstract: In India, the government continues to implement various programs and policies yearned at increasing agricultural production by facilitating the sale of its products and providing tax relief to Indian farmers. However, most farmers cannot benefit from such plans/policies due to a lack of understanding and are prone to misinformation and scepticism. Farmers are well aware of the risks posed by climate variability and adverse weather conditions. They are unsure which crop to grow due to changes in soil structure caused by unpredictable weather conditions. These are just some of the problems facing Indian farmers. Extensive research has been waged on the importance of farmers to the nation, how they contribute to the national gross domestic product, why they commit suicide, and how beneficial efforts and programs affect them. In this review article, mainly discuss the government's agricultural and production policies, Indian farmers' conditions, government initiatives to alleviate the problem of farmers, advances in sustainable agriculture technology, policies and suggestions on the development of farmers.

Keywords: Economy, Government policy, Climates, Soil health, Farmer

India has been an agricultural economy for many years in addition to agriculture has played an important role in the Indian economy ampersand 58% of all workers are involved in agriculture (Mospi 2021). India's economic activity depends on 55% of Indian agricultural land (Sharma et al 2021). Bedide (2021) states that the "Farmer's Land" is famous in India, because most people are engaged in agriculture, directly or indirectly. India's past speaks volumes about agricultural efficiency, excellent climate and abundant natural resources (Bedide 2019). India (most of its land has wheat, rice and cotton) is also a world-leading producer of spices, legumes and milk (Tyagi 2012). Chemical fertilizer usage, agricultural residue burning, and pesticide use all contribute to global pollution (Dhaliwal et al 2010, Nagendran 2011,). Shaikh and Gachande (2015) stated that the amount of subsoil and macrofauna decreased, which instantly affected the C-N rate and the nitrification function. Most farmers in India are small and marginal owners, and if they invest more in inputs and don't get a higher return because they haven't been able to cope with pests, disease and bad weather, their production costs will increase (Dey 2018).

The agricultural industry has generated 20.19% of India's GDP in recent decades, which has increased to 3% (Mospi 2021). In short, India has the amplest agricultural powerhouse in the world ampersand its backbone is farmers and other agricultural workers. Like many other companies, agribusiness has faced unexpected challenges and problems for decades. Farmers in India face various challenges and obstacles. This assessment will predominately concentrate on farmer circumstances, government efforts, privileges, and proposals for farmers' welfare.

The word "FARMER" shall cover all agricultural operators, farmers, farm workers, tenants and rear farmers, fishermen, beekeepers, gardeners, plotters and planting workers and all other primary agricultural commodities involved in the economic and/or living of cultivated crops and other primary agricultural commodities. Tribal families/individuals involved in shifting agriculture, as well as the gathering, usage, and sale of minor and non-timber forest produce (NPF 2007). Farmers works start from preparation to harvesting. A farmer is responsible for cultivating the land, harvesting crops, seeding, and preserving seeds. Indian farmers direct and indirect linked to economy and GDP (Headey and Masters 2019).

India's Farmers Condition

The majority of farmers are deeply in debt. Agriculture provides a living for more than 58% of farmers in India. (Ghosh et al 2021). Farmer suicides in India are being reported from all across the country. Moneylenders continue to play an important part in agricultural development, with interest payments that surpass the income earned (Esteves et al 2013, Varshney et al 2018). The price of a crop is inversely proportional to its production. The higher the productivity, the lower the price, and vice versa. It is impossible to achieve good rainfall, good productivity, and the best price at the same time. As a result, farmers have limited incomes or no profits or losses (Mishra et al 2018, Challob et al 2020). The cost of producing rice fields is now comparable to the cost of final production. However, rice grass needs to be reused as feed for cattle, which is beneficial to farmers. Costs need to be kept low if crops are damaged by excessive rain or drought condition, or if everything is going well and productivity is low (Gulati et al 2018).

Scholars have given numerous causes for farmer suicides in India, including monsoon failure, climate change, excessive debt, government policies, mental health, personal and familial difficulties (Deccan 2018, Kumar 2016). The major causes are as follows (Fig. 1):

Input costs: A foremost reason for farmer suicides in India has been the rising inconvenience on farmers due to high agricultural input prices. The conclusion of these variables is apparent in the general increase in agrarian costs; for wheat, the cost is now three times greater than it was in 2005 (Singh et al2016, Anonymous 2020).

Manure and seed prices: Whether it's manure, crop protection chemicals, or just manufacturing seeds, farming has become prohibitively expensive for already burdened farmers (Dey 2018).

Agrarian equipment costs: Input expenses are not restricted to fundamental raw materials, however. The usage of agricultural gear and equipment such as tractors, submersible pumps, and so on adds to the already growing expenses. Furthermore, these secondary inputs have grown increasingly difficult to get for small, marginal farmers (Singh et al 2016, Rao 2017).

Labour costs: Similarly, the cost of recruiting employees and animals is rising. While this may represent an improvement in workers' socioeconomic condition, mostly as a result of MGNERGA and a rise in the minimum basic income, it has not coincided with the agricultural sector's boost (Singh et al 2016, Anonymous 2021).

Distressed due to loans: According to NCRB statistics, the victims of 2,474 of the 3,000 farmer suicides investigated in 2015 defaulted on local bank loans. This is a strong enough signal to draw parallels between the two. However, whether or if the banks harassed them is a debatable topic that needs more exact empirical evidence (Kumar 2016).

Furthermore, a departure from the norm revealed that usurers lent just 9.8 percent of the loans taken out by these farmers. As a result, creditors' pressure or power may be far from being a major driving force, as is commonly assumed. Another cause of strong connections between farmer suicides and debt is the prevalence of both. Karnataka had 946 debt suicides, while Maharashtra had 1,293 debt suicides (Fig. 2). Remember that both states have among the highest rates of farmer suicides and debt (Kumar 2016, Deccan 2018, Anonymous 2021).

Lack of direct market integration: Although efforts such as the national agricultural market and contract farming are assisting in integrating farmers' goods directly with the market, eliminating the role of middlemen, reality remains behind (Anonymous 2021).

Lack of awareness: Because of their inability to capitalize on the benefits of government programs, marginal smallholder farmers have been particularly susceptible as a result of the digital divide and literacy gap. This is evident in continued unsustainable agricultural practices, such as sugarcane cultivation in water-stressed areas (Kumar 2016, Dey 2018).

Water management: The concentration of these suicides in water-stressed parts of states such as Maharashtra and Karnataka is an indication of how the water crisis, and therefore the inability to satisfy production needs, has exacerbated the threat. This is especially true in light of the ongoing failure of the monsoons (Kumar 2016).

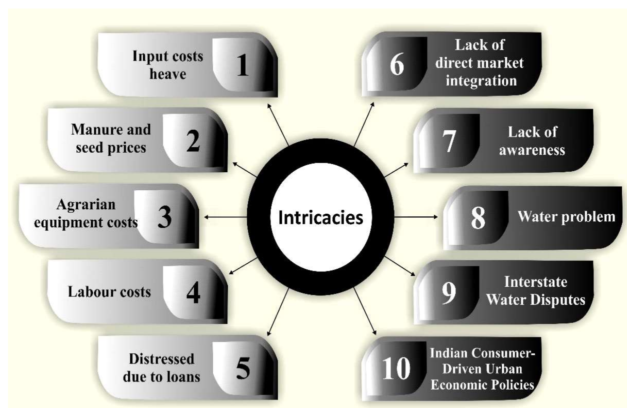

Fig. 1. Multifarious farmers intricacies

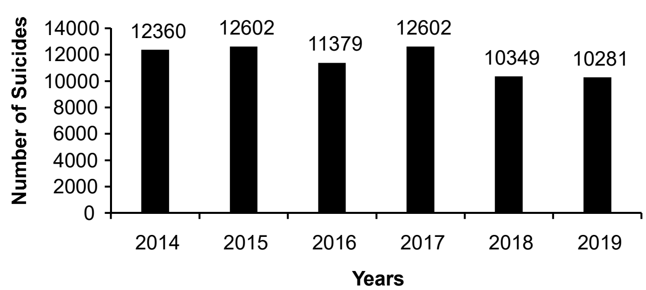

Fig. 2. Number of farmer suicides in India (Hossain et al 2020)

Interstate water disputes: States' unwillingness to satisfy each other's water requirements has exacerbated the already-existing issue. One example is the newly resurrected Kaveri conflict, in which Karnataka and Tamil Nadu struggled with water shortages both within and outside the court, to the point of refusing to comply with the court's order (Singh et al 2016, Dey 2018, Anonymous 2021). Climate change has been the last nail in the coffin, increasing the uncertainties associated with the already unpredictable monsoon system and, by extension, agricultural productivity. While flash floods have resulted in crop losses, delayed monsoons have resulted in a year-over-year reduction in production (Rao 2017).

Indian consumer-driven urban economic policies: Urban consumers drive India's political economy more than rural producers. This is evident in the speed with which price restrictions are imposed in the event of a price increase (imposition of minimum export prices, inclusion of goods in essential products, etc.) and the gradual removal once the price is under control. To preserve our steel sector, we established a minimum import price. This differential handling of the agricultural sector also restricts profit margins and, as a result, farmers' ability to break free from the debt cycle (Kumar 2016, Deccan 2018, Dey 2018). Loan exemptions rather than restructuring and reinvestment measures: our approach to controlling farmers' debt and hence farmers' suicides have been pacification strategies, such as the UP government's recent decision to forego loans worth 36 billion rupees. Surprisingly, this occurs at a time when agricultural output is supposed to rise following a strong monsoon (Singh et al 2016, Rao 2017). In essence, crop failure, unsustainable output, and farmer indebtedness as a result of failing to enhance the farmer's economic standing are the main forces behind these suicides.

Government Initiatives: The significant difficulties now are that agriculture development is no longer a primary focus for policymakers, as shifting paradigms of development theory at the global level and specific events in India lower agriculture to a secondary priority. The post-war development theory literature highlighted the importance of agricultural technology up-gradation as a prerequisite for industrial expansion, which was then regarded as the sole indicator of a country's success (Kumar 2019). The Indian government prioritizes farmer welfare and implementing various farmer welfare programs to revitalize the agricultural sector and improve its economic conditions (Balkrishnaet al 2020). Several new initiatives have been introduced by the government, including the Soil Health Card Scheme, Neem Coated Urea, Paramparagat Krishi Vikas Yojana (PKVY), Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), National Agricultural Market (e-NAM), Pradhan Mantri Fasal Bima Yojana (PMFBY) (Table 1), and others All farmers profit from these initiatives.

Actions Benefiting Indian Farmers

Sustainability Ideas: Some recent central government development programmes aimed at increasing output while decreasing costs include the *Pradhan Mantri Krishi Sinchai Yojana*, the *Soil Health Card*, and the *Prampragat Krishi Vikas Yojana*. The *Pradhan Mantri Fasal Bima Yojana* is another significant project that provides crop and income insurance. Aside from risk coverage, it will stimulate agricultural investment. Another notable effort with a high potential for increasing productivity and agriculture revenue is river interconnection (SFAC 2013, Rao et al 2006, Kumar and Khurana 2021). These programs must be executed in a time-based way to have the intended effect on the financial health of farmers. Quality of seed and efficient manure usage are critical foundations of productivity development. It's also been noted that increased electricity supply to agriculture leads to increased efficiency and economy. Most states have a relatively limited supply of power for the agricultural industry (GOI 2017).

Advancement in technology: There is growing evidence that agricultural technologies, such as precision farming, can substantially increase farmers' output and income. In addition, the current engineering such as laser leveler, precise sowing and sowing and methods such as CRS for rice intensification, direct rice sowing, non-tillage, raised bed sowing and hill sowing, enable technically highly efficient cultivation (Rao et al 2009, Varshney et al 2018, Tyagi 2012). Their commercial profitability is low and these technologies are being developed by the government. Requires an extension significant adoption by farmers. It should emphasize teaching farmers about the potential of this technology, promoting access to finance and developing a regulatory climate that allows them to embrace it (Esteves et al 2013, Dandekar and Bhattacharya 2017, Chapagain and Raizada 2017, Dey 2018, Bedide 2021).

Institutional: The size of Indian agriculture is dominated by marginalized and small farmers who face tremendous difficulties. Small farm size prevents many farmers from diversifying their fruits and vegetables, owing to price risk and an uneconomic lot for sale (Mariappan and Zhou 2019). Small-scale farmers in various input and output market transactions are equally disadvantaged in terms of bargaining power. This barrier can be addressed by organizing farmers through institutional mechanisms such as farmer organizations (Singh 2008). The SFAC has offered examples of successful collective action by farmers working via established institutions. It provides convincing evidence

Table 1. Various schemes implemented by the Government of India

Aim	Implementing agency	Budget allotation	Beneficiary	Present standpoints	Gaps	Reference
Pradhan Mantri Kisan Samman Nidhi Yojana, 2018						
Support Rs 6, 000/year for small and marginal farmers of India. Financial assistance to all land-holding qualified farmer families	Central Sector Scheme under PM-KISAN	Rs 75, 000 Crore (2021-22)	The Scheme is predictable to reach around 12.50 crore, farmer families	Farmer families with total cultivable holding upto 2 hectares provided benefit of Rs.6000 per annum per family payable in 3 equal installments, every 4 months. 1st installment to eligible beneficiaries during this financial year 2018-19for the period from 01.12.2018 to 31.03.2019.	Many farmers submitted their application forms after the announcement of the scheme on February 1. But due to limitations in the government machinery, not all of them were registered in the first period.	Indian budget 2021, Jagadeeswari et al 2021, Balkrishna et al 2020
Pradhan Mantri Kisan Maan Dhan Yojana, 2019						
On reaching the age of 60 years, the scheme provides Rs. 3000/- month for Small and Marginal Farmers	Ministry of Agriculture & Farmers' Welfare, Department of Agriculture, Cooperation & Farmers' Welfare, Government of India with the Life Insurance Corporation of India (LIC).	Rs. 50 crore (2021-22)	In the first three years, the Scheme intends to reach about 3 crore participants.	If farmer dies after the 60 years; the spouse will receive 50% of the pension as Family Pension. After the death of both the farmer and the spouse, the accumulated corpus shall be credited back to the Pension Fund.		Indian budget 2021, Balkrishna et al 2020
Pradhan Mantri Kisan Suraksha Abhiyan Utthaan Mahabhiyan (Kusum) Yojana, 2019						
Increase farmer income and provide sources for irrigation and de-dieselizing the agriculture area. Farmers in the country for the implementation of solar pumps and grid-connected solar and other renewable energy facilities.	Ministry of New & Renewable Energy	1,000 crore (2021-22)	Until the 28th of February, 2021, a total of 24,688 independent solar pumps and 64 grid-connected farm pumps had been solarized.	1 Large Scale Solar power generation projects are being installed to achieve the ambitious target of 100 GW of Solar Power generation by 2022. Farmers increase their income by utilizing their barren and uncultivable land for solar or other renewable energy based power plants.	Limitations in construction of new solar power plants.	Indian budget 2021,PIB 2020, GOI 2021
Pradhan Mantri Fasal Bima Yojana (PMFBY), 2016						
Provide maximum premium during 2% Kharif, 1.5 % Rabi food & oilseed crops, and 5% annual commercial or horticultural crops, with the remaining actuarial or bidded premium split equally by the Central and State Governments.	Department of Agriculture, Cooperation & Farmers Welfare (DAC&FW), Ministry of Agriculture & Farmers Welfare (MoA&FW), Government of India (GOI)	16,000 crore (2021-22)	A total of 224.7 lakh farmers will benefit from the program till the year 2019-20.	Wider coverage area: Unlike the previous insurance plan, this coverage also includes disasters such as riots, hailstorms, floods, etc Reasonable premium: for Rabi crop 1.5%, Kharif 2% and commercial crop 5% same premium rate	Financing mechanism: premium subsidies are divided between the state government and the central (50%). The plan may not be completely centrally supported. Failure to implement Settlement delay	Indian budget 2021, Tiwari et al 2020, Kumar et al 2021

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Table 1. Various schemes implemented by the Government of India

Aim	Implementing agency	Budget allotation	Beneficiary	Present standpoints	Gaps	Reference
Pradhan Mantri Krishi Sinchai Yojana (PMKSY), 2016						
Irrigation supply chain, like distribution network, farm level applications, and water sources (One drop more crop)	Ministry of Agriculture & farmer Welfare	4,000 core (2020-21)	PMKSY-PDMC has covered an area of 46.96 lakh ha. under Micro Irrigation during the previous five years.	Convergence of irrigation investments at the field level, expansion of cultivable land under guaranteed irrigation, improved on-farm water usage efficiency to decrease water waste, and increased adoption of precision irrigation.		Indian budget 2021,Srikala 2020, Chaudhari 2021
National Agriculture Market (e-NAM), 2016						
e-marketing platform (One Nation One Market)	Ministry of Agriculture and Farmers' Welfare, Government of India.	410 crore (2020-21).	The e-NAM site has already integrated 585 mandis from 16 states and two union territories, and it will soon be expanded to encompass another 415 mandis, bringing the total number of e-NAM mandis to 1,000.	NAM portal networks existing APMC (Agriculture Produce Marketing Committee) / Regulated Marketing Committee (RMC) market yards, sub-market yards, private markets and other unregulated markets to unify all the nationwide agricultural markets by creating a central online platform for agricultural commodity price discovery.	The state APMC Act must have a specific provision for e-auction / electronic trading as mode of price discovery.	Indian budget 2021, Yadav et al 2021,Manjula 2021
Soil Health Card, 2015						
Implementation of micronutrients and soil ameliorant (Swasth Dhara, Khet Haraa)	Department of Agriculture & Cooperation Ministry of Agriculture Government of India	315 crore (2021-22)	6954 villages were chosen by the State/UT, where 20,18 lakh samples were collected, 14,65 lakh samples analyzed and 13,54 lakh cards delivered to farmers, against the objective of 26,83 lakh samples.	To make agriculture more productive, sustainable and climate resilient; to conserve natural resources; to adopt comprehensive soil health management practices; to optimize utilization of water resources; etc	In certain villages, GPS signals are not caught. In the state of Telangana, new AEOs were appointed in February 2017. As a result, they were unable to mobilize farmers who received SHC last year. Due to a lack of soil testing labs in some mandals/villages, SHC was not supplied to farmers.	Indian budget 2021,Meena & Chadda 2021, Stott et al 2021
Paramparagat Krishi Vikas Yojana, 2015						
Promote organic farming	Department of Agriculture, cooperation and Farmers Welfare	450 crore (2020-21)	Under the PKVY initiative, 237820 hectares of land have been transformed into organic farming land, benefiting 3,94,550 farmers.	PKVY aims at supporting and promoting organic farming, in turn resulting in improvement of soil health. The Scheme targets to form 10,000 clusters of 20 ha each and bring nearly two lakh hectares of agricultural area under organic farming by 2017-18	The cluster chosen for Organic Farming shall be 20 ha or 50 acres in extent and in as contiguous a form as possible.	Indian budget 2021, Reddy 2020, Vijai & Elayaraja 2021

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Table 1. Various schemes implemented by the Government of India

Aim	Implementing agency	Budget allotation	Beneficiary	Present standpoints	Gaps	Reference
Weather Based Crop Insurance Scheme, 2016						
Insurance for crop seeds, oilseeds, and horticulture crops	Department of Agriculture & Cooperation (DAC) and Farmers Welfare, Government of India	4,813 core (2020-21)	A total of 15 lakh farmers have benefited in kharif season (2016).	To ease the burden of insured farmers due to the possibility of financial loss due to crop loss due to bad weather conditions such as rainfall, temperature, wind, humidity, and so on..	Only severe weather events that potentially result in significant crop losses are included.	Indian budget 2021, Standing committee 2021, Dupdal et al 2020

of value chain integration for farmers (SFAC 2013). There are several other successful examples of greater output and higher market returns achieved by collective action via group action or some type of organization (Gupta 2015). Some of the organizations, particularly those in remote and underserved areas. By June 2016, SFAC has promoted 510 FPOs with 5,71 Lakh farmers in 28 nations (GOI 2017). The FPOs were likewise outstanding. Some states, as well as NABARD, encourage FPOs. However, there are few FPO numbers and networks, which should be increased to help farmers to decrease transaction costs, get access to technology, enhance bargaining power, and integrate into value chains (SFAC 2013).

Suggestions for farmers' welfare: Farmers in India, especially small and marginal farmers, are under a lot of stress. The situation is expected to worsen unless immediate steps are taken. A farmer-centric approach to agriculture is required for the welfare of farmers and overall improvement of the agricultural sector in India. Some of the major areas of concern that needs to be focused upon are given below.

Better agricultural inputs: Inputs determine the overall yield and quality of agricultural output. Hence, it is necessary to ensure availability of high-quality seeds and agrochemicals at affordable rates. Similarly, irrigation facilities must be provided wherever possible.

Access to credit facilities: Availability of credit facilities at affordable terms and conditions is necessary for the farmers to purchase good quality agricultural inputs. In addition, financing options to upgrade farm infrastructure and start secondary agricultural activities should also be available to improve farm productivity and profitability (Balkrishna et al 2020).

Efficient agricultural extension services: India has extensive research infrastructure for agriculture in the form of ICAR institutes, Central and State agricultural universities, and other research institutions (Singh and Aggarwal 2020). However, the lab to land transfer of technologies is not efficient enough. Hence, efforts must be made to strengthen the agricultural extension services, with a focus on small and marginal farmers (Balkrishna et al 2021).

Farmer-centric policies: Policy interventions have the maximum impact on farmers' income (Tyagi 2012). The lack of participation of the organized private sector is a major impediment to unlocking the full potential of Indian agriculture. The liberalization of the agricultural sector would increase the competitiveness of the sector and promote its development (Bedide 2021). Structural reforms in the agricultural sector, such as land leasing, contract farming, and agro-forestry, would be beneficial to kick-start growth in the agricultural sector (Rao et al 2006, Tyagi 2012, SFAC 2013, Gulati et al 2021). Some of the major areas where policy interventions of the government could have a beneficial impact are mentioned below.

Market reforms for remunerative prices: Market reforms are necessary to enhance competition in the agricultural sector and ensure remunerative prices for the farmers (Shaikh and Gachande 2015). Market prices must be kept above the MSP during harvest season through various mechanisms, such as direct purchase and shortfall price payment (Varshney et al 2018, Sharma et al 2021).

Investment for modernization of agriculture: Some of the latest agricultural practices, such as precision farming, hydroponics, aeroponics, and IOT implementation, are costly endeavors. However, they are necessary to increase agricultural efficiency, especially in the current agricultural scenario. Hence, investments in the agricultural sectors, especially by the private sector, can help to modernize farm operations (Shaikh and Gachande 2015, Rao et al 2006, Jain and Kannan 2021).

Supply chain and market linkages: Traditional supply networks in agricultural sector are exploitive for the farmers (Jain and Kannan 2021). Strategies are required to integrate small and marginal farmers to the modern agricultural supply chain. Agricultural facilities, like warehousing, must be made accessible to the farmers at affordable prices, especially for perishable agricultural products (Aditya et al 2017, PIB 2021, Gulati et al 2021). Market linkages must be developed to leverage the demand for fresh and high quality agricultural products (Aditya et al 2017, GOI 2017, Balkrishna 2020).

Farmers' cooperatives: Small-scale farm operations are often not viable economically (GOI 2017, Mospi 2021). Collective action, resource pooling, and group marketing through various groups, such as Farmers Producer Organizations (FPOs), can help to carry out agro-business operations in a professional manner. Involvement of government agencies in the formation, maintenance, and development of FPOs can effective in enhancing farmers' income through improved output and market connections (GOI 2017, PIB 2021, Mospi 2021, SFAC 2013).

Agro-processing: Value addition to primary agricultural produce through agro-processing industries is an effective way to capture more value from agriculture. However, the agro-processing industry in India is still at nascent stages and is plagued by various issues, such as inconsistent supply. Policy changes, such as contract farming, can help to bridge the gap between farmers and processors (SFAC 2013, Mospi 2021).

CONCLUSION

Indian farmers labor really hard to provide food for their families. The government initiates many schemes/policies for farmers, however owing to a lack of knowledge and misinterpretation. Farmers are not reaping the full benefits of policies. They do not want to go through any paperwork if they can receive money with no paperwork from landlords at a high interest rate. The government is working to modernize farmers, however small and marginal medium farmers do not have enough money for an Android phone and lack understanding. The government raises awareness through campaigns, advertisements, and other means. If we modify some policies/schemes, we get better results in the future. Farmers are being informed about new policies and initiatives that may aid India's growth.

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Received 16 January, 2022; Accepted 23 May, 2022

Indian Journal of Ecology (2022) 49(3) (SI): 1044-1050
DOI: https://doi.org/10.55362/IJE/2022/3632

Manuscript Number: 3632
NAAS Rating: 5.79

Doubling Farmers' Income in India: Progress, Gaps and Futuristic Approaches

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Abstract: In India, the agriculture sector is constantly improving its mechanism to maximize output and ensure food security. However, a large population is leaving farming practices because of the low-income generation. As a result, in 2016, the government of India formed an inter-ministerial committee for the evaluation of existing problems and then recommends feasible strategies to accomplish the mission of 'Doubling Farmers' Income by 2022'. In this review, we have discussed the concept of doubling farmers' income, its present standpoints, challenges and the role of the Indian government in mitigating the same. Further, the innovative approaches to meet the aforementioned goal have also been highlighted. The Indian government has supported various development programs, implemented a large number of schemes and recently, additional income transfer under the PM-KISAN scheme to double farmers' income. Innovative agricultural approaches like advanced farming methods, smart agriculture, diversification and commercialization, climate smart agriculture and nutrition farming if implemented at Pan India level will definitely resulted into income generation. Despite tremendous efforts by the Indian government, some challenges still exist in the agriculture sector and this study gives valuable recommendations that would act as pillars in the policymaking to achieve the 'doubling farmers' income initiative.

Keywords: Agriculture sector, Farmer's income, Current progress, Gaps, Future approaches

The Indian agriculture sector is one of the major contributors to India's economy, providing about 17.1% of the country's Gross Value Added (GVA). Agriculture is successfully providing livelihood to about 70% of rural households in India (Balkrishna et al 2021). The production of cereals, oil crops and pulses was recorded in the year 2019 at 324.3, 64.8 and 21.5 million tonnes respectively, as against 296.01, 58.7 and 20.0 million tonnes in the year 2014 respectively (FAOSTAT 2021). Similarly, the productivity of other major crops of India has also registered a significant increase. It also includes trade and market economy, through which developed nations have established their dominance over other countries. Agriculture plays a vital role in creating employment and livelihood options which bring development which is two to four times as effective as any other developing alternative. Thus, making it a powerful tool to address the underlying issues of poverty in Indian communities by developing a rich nutrition reservoir in India as well as in the world (Gills and Sharma 2021). With the emergence of the Green Revolution, traditional farming practices were improved, more land was purchased for irrigation, agricultural mechanization in North India, increased use of fertilizers, pesticides, high-yielding seed varieties, institutional support policies were introduced for example subsidies for fertilizers, groundwater extraction, MSP (Minimum Support Price), purchase of food grains (mainly rice & wheat) and public distribution (Tilman et al 2001, FAO 2003). Ultimately India becomes the second-largest producer of both wheat and rice in the world. However, even after more than six decades of the green revolution, the condition of our farmers remains destitute as they are forced to grow high-cost crops instead of more nutritious and low-cost crops like pulses and millets (Swaminathan and Kesavan 2017). The reason behind this farmer's economic crisis is the need to produce more than the limited natural resource base, which is shrinking over time, affecting the production capacity as well as the ecosystem. Not only this but other factors are affecting the income of farmers in India, including market price distortions, climate variability and extreme events such as droughts, floods and cyclones, innovations, changing consumer preferences, and labor migration (Jayaraman and Murari 2014, Acharya 2020). Recently, the COVID-19 pandemic has forced farmers to stop their farm work as well as restrict their access to the market due to the lockdown. Although the farmer had a market surplus, procurement was hampered with irregular collection from the farm due to inadequate labor and logistics. The plight of providing availability and accessibility to safe and healthy food to the vulnerable 15% of the population is very real and painful.

Past trend in farmers' income: In the past, the agriculture sector in India has primarily focussed on increasing agricultural output and boosting food security for doubling the farmers' income. Indian agriculture sector during the period 1965 to 2015, was successful in multiplying its food production by 3.7 times with a 2.55-fold increase in the population (Chand 2017). According to the NSSO 70th survey (2002-03 to 2012-13) and NABARD financial inclusion survey (NAFIS) (2016-17), in spite of an increase in the farmers average monthly income from ₹6,426 (2012-13) to ₹8,931 (2015-16), this income turned out to be lower than not only the fixed minimum wages for unskilled workers in agri-sector but also less than 20% of the country's average per capita income (NSSO 2013, NABARD 2016, Dalwai 2018). Moreover, the ratio of the income farmer concerning the population working in the non-farm sector was also reported to be 3.12 for the year 2011-12, which was the sole reason for the deteriorating disparity between the two (Chand and Parappurathu 2012). The further distressing fact is that out of 90 million farm households, 61 million have ≤1-hectare agriculture landholding with a net negative monthly budget. These were the outcomes of the existing severe issues of high indebtedness, recurrent crop failures, adverse terms of trade, uncertain and erratic returns of the produce at the marketplace, supply of substandard and spurious inputs, and the associated crop losses (Romanenkov et al 2008). All these reasons were enough to understand that progressing with the existing strategy would lead to detrimental effects on the overall Indian agricultural economy. In 2016, the government of India formed an inter-ministerial committee for the evaluation of existing problems and then recommends feasible strategies to accomplish the mission of 'Doubling Farmers' Income by 2022'. Possible sources for enhancing the farm income growth rate are listed in Table 1 (Chand 2017).

Table 1. Various sources for increasing farm income in the agriculture sector

Inside agriculture sector		Outside agriculture sector	
Improvement in agricultural productivity	• 2000-01 to 2013-14, both the aggregate crop productivity and the required input productivity increased by the same rate of 3.1% annually. • The rate of generation of total farm income would increase to 16.7% by 2020-21 and 25% by 2023-24 as compared to 2013-14. • livestock productivity was sought to increase by 10.8% and 16.6% by 2020-21 and 2023-24 (increase the total farm income to 27.5% by 2020-21).	Repositioning cultivators from farm to non-farm occupations	• In 2011-12, the worker productivity in the rural areas accounted for ₹62,235 per worker (64% farm sector workforce) and ₹1,71,587 per worker (39% non-farm sector workforce). • Between 2004-05 to 2011-12, NSSO has revealed that there has been a sharp decline of 34 million individuals. • The agricultural workforce is expected to fall to 55% by 2022-23, including a 13.4% reduction in cultivators.
Improvement in total factor productivity	• NITI Aayog policy report TFP in the Indian agricultural sector heightened to 2.62% during the period 2004 to 2012 and with this rate, the farmers' income is expected to grow to 26.3% by the year 2022-23.	Advancement of trade terms for farmers	• NITI Aayog policy reports the farmers' income during 2011-12 to 2015-16 suffered a major setback due to crucially lower growth in constant prices of value-added agricultural products and also due to 50% higher increase in CPIAL than the increase in farm gate process of agricultural produce. • Two major changes: 1. Online trading as market reformation 2. Opening markets to traders outside the mandi as a unified national agricultural market would bring a remarkable change in increasing the farmers' income considerably.
Increase in cropping intensity	• Low crop intensity is supposed to be the inaccessibility to sufficient water for proper irrigation • Pat rate of 0.7% for an increase in cropping intensity in the country, the farmers' income can be significantly increased by 3.4% by the year 2022-23 and 4.9% by the year 2025-26.		
Diversification towards high-value crops	• 2013-14, 77% of the gross cropped area of staple crops produced only 41% of the total crop output, while just 19% of the gross cropped area. • The crop output can easily increase to 1% each year, leading to 5% increase in the farmers' income by 2022-23.		

Source: https://www.niti.gov.in/

Current progress: After evaluating the trends and identifying the gaps, the Government of India proposes various programs and schemes as solutions for the development of the agriculture sector. Agriculture in India is supported by the respective state governments, where they are responsible for its development by implementing these programs and schemes. Keeping in view the increase in crop productivity, remunerative returns, and income support, the Ministry of Agriculture and Farmers Welfare implemented several initiatives (Fig. 1) for the welfare of farmers in 2020 (Minister of Agriculture and Farmers Welfare 2020). The initiative is primarily focused on increasing the income of farmers and with this, the government has supported various development programs, schemes, reforms, and policies, which include higher budgetary allocation, corpus fund creation through non-budgetary financial resources and additional income transfer under the PM-KISAN scheme. Taking into account all the commodities and sectors in agriculture, a pathway has been formulated for the implementation of the mission of doubling farmers' income by 2022 (Sendhil et al 2017a, Sendhil et al 2018, Verma et al 2019).

Irrigation is supposed to be the best insurance against drought. Thus, to improve irrigation technology, the states have been propelling towards 'per drop more crop'. The Pradhan Mantri Krishi Sinchai Yojana (PMKSY) is focussing on the expansion of farm-level micro-irrigation with regularly tracking of 99 priorities over 7.6 million ha land and work towards more crop per drop as a national mission to improve crop productivity.

Present gaps and interventions: The history of agricultural reforms carried out in India since independence begins with the green revolution, followed by the introduction of various acts such as Agricultural Produce and Livestock Marketing (APLM), Agricultural Produce and Livestock Contract Farming and Services for promotion and facilitation of agriculture industries, e-NAM and 'Pradhan Mantri Annadata Aay Sanrakshan Abhiyan (PM -AASHA)'. The need to maintain the supply chain that was provoked during the Covid-19 lockdown and the prevailing circumstances, the government announced three ordinances on farm bills which were eventually passed as three farm laws in the year 2020, to institutionalize agricultural reforms through legislation. These three laws were 'The Farmers Produce Trade and Commerce (Promotion and Facilitation) Act 2020', 'The Farmers (empowerment and protection) Agreement in rice Assurance and Farm Services Act 2020' and 'The essential Commodities (Amendment) Act 2020' (Dev 2020). The above-stated three laws have enormous potential to attract investments and entrepreneurship development among young and educated individuals with innovative intellectual abilities (Ashrit 2021).

Innovative Agricultural Approaches

Advanced farming methods: Urban and peri-urban agriculture has been recently gaining attention due to its sustainable nature, as it uses urban trash, reusable natural

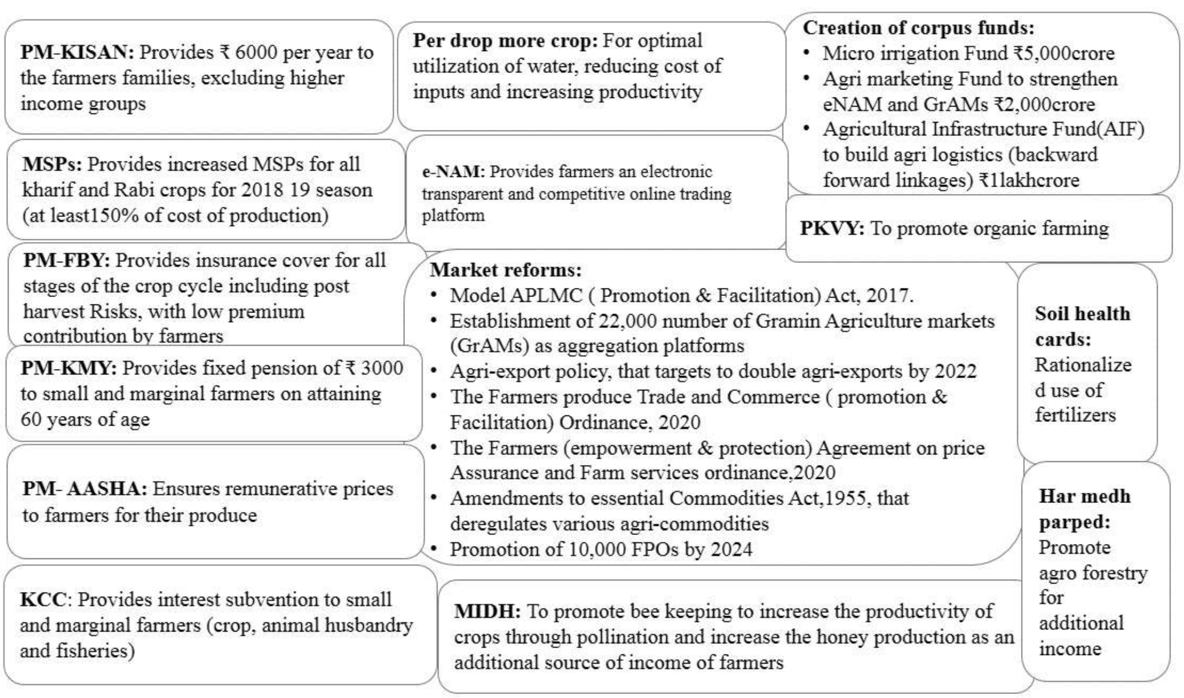

Fig. 1. Indian government's recent initiatives toward doubling of farmers' income

resources, and waste for production, processing and marketing of agricultural produce. (Antonio 2017, Ebel 2020). Some of the types of urban and peri-urban agriculture include allotment gardens (medium size vegetable garden in the municipal area), vertical farming (vertically inclined planes, vertically piled stratums & another plant-growing substrate integrated), fertigation, aeroponic and aquaponic (Jain and Janakiram 2016), a community garden (single or combination of multiple small pieces that has been planted), educational gardens (development of urban agriculture in an educational institution), micro-gardens (intensive cultivation practice) and aquafarming (farming of aquatic in wastewater), etc. Organic farming is another method of crop cultivation which is become important due to its huge advantages on income generation and eco-friendly (IFOAM 2009, Balkrishna et al 2021). It is considered an environmentally friendly technique because it restores carbon and other necessary nutrients in the soil (Srivastava et al 2018).

Smart agriculture: The smart farming system is the need of the hour due to a decrease in soil productivity, increase in climate change, and adverse environmental impacts. This includes implementation of advanced technologies such as the Internet of Things (IoT) with automated and connected devices, in the existing food production system (Balkrishna et al 2020) and act as a way of the temporal and spatial application of capital-intensive and hi-tech modern Information and Communication Technologies (ICTs) such as (artificial intelligence (AI), machine big data analysis, learning, etc.) in on- and off-field activities. For instance, high precision sensitive gears called sensors, which can detect minute changes in light, moisture, and temperature have found their application in various agricultural activities like weather monitoring, information system, and precision agriculture, IT-based post-harvest produce handling, etc. Other AI-based applications include smart harvesting, smart irrigation, smart greenhouses, quality-controlled processing, mechanized grading, price forecasting, etc (Gill and Sharma 2021). Smart agriculture can pave a way to enhance agricultural productivity, address issues in the supply chain, and most interestingly can virtually interconnect the farms make them intelligent in decision-making. This can be executed using AI-based drones, sovereign tractors, robotic artilleries, etc (Gill and Sharma 2021). Thus, using machine learning and artificial intelligence can provide a smart way of the food production system, thereby having a direct impact on poverty alleviation and increasing the farmers' income.

Diversification and commercialization: Agricultural products with high-value yields in low volumes can be an effective way of reducing farmers' income distress and creating a sustainable economic impact of the agriculture sector in India (Meena et al 2018, Deogharia 2018). Diversification is essentially important to meet the changing dietary demand with nutrition awareness (FAO 2004, Joshi et al 2004). Chand (1996) stated that agricultural diversification can be prompted by diverting farming from a single crop to the cultivation of multiple crops or livestock. This can include the cultivation of flowers, honeybees, fisheries, mushrooms and exotic vegetables, etc (Basantaray and Nancharaiah 2017). Overall, crop husbandry and crop-based product development is an innovative technique to not only increase farmers' revenues but also provide them with an extensive range of options for utilizing their agricultural lands that would conserve the environment and create employment opportunities (Maggio et al 2018). Therefore, with increased productivity, reduction in the cost of production, and increased risk-bearing against yield loss from climate change, the income of farmers can be increased substantially. Another commonly used method for crop diversification is crop rotation, which is also used for farmers' income generation even with erratic climates (UNFCCC 2009, Smith et al 2008). Crop rotation is the suitable arrangement of consecutive crops in a pattern that promotes the facilitation of different plants to pull nutrients in different magnitudes from various levels (Rahman 2009).

Climate-smart agriculture: With extreme changes in global climatic conditions, the food and nutrition crisis has also intensified to a great extent (World Bank 2019b). Climate-smart agriculture (CSA) is an integrated advanced agriculture approach that focuses on addressing agricultural challenges related to climate change (FAO 2010, Olorunfemi et al 2019). In the socio-agricultural scenarios, the terms adaptation and mitigation play an important role in managing climate change (CIFOR 2011, FAO 2012a). Climate adaptation is the ability of a production system to identify and take advantage of opportunities to cope up with climate variability and extremes, as well as to deal with the costs and consequences of human-induced climate changes (Pan and

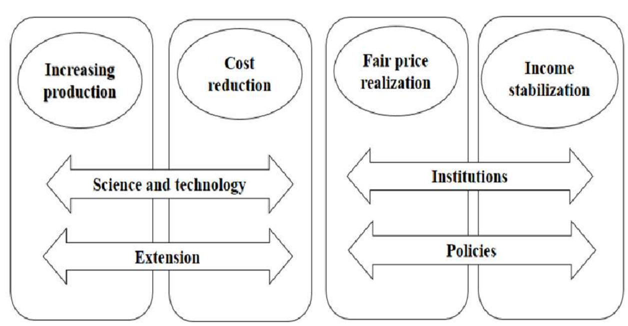

Fig. 2. Framework for implementation of the mission of doubling farmer's income by 2022

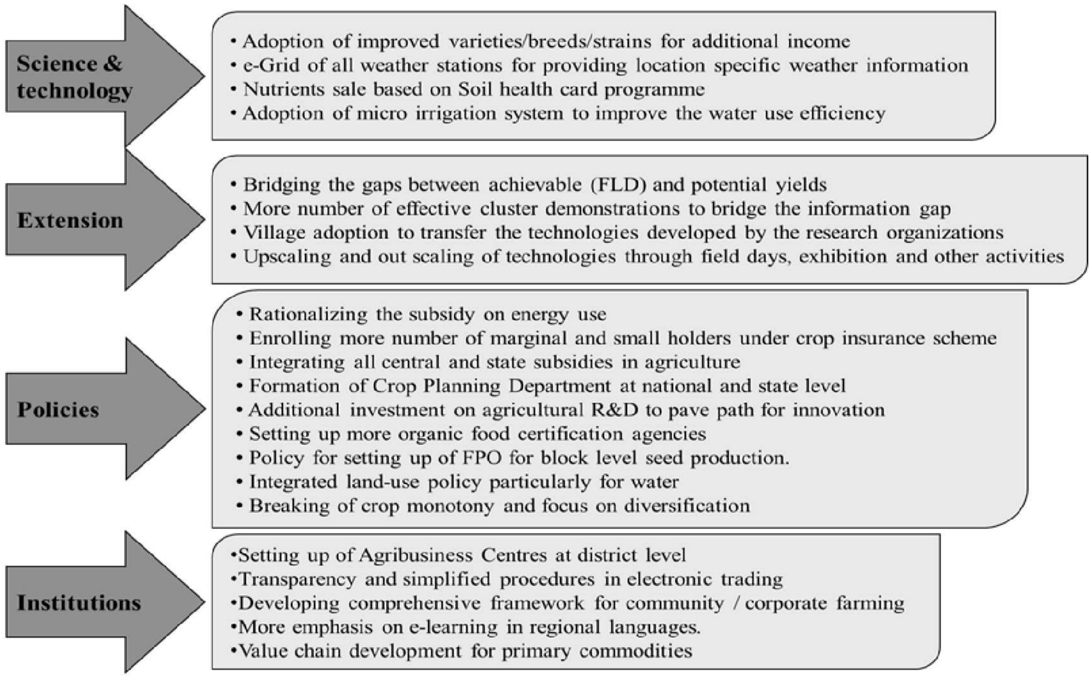

Fig. 3. Potential strategies to increase annual farm income

Zheng 2010). The effort to eradicate or diminish the long-term risk and perils of climate change to human life, living components, and any property of the production system, is recognized as climate mitigation (Lu 2013, Duguma et al 2014). With the extent of climate change in the present scenario, the adaptation strategies have become as important as mitigation plans (Campillo et al 2017, OECD 2018, UNFCCC 2019), because of the harm that has been done to the environment, especially in terms of increased temperature, the mitigation efforts and strategies won't be able to prevent the increasing temperatures till the year 2100 (OECD 2018, Vogel and Meyer 2018).

Nutrition farming: Nutrition-sensitive agriculture is based on the principles of increasing availability and accessibility of the food, encouraging sustainable and diverse production, increasing nutritional content and making food more nutritious (FAO 2014, Nagarajan et al 2014). For this purpose, nutri-farms or nutri-gardens have attracted much attention in nations targeting nutritional security. Nutrition farming requires an integrated approach with the cultivation of high nutrient density fruit and vegetable crops and biofortified crops (Bouis et al 2013, Bouis and Saltzman, 2017) that is carried out following good agricultural practices for higher productivity and improved soil quality. Thus, nutritional farming fulfils the two essential objectives of providing essential nutrients and additional income through crop diversification and the low cost of cultivation (Jaenicke and Virchow, 2013). In India, National Agricultural Research System (NARS) in hand with the international crop organization has established various breeding programs to enhance the nutrient quality of crop production, also known as biofortified crops. So far, biofortification has imparted a positive increase in the nutritional quality of various crops, including iron-biofortified pearl millet (Finkelstein et al 2015), zinc-biofortified wheat (Rosado et al 2009, Singh and Govindan 2017, Sazawal et al 2018).

CONCLUSION

In India, farmers form a major proportion of both producers as well as consumers. Thus, improving crop production and productivity, along with efficient and profitable farming, as a part of a pioneering growth strategy, can contribute significantly towards reducing hunger and poverty. Various countries have already set an example of agricultural development through small farmers and have shown that agricultural development is twice as effective in rural income generation as the development from other sectors. And using agriculture for economic development, especially in agriculture-based countries like India, requires continuous evaluation of smallholder farming practices to increase agricultural productivity. Agricultural productivity can be increased with science and technology interventions, government policies of extension services and institution-led reforms. Simultaneously, there should be a defined path and a time frame to work on such interventions and achieve a set goal within the time frame. As per the vision of the government, the target of doubling the income of farmers by 2022 is not an easy yet very laudable goal. But, relentlessly working on gaps and loopholes with concerted efforts, as per the action plan suggested in mission mode, with special emphasis on the welfare of our farmers, can bring about the necessary changes for overall agricultural development for national economic development with a special emphasis on the welfare of our farmers, who are solely responsible for fulfilling our needs for desired foods.

AUTHOR CONTRIBUTIONS

All authors have made a substantial and direct contribution to the work.

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Indian Journal of Ecology (2022) 49(3) (SI): 1051-1056
DOI: https://doi.org/10.55362/IJE/2022/3633

Manuscript Number: 3633
NAAS Rating: 5.79

Effect of Skill Development Initiative on Income and Input of Organic Growers in Some Southern Indian States

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Abstract: Agroecosystem health, biodiversity, biological cycles and soil biological activity are all enhanced by organic farming, which is an integrated production management method. The present study aims to investigate the impact of organic farming on input cost and crop yield on the lands of small as well as marginal scale farmers who underwent training as per the guidelines of National Skill Development Corporation (NSDC) and the Agriculture Skill Council of India (ASCI) in southern India (Andhra Pradesh, Karnataka, Telangana). A two-staged process was implied where ASCI trained 24 scientist of Patanjali Organic Research Institute (PORI) as per standard document QP AGR/Q1201. PORI scientists trained 50 farmers in selected states and they in turn trained 5,058 farmers as a farmer to farmer approach. The results revealed low input cost, increment in crop production and good soil fertility. The net profit attained from paddy, red chilli, sugarcane and cotton in Andhra Pradesh was Rs.27500, 38500, 90000, and 19000, respectively whereas net profit attained from paddy, turmeric and cotton in Telangana was of Rs. 12466, 61200, and 54000, respectively. Thus, there is a need to formulate a long-term perspective plan focussing on the progress of the organic agricultural sector in terms of production and productivity.

Keywords: Agri-input, Profitability, Organic farming, Training program, Soil health

The primary source of livelihood for about three-fourths of the Indian population is agriculture and its allied sectors (Singh 2021). Agriculture in India has a long history, dating back to the Indus Valley Civilization (Vasey 2002). But lately, it is undergoing a structural transition in India that is resulting in a crisis. As India's economy is consistently growing because of industrial and service sectors, the relative contribution of agriculture's proportion in India's Gross Domestic Product (GDP) is progressively declining over time (Yadav et al 2019). The leading cause behind this shift is that agriculture is no longer a profitable economic activity compared to other sectors, so its income is insufficient to cover the cultivators' expenses. Moreover, in the past few years, the increase in agricultural production output is gradually increasing, but the injudicious use of pesticides, heavy metals, chemical fertilizers, antibiotic residue, nitrate, and genetically modified organisms that contributes to colossal adverse health effects. An inadequate application of chemical fertilizers makes the soil compact, reduces soil fertility, pollutes air and water, with increase in greenhouse gases, and thereby poses threat to human and environment (Sharma and Singhvi 2017).

As an effort to yield more nutritious and safe food, organically cultivated foods demand has led to an upsurge in past years due to their health benefits (Rembialkowska 2007, Dangour et al 2010). Ecologically stated organic farming is more environment-friendly than conventional farming and promotes consumer health by keeping soil healthy and maintaining the integrity of the ecosystem (Srivastava et al 2018, Singh 2021). Among 172 nations that practice organic farming, India is distinctive in that it has 650000 organic farmers, 699 processors, 669 exporters, and 720000 hectares under cultivation. Nevertheless, with merely 0.4 percent of total agricultural land under organic cultivation, the industry has a long journey ahead (Bordolo 2016). India's soil is endowed with various naturally accessible organic nutrient supplies that help organic farming (Adolph and Butterworth 2002, Reddy 2010, Deshmukh and Babar 2015). The southern states like Karnataka, Andhra Pradesh, Telangana has diverse agriculture production exposed to long coastal lines, has varied agro-climate zones, distinguished soil types, and natural vegetation to grow Cotton, maize, pulses, oilseeds, fruits, and vegetables. The current study implemented and investigated the effect of skill development in various approaches of organic farming on the lands of small (1-2-hectare land holding) as well as marginal (land holding <1 hectare) scale farmers of Karnataka, Andhra Pradesh, and Telangana by minimizing input cost and enhancing net profit in an environmental- friendly manner.

MATERIAL AND METHODS

The study's goal was to develop a model for enhanced organic output that would result in enhancing farm revenue through a demonstrative farmer to farmer strategy in Karnataka, Andhra Pradesh, and Telangana. The Agriculture Skill Council of India (ASCI) edified a 24-member team of expert master trainers from Patanjali Organic Research Institute (PORI) for eight days in September, 2018 at PORI, Haridwar, India, who comprehended the regional dynamics and farmer profiles. The training was based on National Skill Development Corporation (NSDC) and ASCI document QP-AGR/Q1201 and its detail is depicted in Figure 1 (https://nsdcindia.org/sites/default/files/QP_AGR-Q1201_Organic-Grower.pdf).

The master trainers were allied with farmers of Karnataka, Telangana, and Andhra Pradesh, for skill development under organic farming techniques and agricultural excellence trained certain farmers, for eight days (120 hours) in ICAR institutions/universities and are referred as farmer scientists. The selected farmer scientists consented to provide 0.4 ha land for organic farming experimental research, and designated as farm labs. The farmer scientists maintained these farm labs with the collaboration of PORI scientists. PORI supported the farmer scientist with numerous biofertilizers (depending on soil analysis results) and a soil testing kit called 'Dharti ka Doctor' (an indigenous PORI kit) to detect pH, organic carbon, and NPK [nitrogen (N), phosphorus (P) and potassium (K)]. these farmer scientists further trained fellow farmers of their region. The fellow farmers were trained about the approach, the tools, technology and methods including extension method. The farmers who practiced organic farming methods were examined by several government agencies and categorized as unsuccessful or successful depending on their knowledge and practical skills. PORI interviewed organic growers and their experiences were recorded and available online at http://patanjalifarmersamridhi.com/img/Flip%20Book/turnjs4/samples/basic/Orgainc_Farming.html.

RESULTS AND DISCUSSION

The small and medium scale farmers successfully attained skill development on various aspects of organic farming as revealed via following parameters.

Statistics of training program: The training program in three different states of southern India (Karnataka, Telangana, and Andhra Pradesh) integrated 26, 11 and 13 farmer scientists, respectively. In Andhra Pradesh, Karnataka, and Telangana, the program was successfully implemented in 4, 7 and 3 districts, respectively. State-wise implementation statistics revealed enrolment of 1816, 1717 and 1525 farmers in total, respectively. However, only 1438, 1088 and 1046 farmers were certified after evaluation by government agencies (Fig. 2).

Soil analysis and input supply by PORI: The fertility of the soil is significant in influencing the productivity of all farming methods. In Andhra Pradesh, primary Kharif crops grown in the state include rice, maize, jawar, bajra, ragi, and pulses, which are recognized for their high nutritional content and are the staple food of millions of people. During the Kharif-2019 season, farm labs grew paddy and received free phosphate rich organic manure (PROM), Poshak, Jaivik Khad, phosphate solubilizing bacteria (PSB), Rhizobium, and farm yard *manure (FYM)* to apply in the fields, as well as *Trichoderma* and *Pseudomonas* to combat fungal infections.

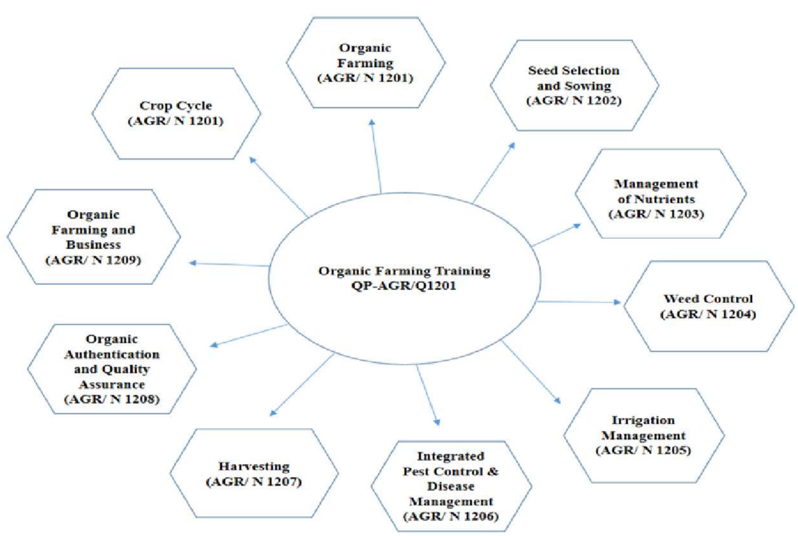

Fig. 1. Schematic representation of components of organic farming training program

The six different types of soil in Andhra Pradesh include red soil (65%), black soil (25%), alluvial soils (5%), costal sands (3%), laterite and lateritic soils (1%), and problem soils (1%). Moreover, soil testing at farm labs found that nitrogen (281-700 kg ha^{-1}), phosphorus (11-35 kg ha^{-1}) and potash's levels (151-300 kg ha^{-1}) were moderate to high. The organic carbon concentrations ranged from 0.4 to 0.8, whereas the pH ranged from 6.9 to 7.3. Karnataka's agricultural industry is distinguished by immense steppes of the drought-prone region and occasional pockets of irrigated territory. The most prominent types of soil categories identified in Karnataka were red soils (red gravelly loam soil, red loam soil, red gravelly clay soil, red clay soil); black cotton soil (gravelly soil, loose, black soil, basalt deposits); and lateritic soils (lateritic gravelly soil, lateritic soil). Soil degradation (soil compaction, salinity, sodicity, waterlogging, and pesticide residue), multiple nutrient shortages, low organic carbon content, and a reduction in productivity have been documented in the state under various agricultural methods. Additionally, the pH of the soil in the state ranges from 6.5 to 8.2. Soil testing in farm labs revealed that nitrogen (141-700 kg ha^{-1}), phosphorus (6-35 kg ha^{-1}), and potassium (101-300 kg ha^{-1}) levels ranged from low to high while organic carbon concentrations range from 0.4 to 0.7.

Subsequently, during *Kharif*-2019, all farm labs received free biofertilizers and pesticides such as phosphate rich organic manure, Poshak, Jaivik Khad, PSB, KMB, Rhizobium, and FYM use in the fields, as well as *Trichoderma* and *Pseudomonas* to fight against fungal infections. Kannan and Ramappa (2017) showed in a study that farmers' training on fertilizer application and education had positive and significant effect on adoption of soil nutrient technology to yield paddy in Karnataka, India.Additionally, the qualitative soil testing of Telangana state revealed the presence of vertisols, alfisols, inceptisols, and entisols. The primary constraints of all crops were drainage and texture. In addition, the primary constraints for crop growth in all soils were drainage, texture, coarse fragments, soil depth, pH, and organic carbon (OC). Soil testing at eight farm labs found that phosphorus (6-17 Kg/ha) and potash's (101-200 Kg/ha) levels are low to medium, while nitrogen levels are medium (281-420 Kg/ha). Organic carbon concentrations range from 0.5 to 0.7 and pH ranged from 6.5 to 7.5. All farm labs received free Prom, Poshak, Jaivik Khad, PSB, KMB, *Rhizobium*, and FYM to use in the fields and *Trichoderma* and *Pseudomonas* to combat fungal infections.

A similar technique for estimate of marginal impacts has been adopted by Khanna (2001) to examine the adoption decisions of soil testing and variable rate of technology for fertiliser application. The study revealed that because organic elements are restored by adding fertilizer, there is a natural loss of organic elements from the soil after each cropping cycle. In order to enhance the sustainability of organic practices, soil organic activity must be increased. It was demonstrated unequivocally that the biofertilizers contributed to Good Agricultural Practices by applying low organic inputs in farmer's fields, which lead to the improved productivity of safe food in selected agroecosystems. To preserve soil fertility, strategies such as mixed farming, producing crops that attract insects, relay cropping, and so on were employed to maintain a balance in the physical and chemical characteristics of the soil. Farmer trainees also

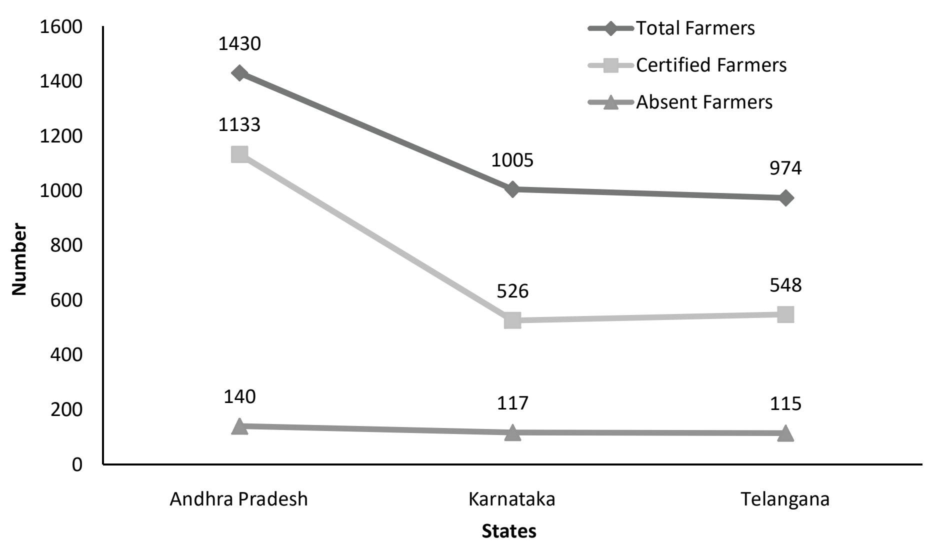

Fig. 2. State-wise detail of farmers involved in training program

gained insight on an integral part of soil management and focused on differences in soil types that defined specific interventions to enhance the soil quality for the land use selected.

Impact of training on input cost and profitability: Agroecology is a scientific study, cultural practices, or a social movement to establish agricultural and farming systems that make the most meaningful use and conservation of natural resources while requiring minor external inputs (Wezel et al 2009). The profit is assessed when the individual compares the advantages of conventional agriculture with organic farming. In Andhra Pradesh, the average cost of cultivation in farm labs under paddy, red chilli, sugarcane, and cotton was INR 32,750, 97,500, 2,10,000 and 35,000, respectively, whereas the net profit was calculated to be INR 27,500, 38,500, 90,000 and 19,000, respectively. In contrast, the average cost of cultivation in Karnataka farm labs for paddy crop and banana was 40,321 per acre and INR 84,250 respectively, with a net profit of INR 53,472 and 76,750, respectively. Moreover, in Telangana, the average cost of cultivation in farm labs under paddy, turmeric, and cotton was amounted to be 32,133 per acre, 62,000 per acre, and 24,000 per acre, respectively, with a net profit of INR 12,466, 61,200 and 54,000, respectively in farm labs (Table 1). The results stated above clearly depicted that horticulture provided relatively significant returns while also benefiting the soil ecology.

Organic Farming Issues: Farmer's Perspective

The adoption of new technology or farming techniques has piqued the curiosity of many people throughout the years. Farmers in India had been practicing eco-friendly agriculture for generations before the arrival of the 'green revolution,' which was based on the traditional agricultural practices used in western nations. For a variety of reasons, many small and marginal farmers have not entirely embraced conventional farming and continue to practice a more or less environmentally friendly method. They control self-regulated ecological and biological processes by utilizing local or farm-derived renewable resources. In the southern states like Andhra Pradesh, Karnataka, and Telangana, farmers agreed to start growing crops with organic methods after observing its profit and advantages. Nevertheless, they still need proper extension and training on using bio-fertilizers and bio-pesticides in the fields. Seed accessibility is also critical for native or high-producing cultivars. However, under present training program, trainers were motivated to make good networks and search reliable seed companies, from whom they and the farmers they have trained may get good quality seed of crop varieties in advance before sowing. Product price premiums, natural resource conservation in the form of better soil, nutrients and water quality, soil erosion prevention, and preservation of natural and agro-biodiversity are significant advantages attained with organic farming in the respective states.

Impact evaluation of PORI's training program by OP&HS: A third party, OP & HS, commenced the impact assessment of farmer scientists to understand the project's efficacy. The assessment of the trainee farmers instilled a sense of discipline and sincerity in the applicants, intending to retain, recalling, and implementing what they had provided to them in terms of teachings and practical application. The aggregated response showed that 92% of the trainee farmers had not undergone training in the southern region in the past. Moreover, almost 27% of the respondents acknowledged that they received proper advice and guidance on farming, while 27% assisted in farming and 45% ensured that things were done correctly. In addition, 40% of the farmers in the southern part felt that the most substantial benefit they received was reducing input costs. Organic farming has traditionally been considered to increase crop quality; this has been proven via farmer reactions. The farmers perceived an immediate and apparent improvement

Table 1. Crop wise input cost and profit details in southern states of India

States	Crop	Average cost (INR per acre)	Gross income (INR)	Net profit (INR)
Andhra Pradesh	Paddy	32,750	60250	27,500
	Red Chilli	97,500	1,36,000	38,500
	Sugarcane	2,10,000	3,00,000	90,000
	Cotton	35,000	54,000	19,000
Telangana	Paddy	32,133	44,599	12,466
	Turmeric	62,000	1,23,200	61,200
	Cotton	24,000	78,000	54,000
Karnataka	Paddy	40,321	93,793	53,472
	Banana	84,250	1,61,000	76,750

in quality. The Southern states had a nearly 96% reflection of quality. Additionally, 63% of respondents believed there was some increment in crop proportions, whereas 37% said there was no increase in output. Reduction in the input cost directly impacts the income and thus becomes an essential element to be examined. Among respondents from the southern region, 61% said they saved up to 30% on pesticide input costs by using adequate bio-pesticides as per soil testing reports. The organic activity of soil is a daunting task that must be followed as a sustainable agricultural practice to enrich and promote soil organic activity, resulting in increased soil fertility. The OP&HS designed questionnaire showed that 98 percent of responders in the southern state used organic enrichment. Subsequently, it was observed that 98% of the cultivators had adopted an utterly organic procedure for making bio-pesticide (Table 2). According to the study's framework, different crops would have to be introduced in each of the locations to improve income. However, many farmers expressed concerns about weather and water availability at the onset of this study. In addition, 84% of respondents from the southern region were able to retain and recollect what they had been taught, and the insights provided on alternative crops that may benefit them were valuable (Impact assessment report 2021).

Recommendations

There is a high-profit gain from organic sugarcane and red chilli in Andhra Pradesh state. However, certain places were considered suitable for sugarcane than others, and vice versa for red chilli. In Karnataka, both paddy and banana crops were high profit fetching crops as per the present study. Additionally, millets can be produced in enormous quantities for marketing purposes since more people choose to eat millets instead of rice owing to health concerns such as diabetes, high blood pressure, and obesity. Furthermore, alternate agricultural methods were suggested in the Andhra Pradesh and Karnataka regions, which were less good for one crop but extremely suitable for another. Subsequently, cotton and turmeric are also high-profit crops in the Telangana state. Cotton grows poorly in some areas but thrives in others, and vice versa. To maximize benefits, farmers should have access to new kinds of high-quality seeds, the biofertilizers should be applied based on the soil test report and also be made available to farmers on a timely basis. The vegetable cultivation is more profitable in organic farming than field crops. Crop rotation using pulses (green gram/black gram, pigeon pea, and soybean) and vegetables in *Rabi* season would enhance production and support prices for crops cultivated in *Kharif* season. In continuation, organic producers should make an effort to self-market their products by advertising them through mass media and social media, the internet, and personal contacts, as well as by establishing organic food shops in residential areas. Because organic farming used to generate lower money than conventional farming, early support for organic farmers may be more advantageous.

Table 2. Impact assessment by OP and HS

Parameters	Sub-parameters	Impact statistics (%)
Training status	Trained prior	8
	Trained first time	92
Trainee feedback on farmer scientist	Assisted in farming	27
	Regular Supervision	45
	Improvement required	1
	Advice and guidance on farming	27
Impact of training	Knowledge enhancement	24
	Reduction in input cost	40
	Increase in production	9
	Overall benefits	27
Impact on output quality	Positive	96
	Not sure	4
Increment in crop proportions	Positive	63
	No increase	37
Pesticide expense cost	Saved up to 30%	61
	No saving	4
	Non-irrigated	21
Organic enrichment of soil	Adopted	98
	Not yet	2
Adoption of biopesticides	Completely organic	98
	Partial use of chemical pesticide	2
Knowledge of alternative crops	Affirmed	84
	Denied	16

CONCLUSION

This training program has successfully helped a considerable number of individuals in accomplishing their goals. Farmers gain insight into revolutionary organic farming methods that enhanced crop yield, with minimal input cost, the net profit on various crops ranged between INR 12466 to 90000. The goal of the study was sustained with 98% adoption of bio-pesticides. Additionally, 40% of respondents revealed reduction in input cost. Formation of clusters, self-help groups, and other efforts are still needed to promote organic farming. However, more thorough scientific analyses at both the experimental and field level are required in order to comply with an organic agriculture system with clear management guidelines. Organic farming would grow tremendously in India if properly encouraged.

AUTHOR CONTRIBUTIONS

All authors have made a substantial contribution to the work.

ACKNOWLEDGEMENTS

The authors are grateful to Revered Swami Ramdev, Patanjali Yogpeeth, Haridwar and Patanjali Research Foundation Trust for providing all the necessary facilities and all the members of PORI for their help in the implementation of training program. In addition, authors are highly thankful to ASCI and NSDC, Govt. of India for immense support.

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Received 06 February, 2022; Accepted 22 May, 2022

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Indian Journal of Ecology (2022) 49(3) (SI): 1057-1067
DOI: https://doi.org/10.55362/IJE/2022/3634

Manuscript Number:3634
NAAS Rating: 5.79

Phytoremediation: Current Techniques and Futuristic Opportunities

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***Abstract*:** Rapid industrialization, current agricultural practices, and other human activities increase the quantity of toxic heavy metals in the atmosphere, which has a significant negative influence on all forms of life, altering their properties. This type of heavy metal pollution is harmful to both the environment and human health. Heavy metal exposure causes nervous system diseases in children by being mutagenic, endocrine disruptive, carcinogenic, and teratogenic. Phytoremediation is also an appropriate approach for the cleanup of water and soil adulteration. Furthermore, it has become increasingly popular. Phytoremediation helps to repair polluted soil and water by extracting and stabilizing polluting heavy metals, a process known as phytoextraction. Phytoremediation has evolved as a practical and successful method for removing a wide spectrum of pollutants in situ in recent years. It is often recognized as a more ecologically friendly alternative to conventional environmental restoration techniques. Significant progress has been made in the remediation of environmental pollutants in recent years. Phytoremediation, despite a number of challenges, is a promising technique with considerable prospective uses. The entire utilization of by-products, as well as the overall economic viability of phytoremediation, will remain the most crucial criteria for global acceptance. The present review looks at the existing status of environmental pollution, as well as the toxicity profiles of crude oil and polycyclic aromatic hydrocarbons (PAHs), global heavy metal leaks, and remediation technologies and applications. It also highlights the recent scientific developments and also, revises plant-based remediation approaches for damaged terrestrial and aquatic environments.

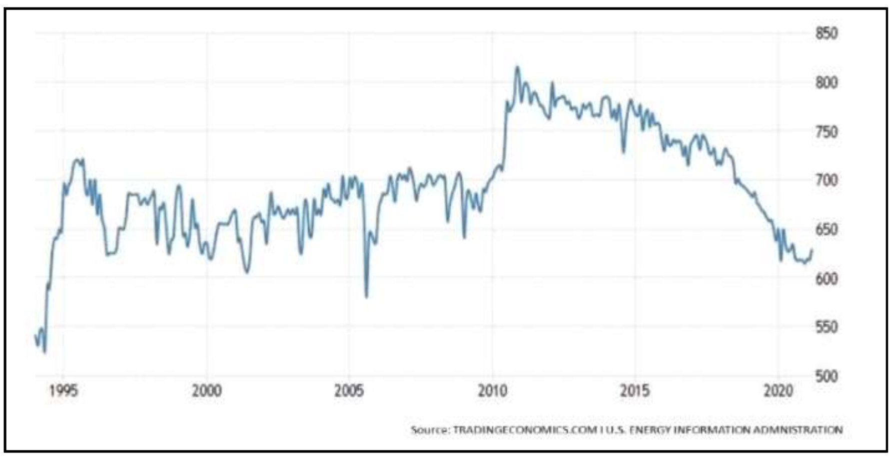
Keywords: PAHs, Heavy metals, Phytoremediation, Microorganisms, Nano-bioremediation

Environmental contaminants are a global problem that impacts both animal and human health. Phytoremediation is a novel approach for detoxifying the environment of hazardous contaminants, and it might be a low-cost, long-term solution for developing countries to improve their economies. It is the technique of reducing the amount of pollutants in the environment or their harmful effects by employing plants and associated soil microbes. Phytoremediation is well-known as a cost-effective environmental restoration method that is a potential alternative to soil-damaging engineering processes (Greipsson 2011). Phytoremediation is frequently employed because of its cost-effectiveness, environmental friendliness, and long-term viability (Emenike et al 2018, Li et al 2020b, Wu et al 2021). Phytoremediation, a green technology, is a method of regulating and conserving the soil medium from heavy metal contamination by using hyperaccumulator plant species (Saxena et al 2020). Plants and microorganisms are used in phytoremediation to remove contaminants from the soil through enzymatic reactions (Greipsson 2011). To clean polluted soils, phytoremediation is frequently employed in waste, agricultural, and industry regions (Urionabarrenetxea et al 2021). The primary goal of phytoremediation is to prevent contaminants from migrating into ecosystems (Wang et al 2020). This ecologically friendly and cost-effective technology works well and has a high tolerance for organic and inorganic contaminants. To increase the effectiveness of collecting and eliminating contaminants from contaminated soil, high biomass species such as herbaceous field crops are utilized (Bhardwaj et al 2014). The economic benefits of phytoremediation, such as biomass production and bioenergy generation, can help to boost the national economy. Plants with a high biomass are typically utilized to make wood and paper (Licht 2005). Human health has become more sensitive to hazardous metals as a result of anthropogenic and occupational activities such as industrial operations, current agricultural methods, untreated chemical waste, and municipal waste management (Rai 2019, Shazia Parveen 2021).

Oil (crude) spills and hydrocarbon contagion: One of the prime elements, causing long-term antagonistic effects on marine and terrestrial lives are oil spills (Mulani et al 2017).

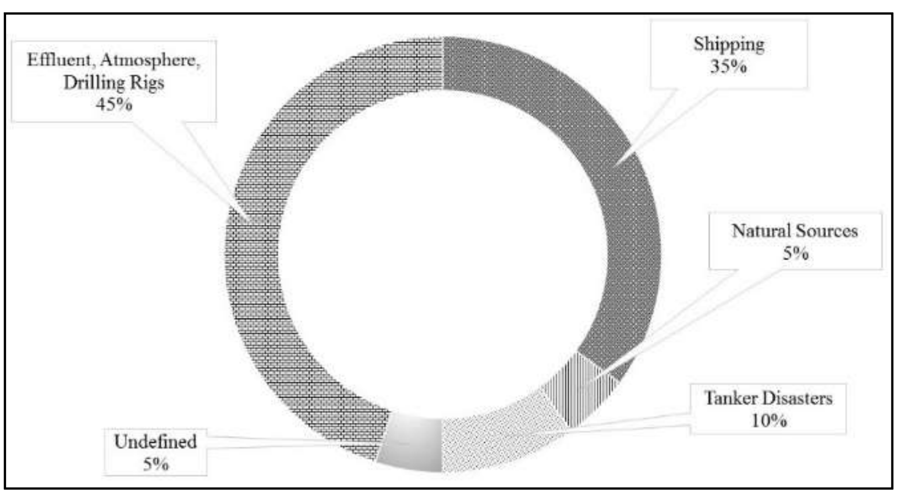
Oceans carry most of the worldwide oil production henceforth, coastal and marine environs are exposed to accidental oil spills (McGenity et al 2012, US EIA 2014). Hydrocarbon segment has been experiencing radical changes worldwide leading to increased industrial activities (Mandal et al 2011). From 1994 to 2021, India's crude oil output averaged 693.53 BBL/D/1K, with a high of 813 BBL/D/1K in 2010 and a low of 526 BBL/D/1K in 1994. The country produced 613.21 BBL/D/1K crude oil in 2021 (Trading Economics 2021). The main hydrocarbon components of crude oil include saturates, aromatics, resins, and asphaltenes. Saturates are categorized into alkanes (paraffin's) and cycloalkanes (naphthenes) on account of their chemical structures (Margesin and Schinner 2001). The presence of one or more aromatic rings distinguishes aromatic fractions. Because of their persistence, mutagenicity, and toxicity, polycyclic aromatic hydrocarbons are a major source of concern (Ovalles et al 2012). Polar compounds make up resins and asphaltenes. Asphaltenes and resins are expected to make up about 10% of the crude oil content (Gaspar et al 2012).

Oil contamination: sources and magnitudes: Natural disasters, oil seepages, incidents with vessels, either collisions or groundings, or from offshore oil platforms, either through human error or due to technical and mechanical faults in oil exploration activities/storage, account for a significant portion of the oil that enters the marine waterways (McKew et al 2007, Mei and Yin 2009, Sheppard et al 2013). Greater threats have been impersonated by marine oil spills, causing widespread damage to the marine coastal environments (Venosa and Zhu 2005). Oil spills will always be a possibility, even of the most advanced technologies in offshore drilling and vessel navigational equipment, necessitating the development of a treatment technique (LaMontagne et al 2004). Prime route-causes of oil spill incidents are given in Figure 2.



Source: www.tradingeconomics; US energy information administration

Fig. 1. Crude oil production in India



Source: World ocean review maribus

Fig. 2. Major route-causes of the oil spill incidents

Prime oil spill occurrences: Inland oil spills have garnered less attention than sea oil spills. Freshwater spills, on the other hand, are fairly prevalent (Fingerman and Nagabhushanam 2005).

Global status: Oil spills have taken place all over the world and even in India (Table 1). During the Gulf War in 1991, the largest oil spill happened in Kuwait (www.cleanerseas.com). The 2010 Gulf of Mexico oil leak is known as the world's greatest unintentional disaster (en.wikipedia.org).

National status: In India, there have been around 70 oil spills near the coast (IMO, 2011). The largest oil leak in India was reported in 2017, with an estimated 800 tonnes of oil spilled. Paradip Port incident, 2009 is another occurrence that has been reported (Bhambi 2013).

Indian hydrocarbon impurity menace: Developing countries, such as India, should be prepared to deal with oil spills in the future (Bhambi 2013). The National Oil Leak Disaster Contingency Plan was first created in India in 1996 (and updated in 2002) with the goal of preventing oil spill disasters in India's Maritime Zones (Fig. 3). The Indian refining industry has done a fantastic job of establishing itself as a worldwide agency (Indian-petroleum-refining-industry). Indian ports and refineries (Table 2 & 3) are a major shipping corridor of India

Curative measures: Catastrophic oil spills and environmental warning have increased public recognition of storage and transportation risks. Therefore, effective therapies to deal with this problem are obligatory (environmentalpollutioncenters.org).

Remediation methods: conventional: Traditional remediation methods contain physical removal of adulterated materials (Table 4). These procedures use chemicals, mainly shoreline cleaners, usually organic solvents with or without surface-active agents (worldwidescience.org).

Physical methods: Physical confinement and mass or free oil recovery is the preferred response option for cleaning up oil spills in freshwater and marinecoastal environments (Fig. 4).

Chemical methods: Due to differences in their effectiveness and concerns about their long-term toxicity and environmental impact, chemical methods have not yet been widely used (Fig. 5).

Biological methods: Bioremediation is considered an effectual and environment-friendly treatment strategy for polluted shorelines (Nikolopoulou et al 2013). It is cost-effective, has fewer disturbances on site and is more environments friendly (Oh et al 2000). There are 4 different methods for bioremediation (Fig. 6). The demonstration of different limiting factors of bioremediation is being shown in Fig. 7.

Bioremediation: Available products: Most of the methods are currently used to clean up a large number of oil spills including biological agents. There are several companies and research institutions all over the world dedicated to the development of new technologies (Fig. 8). These organizations/companies have created and offer a variety of microbial bioremediation products for agricultural, industry, commercial, aquatic pond management, and home use, as shown in Table 5. In India, the Tata Energy Research Institute (TERI) has developed an indigenous bacterium and obtained a consortium of patents, known as Oilzapper.

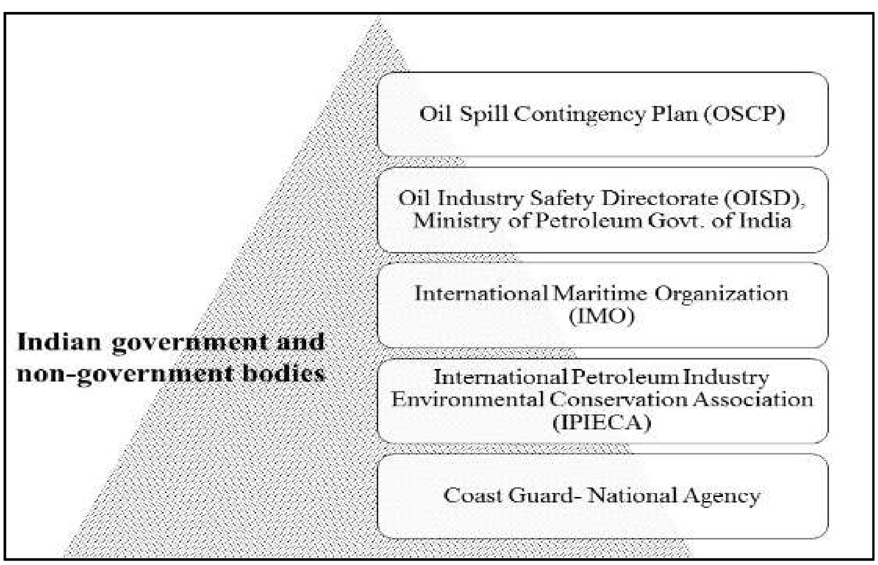


Fig. 3. Indian government and non-government bodies engaged in the monitoring and handling the oil spill disasters

Table 1. Major oil spill incidents in India and the world in chronological order

Spill/Vessel	Location	Date of incident	Maximum spilled (in tons)	Route of spill
Emerald	Israel, Mediterranean shoreline	11.02.21	Unknown	Via an attack on an Iranian tanker that went awry,
Chevron Richeavy metalond Refinery	United States, California, Richeavy metalond	09.02.21	1.9	Pipeline leak
El Palito Refinery	Venezuela, Golfo Triste	08.08.20	2,700	Pipeline leak
2020 Colonial Pipeline gasoline spill	United States, North Carolina, Huntersville	08.08.20	38,000	Pipeline leak
2020 Pointe D'Esny MV Wakashio oil spill	Mauritius, Ile Aux Aigrettes and Mahebourg	25.07.20	4,300	Leakage
Trans-mountain oil spill	Canada, British Columbia, Abbotsford	14.06.20	184.87	Leakage
Diesel (Norilsk) fuel spill	Russia, Norilsk, Krasnoyarsk Krai	29.05.20	17,500	Leakage
Pumping of sludge from a vessel by Tanker truck	New Zealand, Tauranga, Bay of Plenty	30.03.20	1.7	Accident
T.G. Williams Well No. 1 tank battery	United States, Texas, Oakland Creek, Longview	30.03.20	Unknown	Leakage
Greka Energy oil facility	United States, California, Santa Maria	30.03.20	Unknown	Leakage
True Oil pipeline	United States, North Dakota, Red Wing Creek	27.03.20	Unknown	Pipeline leakage
Tanker truck rollover	United States, California, Santa Maria, Cuyama River	21.03.20	19.5	Break in a pipeline
Keystone Pipeline 2019 spill	United States, North Dakota, Walsh County, North Dakota	29.10.19	1,240	Leak caused by collision of tankers
Willowton Oil	South Africa, KwaZulu-Natal, near Pietermaritzburg and Durban	08.08.19	Unknown	Pipeline leakage
Brazil (North East) oil spill (suspected source: NM Bouboulina)	Brazil, 733 km from Paraiba	29.07.19	Unknown	Pipeline leakage
Guarello Island iron ore	Chile, Guarello Island, Magallanes	27.07.19	35.4	Pipeline leakage
export terminal diesel spill	Region			
MV Chrysanthi S bunkering spill at sea	South Africa, Algoa Bay, Port of Ngqura	06.07.19	0.4	Pipeline leakage
MV *Solomon Trader* fuel oil spill	Solomon Islands, Rennell Island	05.02.19	80	Pipeline leakage
SeaRose FPSO production ship spill	Canada, St. John's, Newfoundland and Labrador	16.11.18	219	Break in a pipeline
Ulysse-Virginia collision	North of Corsica (international waters)	10.10.18		Pipeline leakage
Port Erin diesel spill (source unknown)	Isle of Man	23.07.18	Unknown	Pipeline break
Doon, Iowa derailment	United States, Lyon County, Iowa	22.06.18	520	Break in a pipeline
Sanchi oil tanker collision with CF Crystal	East China Sea	06.01.18	138,000	Tanker Collision
Keystone Pipeline 2017 spill	United States, Marshall County, South Dakota	16.11.17	1,322	Pipeline break
Delta House floating production platform spill	United States, Gulf of Mexico, near Louisiana	11,12.10.17	1,280	Pipeline break
Agia Zoni II	Greece, Saronic Gulf, Salamis	10.09.17	2,500	Pipeline break
East River insulating oil spill	United States, New York	07.05.17	101	Pipeline break
Energy Transfer Partners Dakota Access Pipeline Leak	United States, North Dakota	04.04.17	0.27	Pipeline break
Ennore oil spill	India, Chennai, Ennore Port, India	28.01.17	251	Collision of Petroleum tanker

Cont...

Table 1. Major oil spill incidents in India and the world in chronological order

Spill/Vessel	Location	Date of incident	Maximum spilled (in tons)	Route of spill
Belle Fourche	US, North Dakota	05.12.16	571	Pipeline leak
Fox Creek	Canada, Alberta	06.10.16	240	Pipeline leak
BP Clair	UK, Shetland, Clair platform	02.10.16	105	Leakage
Colonial Pipeline Leak	US, Alabama	12.09.16	1092	Pipeline Leak
North Battleford	Canada, North Battleford	21.07.16	210	Pipeline spills
ConocoPhillips	Canada, Alberta	09.06.16	323	Pipeline leak
Union Pacific oil	US, Oregon, Mosier	03.06.16	152	Train fire
Shell Gulf of Mexico oil spill	US, Louisiana	12.05.16	316	Released from the pipeline
Refugio oil spills	US, California	19.05.15	330	Pipeline broke
Yellowstone River oil spill	US, Montana, near Glendive	17.01.15	160	Break in a pipeline
OT Southern Star, 7	Bangladesh, Sundarbans	09.12.14	300	Leak caused by collision of tankers
Trans-Israel	Israel, Eilat	06.12.14	4,300	Pipeline
Mid-Valley	US, Louisiana	13.10.14	546	Pipeline
North Dakota	US, North Dakota, Hiland	21.03.14	110	Pipeline spills
North Dakota	US, North Dakota, Casselton	30.12.13	1300	Train collision
North Dakota	US, North Dakota, Tioga	25.08.13	2810	Pipeline spills
Rayong oil spills	Thailand, Rayong	27.07.13	163	The oil leak (from a pipeline)
Napocor Powe Barge 103	Philippines	08.11.13	520	Typhoon Haiyan (Cyclone)
Guarapiche River	Venezuela, Maturin, Monagas	04.02.12	41,000	Pipeline leakage
Nigeria, Bonga Field	Nigeria	21.12.11	5,500	Tanker accident
TK Bremen	France, Brittany	16.12.11	220	High winds have beached a cargo ship
Campos Basin	Brazil, Campos Basin,	07.11.11	400	Shipping activity
Rena oil spills	New Zealand, Tauranga	05.10.11	350	Grounding of MV *Rena* on the Astrolabe Reef
North Sea oil	UK North Sea	10.08.11	216	Accidents
Bohai Bay oil spill	China, Bohai Bay	04.06.11	204	Sea Floor Leak
Little Buffalo oil spills	Canada, Alberta	29.04.11	3800	Damage in the rainbow pipeline system
Mumbai-spill	India, Mumbai, Arabian Sea	21.01.11	55	Pipeline urban spill
Mumbai oil spill /	India, Mumbai, Arabian Sea	09.08.10	800	Collision between Ships
Xingang Port oil spill	China, Yellow Sea	16.07.10	90,000	Explosion of two crude oil pipelines
Deepwater Horizon	The US, Gulf of Mexico	20.04.10	6,27,000	Drilling
Port Arthur oil spills	US Port Arthur, Texas	23.02.10	1500	Oil tanker accidents

Source: List of oil spills, 2021

Many traditional cleaning processes only clean up a portion of an oil spill, whereas current mechanical technologies generally recover more than 10-15% of the oil after a spill. Chemical solutions are more expedient, but they affect the biota in the leaky environment. Due to the widespread use of petroleum hydrocarbons in factories, these production processes have caused a lot of pollution. Bioremediation has become one of the most promising alternative therapy, but little is known and practiced. In short, these same factors need to be emphasized and corrected.

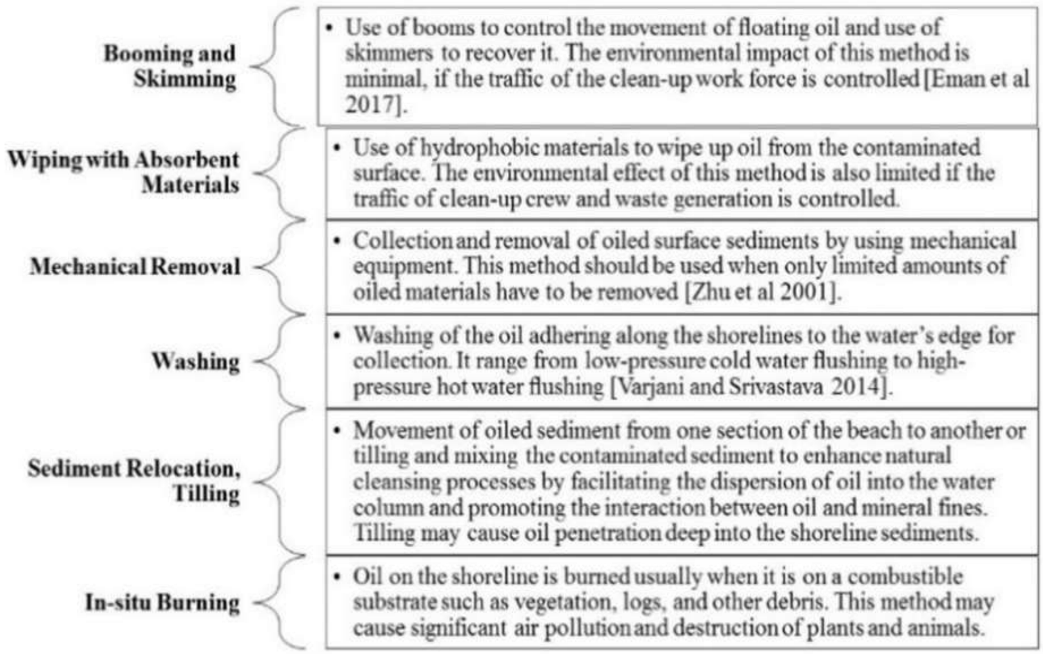


Fig. 4. Commonly used physical methods

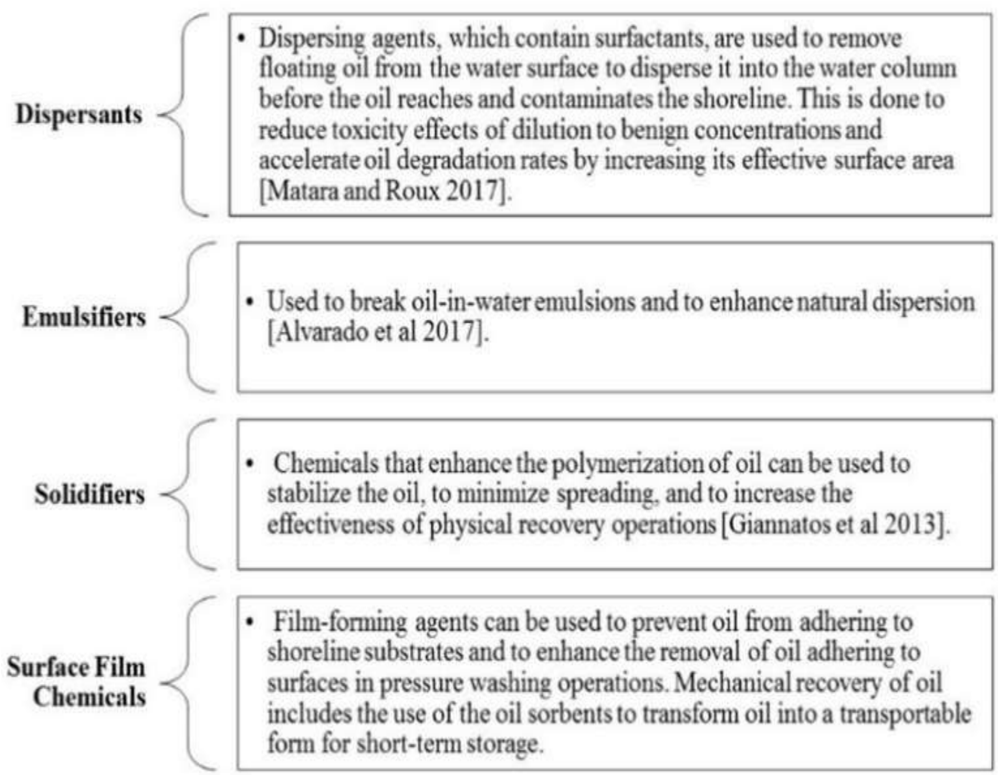


Fig. 5. Commonly used chemical methods

Scope of diverse corrective methods: Compared with physical and chemical methods, phytoremediation or bioremediation provides a very practical alternative method for dealing with oil spills. The current idea of developing phytoremediation tools is to evolve a biotechnological tool to effectively manage contaminants, contaminated water, and soil. Phytoremediation applications that achieve commercial utility includes, plant extraction, plant transformation, plant volatilization, plant stimulation, and plant stabilization.

Mechanistic insights of phytoremediation: Fast-growing grass species are proposed as an efficient strategy for phytoremediation of PAHs in polluted soils. Trees with broad

Table 2. Oil ports transmission in India

Port name	State/ territory
Visakhapatnam Oil Port	Andhra Pradesh
Bharuch Oil Port	Gujarat
Jamnagar Oil Port	Gujarat
Kandla Oil Port	Gujarat
Uran Oil Jetty	Gujarat
Mangalore Oil Port	Karnataka
Kochi Oil Port	Kerala
Mumbai Oil Port	Maharashtra
Mumbai Oil Port II	Maharashtra
Chidambaranar Oil Jetty	Tamil Nadu
Manali Chennai Oil Port	Tamil Nadu

Source: Global Energy Observatory, US

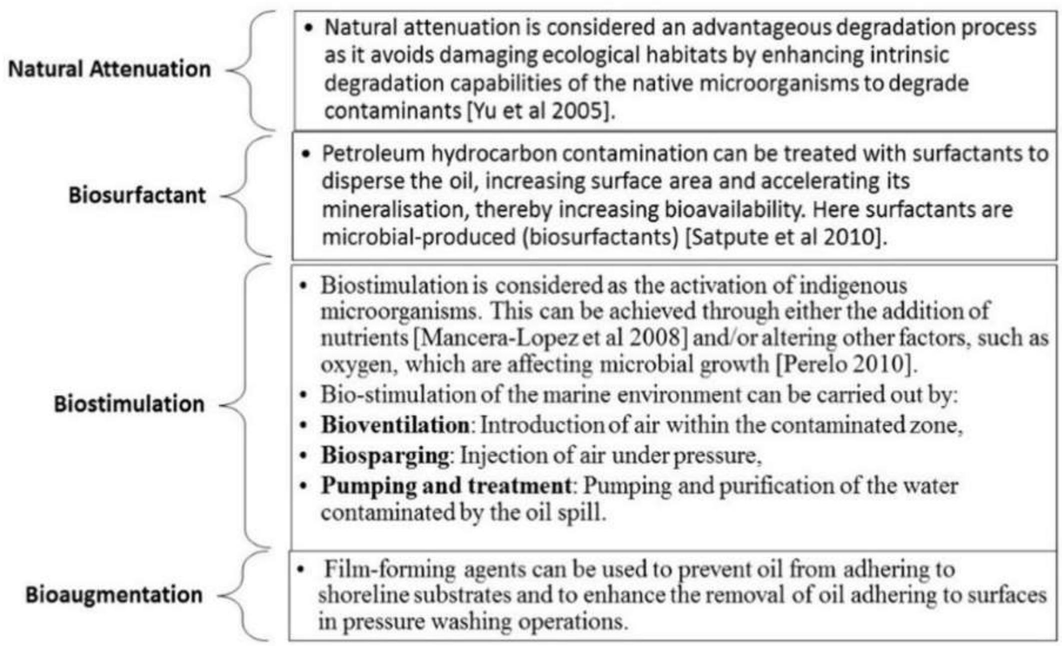


Fig. 6. Commonly used biological methods

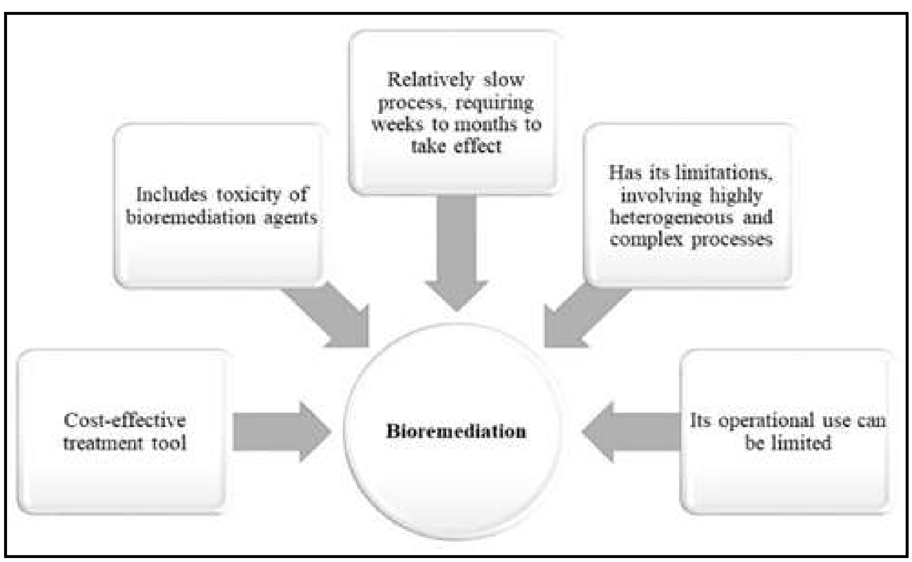


Fig. 7. Limitation factors of bio-remediation

Table 3. Indian oil refineries

Refinery	Oil company	State	Location
Barauni Refinery	Indian Oil Corporation Limited	Bihar	Barauni
Gujarat Refinery	-do-	Gujarat	Koyali
Haldia Refinery	-do-	West Bengal	Haldia
Mathura Refinery	-do-	Uttar Pradesh	Mathura
Panipat Refinery	-do-	Haryana	Panipat
Digboi Refinery	-do-	Assam	Digboi
Bongaigaon Refinery	-do-	Assam	Bongaigaon
Guwahati Refinery	-do-	Assam	Guwahati
Paradip Refinery	-do-	Odisha	Paradip
HPCL	Hindustan Petroleum Corporation Limited	Maharashtra	Mumbai
Visakhapatnam Refinery	-do-	Andhra Pradesh	Visakhapatnam
Heavy Metalel	HPCL-Mittal Energy Limited	Punjab	Bathinda
Mumbai Refinery Mahaul	Bharat Petroleum Corporation Limited	Maharashtra	Mumbai
Kochi Refineries	-do-	Kerala	Kochi
Bina Refinery	Bharat Oman Refineries Limited	Madhya Pradesh	Bina
CPCL	Chennai Petroleum Corporation Limited	Tamil Nadu	Chennai
Nagapattnam Refinery	-do-	Tamil Nadu	Nagapattinam
Numaligarh Refinery	Bharat Petroleum, Oil India and Govt. of Assam	Assam	Numaligarh
Tatipaka Refinery	Oil & Natural Gas Corporation	Andhra Pradesh	Tatipaka
Mangalore Refinery and Petrochemicals Limited	ONGC-Mangalore Refineries and Petrochemicals Ltd	Karnataka	Mangalore
Jamnagar Refinery	Reliance Industries Ltd	Gujarat	Jamnagar (DTA)
Jamnagar Refinery	Reliance Industries Ltd	Gujarat	Jamnagar (SEZ)
Essar Refinery	Essar Oil Ltd	Gujarat	Vadinar

Table 4. Conventional shoreline clean-up options (US, EPA guidelines, 2001)

Response option categories	Technology examples
Natural method	Natural attenuation
Physical method	Washing, Sediment relocation/Surf-washing, Tilling, Booming, Skimming, Manual removal (Wiping), Mechanical removal, Washing, Sediment relocation/Surf-washing In-situ burning
Chemical method	Surface film chemicals, dispersants, demulsifiers, solidifiers

Table 5. Available bioremediation products in the market and their application and limitations

Commercial name of the technologies	Company	Application	Limitations
Micro clean-One TM	Alpha BioSystems, USA	Biological Hydrocarbon Degreaser	A clean-up level of 600 ppm was achieved just took a week
BioWorld Hydrocarbon Treatment (BHT)	BioWorld Products Inc., USA	Bioremediation Enhancer	The product reported as Hazardous
Industrial Class Microbial Blends	Alabaster Corp., USA	Specifically designed for bioremediation of oil spill waste.	Time durability for bioremediation is 2-6 months.
BP Marine Enercare TM	BP Oil International Ltd., UK	Microbiological degradation arises from the contamination of oils	Time durability
UltraMicrobes Facts	Oil spill Contaminant Solutions, USA	Oil spill and industrial application	Time durability
Petro Clean™	Alabaster Corporation, Texas	Hydrocarbon or fuel spill	Time durability
Bactus 303HC	Sanzyme Ltd. (Unisankyo Ltd)	Hydrocarbons, Oily Sludge Bioremediation	Time durability
SDS-043	Halliburton, U.S.A.	Degradation of Drilling Fluids	Certain complex hydrocarbon products such as PAHs and heavy tars are not easily removed by biodegradation.

root systems and high transpiration rates, such as Poplar (*Populus* spp.) and Willow (*Salix* spp.), are good for phytoremediation. Plants immobilise, store, volatilize, and convert these chemicals to varying degrees, depending on the compound, ambient circumstances, and plant genotype. Plants utilize phytoextraction, phytodegradation, phytostabilization, phytovolatilization, and rhizodegradation to assist remediation, as illustrated in Table 6.

Myco-phytoremediation: Fungal phytoremediation, also known as myco-remediation, is a type of bioremediation in which fungus use their degradative ability to remove or neutralize hazardous pollutants in soil and water. However, for hydrophobic organic pollutants, the water phase functions as a nutrition transporter (Kumar et al 2019).

Fungal phytoremediation: A mechanistic approach: Fungal phytoremediation processes could be engineered as sequestration and avoidance mechanisms. Biosorption, precipitation, uptake or efflux, and sequestration, all of which reduce metal toxicity, including the formation of compounds for intracellular chelation and further dilution in plant tissues due to plant growth, exclusion from uptake through precipitation, and chelation in the rhizosphere (Danesh et al 2013). Fungal phytoremediation is influenced by plant and fungus species, the strength of their linkages, plant-soil interaction, soil physical and chemical properties, and biophysical features

Fig. 8. Worldwide companies and research institutes engaged in developing new technologies

Table 6. Phyto-technology mechanisms and significance

Phytotechnology	Levels	Mechanism	Plant	Pollutants
Phytoextraction	Whole plant	Hyperaccumulation in plant	*Helianthus annuus* and *Brassica juncea*	Organic pollutants and metals) Cd, Cr, Co, Pb, Hg, Ni, Ag, Zn) and radionuclides
Phytodegradation	Whole plant	Breakdown and eradication of contaminants	Algae, poplars, and stonewort	Chlorinated solvents, petroleum
Phytovolatilization	Shoot	Volatilization of contaminants in modified from by leaves through transpiration process	Poplars, alfalfa, and *Brassica juncea*	Chlorinated solvents, metals (Se, Hg, and As)
Phytostabilization	Root	Sorption of contaminants	Grasses, *Brassica juncea*, and poplars	Inorganica (Cd, Cu, Cr, Pb)
Rhizodegradation	Root	Decomposition of contaminants by presence of microbes in rhizosphere	Agropyron *smithii* and *Bouteloua gracilis*	Chlorinated solvents, petroleum products

Source: Srivastav et al 2019

Phytoremediation: Role of medicinal and aromatic plants: Aromatic plants are devoid of the possibility of heavy metal buildup from plant biomass, preventing heavy metals from entering food. Because of its application in soaps, detergents, insect repellents, cosmetics, perfumes, and food processing, essential oil export, like phytoremediation, is a major economic concern (Gupta et al 2013).

CONCLUSION

For the eco-restoration of contaminated sites, phytoremediation is an emerging eco-sustainable and clean-green approach. Because of its low cost and solar-powered nature, it offers tremendous potential for application in underdeveloped countries. To minimize environmental pollution, toxicity reduction, and for enhancing phytoremediation efficiency, the employability of cheap, eco-friendly, non-toxic, and degradable organic soil amendments is suggested. Although genetic engineering of metal-accumulating plants and associated microbes with desired characteristics could be a highly useful technology for improved phytoremediation, the risks connected with field use must also be considered. Linking energy crops with phytoremediation could be a cost-effective way to increase biofuel/energy production and metal recovery while also providing other eco-environmental benefits; however, quality testing of biofuels produced is strongly recommended. To improve economic returns, it is advised that novel and existing technologies for the post-treatment of contaminated materials be researched and reevaluated. Detailed and long-term field studies are needed in order to document time and cost data for framing recommendations and persuade regulators, decision-makers, and the general public of phytoremediation's low-cost applicability. The use of nanoparticles for environmental applications is fast growing, and their reactivity is substantially boosted for chemical or biologically induced interactions. The efficiency of phytoremediation can also be boosted by using genetically modified plants. Combining phytoremediation and electro-kinetic remediation could be a great way to improve metal mobility in polluted soil and thus enable plant uptake and phytoremediation.

AUTHOR CONTRIBUTIONS

AB: Conceptualization, funding acquisition, resources; NRD: Supervision, investigation, visualization, validation, writing – review & editing; NS: Data curation, visualization, formal analysis, writing and review – original draft; JS: Data curation, visualization, formal analysis, writing and review – original draft; SM: Data curation, visualization, formal analysis, writing and review – original draft; VA: Project administration, supervision, reviewing and editing.

CONFLICT OF INTEREST

The authors declare that they have no competing interests in the work they have submitted.

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Received 16 January, 2022; Accepted 23 May, 2022

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Indian Journal of Ecology (2022) 49(3) (SI): 1068-1088
DOI: https://doi.org/10.55362/IJE/2022/3635

Manuscript Number: 3635
NAAS Rating: 5.79

Vascular Plants Diversity of Rashtrapati Bhavan Estate, New Delhi, India

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Abstract: The present work was carried out to collect information about different plant species of Rashtrapati Bhavan Estate, New Delhi, India. In present study an attempt has been made to provide an updated checklist of vascular plants from this Estate. The study is based on field survey (2021-22) and previous study of Rashtrapati Bhavan Estate. During the present investigation, 620 species of vascular plants categorised under 609 species of Angiosperms, 10 species of Gymnosperms and 01 species of Pteridophyte belonging to 112 families and 444 genera were recorded. The Fabaceae (60 species) (including Mimosaceae, Caesalpiniaceae) is the largest family among Dicots and Poaceae (25 species) is the largest family of Monocots. According to plant habit 240 species of herbs, 192 species of trees, 108 species of shrubs, 49 species of climbers, 20 species of undershrubs, 7 species of lianas, 3 species of woody grasses (bamboos) and 1 species of aquatic herb were found. The life-form classes were determined by the Raunkiaer's normal spectrum which reveals that the most dominant life form was Phanerophytes with 223 species (36%), followed by Therophytes with 174 species (28%), Chamaephytes with 103 species (16%), Lianas with 54 species (9%), Geophytes with 49 species (8%) and Hemicrytophytes contributing with 17 speces (3%). The biological spectrum of the Estate and on the basis of life-forms the phytoclimate here was Thero-Chamae-Geo-phytic. Systematic enumeration along with family, common name, habit and life-form is given for each species.

Keywords: Biological sepctrum, Delhi, Floristic diversity, Life-from, Rashtrapati Bhavan, Vascular plants

Rashtrapati Bhavan, New Delhi, India, is the residence of the President of the World's largest democracy, symbolizes the strength, the democratic traditions and the secular nature of India. It is situated on Raisina Hills, which is a part of the Aravalli range, extending from Gurugram in the northeast toward Delhi, can be seen immediately to the south, while the fertile Gangetic plains lie to the east. Physiographically, Delhi is dominated by the Yamuna River, the Aravalli Range and the Plains of Delhi, which were formed by alluvial deposits of recent origin. Delhi Ridge, with its four section, the northern, central, south central and southern, is the westernmost extension of the Aravalli range, meeting the Yamuna in two places, the north and east. Besides affecting the temperature of the Thar desert, the Ridge acts as a natural barrier between it and the plains, slowing down dust and wind movement from the desert. This green belt has other known benefits for the local people, too. There are two main geographical features of Delhi, including the Yamuna and the Aravali hill range. The Aravali hill range is covered with forests and is called the Ridge Forest; it is the city's lungs and keeps its environment in balance. Earlier, Maheshwari (1963, 1966), Dakshini and Vijayaraghavan (1970), Viswanathan et al (1982, 1984), Viswanathan and Singh (1986), Sharma and Ahmad (1990a,b, 1991), Sharma (1994, 1997 & 2002), Lal et al (2002), Kumar and Yadav (2005), Naithani et al (2006), Krishen (2006) and Mishra et al (2015a-d, 2019) studied vegetation of Delhi.

Rashtrapati Bhavan Estate is rich in floristic diversity due to the presence of many man made gardens like Mughal Gardens, Herbal Gardens, Spiritual Garden, Bio-fuel and Biodiversity Park, Nakshatra Garden, Bonsai Garden, Cactus Garden and Vegetable Garden (Dalikhana). Earlier, Singh (2007a,b) has published the Trees of Rashtrapati Bhavan (160 tree species with their uses) and pictorial book entitled 'Roses of Mughal Garden' described all the varieties of Roses present in Mughal Gardens. Baviskar (2016) published a book entitled 'First Garden of The Republic' described some important flora and fauna of Rashtrapati Bhavan. After this, no detailed study has been done about the complete flora of Rashtrapati Bhavan Estate. This paper provides complete and elaborated vegetation composition along with biological spectrum of Rashtrapati Bhavan Estate.

MATERIAL AND METHODS

Study area: Delhi is situated in northern part of India and located between latitudes of 28°-24'-17" to 28°-53'-00" North and longitudes of 76°-50'-24" to 77°-20'-37" East. The area of Delhi is 1,483 sq. km with maximum length of 51.90 kms and width of 48.48 kms. Delhi shares its border with the States of Uttar Pradesh and Haryana while bordered on the south-west by a Ridge. The Rashtrapati Bhavan Estate is situated on Raisina Hills, New Delhi, India with latitude 28°-36'-52" North and longitude 77°-11'-59 East with lush green area dominated by various species of trees, shrubs, herbs and climbers which are mostly cultivated and some are naturally occurring in the Ridge Forest of the Estate.

Data collection: Systematic survey of vascular plants was conducted during 2021-2022 in different seasons. The voucher specimens were dried, pressed and mounted on herbarium sheets following Jain and Rao (1977) and deposited in Patanjali Research Foundation Herbarium (PRFH), Haridwar, Uttarakhand for future reference and records. The currently accepted botanical names and authorities were updated following http://www.ipni.org and the families were updated following Chase et al, (2016) (APG IV). The plant species detail includes scientific name, family, common name(s), habit and life-form (Table 2). In the present investigation, Raunkiaer's normal spectrum as modified by Ellenberg and Mueller-Dombois (1974) has been followed to study the phytoclimate. The form, habit, height and nature of perennating buds were carefully noted in the field. All the plants of this area are categorized into Chamaephytes (Ch), Geophytes (G), Therophytes (Th), Hemicryptophytes (H), Lianas (L) and Phanerophytes (Ph) life-form classes.

RESULTS AND DISCUSSION

The vegetation of the Rashtrapati Bhavan Estate comprised of cultivated and naturally occurring species belonging to herbs, shrubs, under-shrubs, climbers, lianas and trees. Cultivated species are representing the ornamental plants of British origin on one hand and the European origin on the other, besides the plants of Indian origin. This area is rich in floristic diversity due to the presence of many man made gardens like Mughal Gardens, Herbal Gardens, Spiritual Garden, Bio-fuel and Biodiversity Park, Nakshatra Garden, Bonsai Garden, Cactus Garden, Vegetable Garden (Dalikhana), Nutrition Garden and the recently constructed Arogya Vanam and also a natural forest known as Ridge Forest, which is rich in naturally occurring vegetation. In present study 620 species of vascular plants belonging to 444 genera and 112 families were reported in which 01 Pteridophyte, 10 Gymnosperms and 609 species of Angiosperms were present. Furthermore, 51 families found were monogeneric and 42 were monospecific. Checklist of plant species with their scientific name, family, common name(s), habit and life-form is given in Table 2. *Nephrolepis cordifolia* (L.) C.Presl commonly cultivated as ornamental plant in pteridophyte group is found in the Rashtrapati Bhavan Estate. In gymnosperms group 10 species belonging to 7 genera and 4 families were reported. The largest genus is *Araucaria* Juss. having 3 species followed by *Juniperus* L. (02 species) and *Agathis* Salisb., *Cupressus* L., *Cycas* L., *Pinus* L., *Platycladus* Spach (01 species each). All the species present here are ornamental and cultivated to beautify the surroundings of The Rashtrapati Bhavan Estate.

Angiosperms (flowering plants) are largest plant group in this study area having 609 species (510 dicotyledons and 99 monocotyledons) belonging to 436 genera and 107 families. Among the ten dominant families, Fabaceae is the largest family having 60 species followed by Asteraceae (36), Poaceae and Malvaceae (26 each), Cactaceae (25), Apocynaceae (25), Asparagaceae (24), Moraceae (19), Lamiaceae (18) and Brassicaceae (17) respectively. As per habit, these plants are classified into 239 herbs, 183 trees, 107 shrubs, 49 climbers, 20 undershrubs, 07 lianas, 03 woody grasses and 01 aquatic herb. Naithani et al, (2006) reported 414 species of angiosperms belonging to 270 genera and 80 families from Ridge Forest of Delhi, out of 37 species belonging to 36 genera were new records for Delhi region. Mishra et al (2015a) published a list of floral diversity

Table 1. Life-form and biological spectrum of plants of the Rashtrapati Bhavan Estate, New Delhi, India

Life from	No. of plants	Rashtrapati bhavan	Raunkiaer's spectrum
Chamaephytes (Ch)	103	16%	9%
Geophytes (G)	49	8%	6%
Therophytes (Th)	174	28%	13%
Hemicryptophytes (H)	17	3%	26%
Lianas (L)	54	9%	*
Phanerophytes (Ph)	223	36%	46%

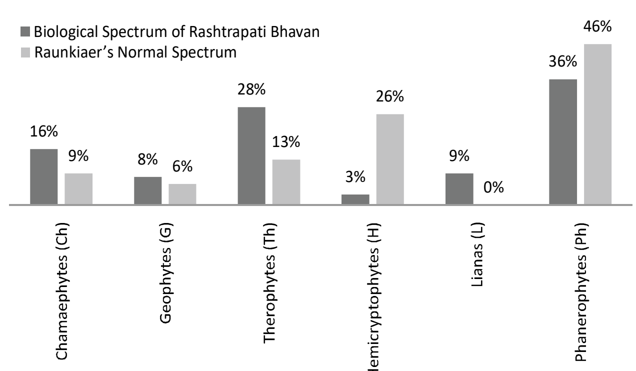

Fig. 1. Comparision of life-form and biological spectrum of plants of the Rashtrapati Bhavan estate, New Delhi, India with Raunkiaer's Normal Spectrum

Table 2. Vascular Plants of the Rashtrapati Bhavan Estate, New Delhi, India

S. No.	Botanical name	Family	Common name	Habit	Life Form
Pteridophytes					
1	Nephrolepis cordifolia (L.) C.Presl	Polypodiaceae	Fishbone fern, Tuber ladder fern	Herb	G
Gymnosperms					
1	Agathis robusta (C.Moore ex F.Muell.) F.M.Bailey	Araucariaceae	Kauri Pine, Queensland Kauri	Tree	Ph
2	*Araucaria columnaris* (G.Forst.) Hook.	Araucariaceae	Christmas Tree, New Caledonia Pine	Tree	Ph
3	*Araucaria cunninghamii* Mudie	Araucariaceae	Colonial Pine, Hoop Pine	Tree	Ph
4	*Araucaria heterophylla* (Salisb.) Franco	Araucariaceae	Norfolk Island Pine, Norfolk Pine	Tree	Ph
5	*Cupressus sempervirens* L.	Cupressaceae	Italian Cypress, Graveyard Cypress	Tree	Ph
6	*Cycas revoluta* Thunb.	Cycadaceae	King Sago Palm, Sago Cycad	Tree	Ph
7	*Juniperus chinensis* L.	Cupressaceae	Chinese Juniper	Tree	Ph
8	*Juniperus procumbens* (Siebold ex Endl.) Miq.	Cupressaceae	Japanese Garden Juniper	Shrub	Ch
9	*Pinus roxburghii* Sarg.	Pinaceae	Himalayan Longleaf Pine, Chir, Saral	Tree	Ph
10	*Platycladus orientalis* (L.) Franco	Cupressaceae	Oriental Thuja, Morpankhi	Tree	Ph
Angiosperms (Dicotyledons)					
1	*Abelmoschus esculentus* (L.) Moench	Malvaceae	Lady's Finger, Okra	Undershrub	Th
2	*Abelmoschus moschatus* Medik.	Malvaceae	Musk Mallow, Mushkdana, kasturidana	Undershrub	Th
3	*Abroma augustum* (L.) L.f.	Malvaceae	Devil's Cotton, Ulatkambal	Shrub	Ph
4	*Abrus precatorius* L.	Fabaceae	Coral Bead Vine, Gunja, Ratti	Climber	L
5	*Abutilon indicum* (L.) Sweet	Malvaceae	Indian Mallow, Kanghi	Undershrub	Th
6	*Abutilon ramosum* (Cav.) Guill. & Perr.	Malvaceae	Sticky Indian Mallow	Undershrub	Th
7	*Acacia auriculiformis* A.Cunn. ex Benth.	Fabaceae	Earleaf Acacia	Tree	Ph
8	*Acalypha indica* L.	Euphorbiaceae	Indian Copperleaf, Kuppi	Herb	Th
9	*Acalypha wilkesiana* Müll.Arg.	Euphorbiaceae	Copperleaf, Joseph's Coat, Fire-dragon	Shrub	Ch
10	*Acanthocereus tetragonus* (L.) Hummelinck	Cactaceae	Fairy Castle Cactus, Triangle Cactus	Shrub	Ph
11	*Achyranthes aspera* L.	Amaranthaceae	Prickly Chaff Flower, Chirchita, Apamarga	Herb	Th
12	*Adansonia digitata* L.	Malvaceae	African Baobab, Gorakh Imli	Tree	Ph
13	*Adenium obesum* (Forssk.) Roem. & Schult.	Apocynaceae	Desert Rose	Shrub	Ph
14	*Aegle marmelos* (L.) Corrêa	Rutaceae	Bengal Quince, Wood Apple, Bael	Tree	Ph
15	*Ageratum conyzoides* L.	Asteraceae	Goat Weed, Bhakumbhar	Herb	Th
16	*Ageratum houstonianum* Mill.	Asteraceae	Floss Flower, Bluemink, Nilo Gandhe	Herb	Th
17	*Agrostemma githago* L.	Caryophyllaceae	Corn Cockle	Herb	Th
18	*Ailanthus excelsa* Roxb.	Simaroubaceae	Indian Tree of Heaven, Marukh, Aralu	Tree	Ph
19	*Albizia lebbeck* (L.) Benth.	Fabaceae	Black Siris, Siris	Tree	Ph
20	*Albizia procera* (Roxb.) Benth.	Fabaceae	White Siris, Safed Siris	Tree	Ph
21	*Alcea rosea* L.	Malvaceae	Hollyhock, Gulkhaira	Herb	Th
22	*Alstonia scholaris* (L.) R.Br.	Apocynaceae	Blackboard Tree, Saptaparni	Tree	Ph
23	*Alternanthera brasiliana* (L.) Kuntze	Amaranthaceae	Joy Weed, Joseph's Coat, Copperleaf	Herb	Th
24	*Alternanthera philoxeroides* (Mart.) Griseb.	Amaranthaceae	Alligator Weed	Herb	G

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Table 2. Vascular Plants of the Rashtrapati Bhavan Estate, New Delhi, India

S. No.	Botanical name	Family	Common name	Habit	Life Form
25	*Amaranthus blitum* L.	Amaranthaceae	Spreading Pigweed, Chaulai	Herb	Th
26	*Amaranthus hybridus* L.	Amaranthaceae	Red Amaranth, Chaulai	Herb	Th
27	*Amaranthus viridis* L.	Amaranthaceae	Green Amaranth, Pigweed, Jangali Chaulayi	Herb	Th
28	*Amberboa moschata* (L.) DC.	Asteraceae	Sweet Sultan	Herb	Th
29	*Andrographis paniculata* (Burm.f.) Nees	Acanthaceae	Creat, Kala Chiryata, Kalmegh	Herb	Th
30	*Anethum graveolens* L.	Apiaceae	Dill, Soya	Herb	Th
31	*Annona reticulata* L.	Annonaceae	Bullock's Heart, Ramphal, Lavani	Tree	Ph
32	*Annona squamosa* L.	Annonaceae	Sugar Apple, Sharifa, Sitaphal	Tree	Ph
33	*Antigonon leptopus* Hook. & Arn.	Polygonaceae	Coral Vine, Mexican Creeper, Love Vine	Liana	L
34	*Antirrhinum majus* L.	Plantaginaceae	Dog flower, Snapdragon	Herb	Th
35	*Argemone mexicana* L.	Papaveraceae	Mexican Prickly Poppy, Pili Kateli, Swarnskhiri	Herb	Th
36	*Argyreia nervosa* (Burm.f.) Bojer	Convolvulaceae	Silky Elephant Glory, Vidhara	Liana	L
37	*Artabotrys hexapetalus* (L.f.) Bhandari	Annonaceae	Ylang Vine, Hara Champa	Shrub	Ph
38	*Artemisia annua* L.	Asteraceae	Sweet Wormwood, Quinghaou	Herb	Th
39	*Artemisia nilagirica* (C.B.Clarke) Pamp.	Asteraceae	Nilgiri Wormwood, Indian Wormwood, Nagdona	Shrub	Ch
40	*Artocarpus heterophyllus* Lam.	Moraceae	Jackfruit, Katahal	Tree	Ph
41	*Artocarpus lacucha* Buch.-Ham.	Moraceae	Lakoocha, Monkey Jack, Barhal	Tree	Ph
42	*Atocion armeria* (L.) Raf.	Caryophyllaceae	Catchfly, Sweet William Catchfly	Herb	Th
43	*Azadirachta indica* A.Juss.	Meliaceae	Margosa, Neem	Tree	Ph
44	*Bacopa monnieri* (L.) Wettst.	Plantaginaceae	Indian pennywort, Water hyssop, Brahmi, Jalbuti, Jalnim, Brahmi, Somvalli	Herb	Th
45	*Balanites roxburghii* Planch.	Zygophyllaceae	Desert Date, Hingot, Hingan	Tree	Ph
46	*Barleria cristata* L.	Acanthaceae	Crested Philippine Violet, Nil Jhinti	Shrub	Ch
47	*Barleria lupulina* Lindl.	Acanthaceae	Hophead	Shrub	Ch
48	*Barleria prionitis* L.	Acanthaceae	Common Yellow Nail Dye, Pila Piyabansa	Shrub	Ch
49	*Basella alba* L.	Basellaceae	Indian Spinach, Vine Spinach, Poi	Climber	L
50	*Bassia scoparia* (L.) A.J.Scott	Amaranthaceae	Summer Cypress, Kochia	Herb	Th
51	*Bauhinia × blakea*na Dunn	Fabaceae	Hong Kong Orchid-Tree	Tree	Ph
52	*Bauhinia acuminata* L.	Fabaceae	Dwarf White Orchid Tree, Safed Kachnar	Tree	Ph
53	*Bauhinia purpurea* L.	Fabaceae	Purple Orchid Tree, Kachnar, Kaniar	Tree	Ph
54	*Bauhinia tomentosa* L.	Fabaceae	Yellow Orchid Tree, Peet Kanchnar	Tree	Ph
55	*Bauhinia variegata* L.	Fabaceae	Orchid Tree, Kachnar	Tree	Ph
56	*Bauhinia variegata* var. candida Voigt	Fabaceae	White Orchid Tree, Safed Kachnar	Tree	Ph
57	*Begonia cucullata* Willd.	Begoniaceae	Clubed Begonia	Herb	Th
58	*Beta vulgaris* L.	Amaranthaceae	Beet, Chukandar	Herb	G
59	*Bischofia javanica* Blume	Phyllanthaceae	Bishop Wood, Paniala, Bhillar	Tree	Ph
60	*Blepharis maderaspatensis* (L.) B.Heyne ex Roth	Acanthaceae	Creeping Blepharis, Utangan	Herb	Th
61	*Blumea lacera* (Burm.f.) DC.	Asteraceae	Lettuce-Leaf Blumea, Jangli Muli	Herb	Th
62	*Boerhavia repens* L.	Nyctaginaceae	Anena, Creeping Spiderling	Herb	H

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Table 2. Vascular Plants of the Rashtrapati Bhavan Estate, New Delhi, India

S. No.	Botanical name	Family	Common name	Habit	Life Form
66	*Bougainvillea glabra* Choisy	Nyctaginaceae	Bougainvillea, Paperflower, Booganbel	Shrub	Ph
67	*Brachychiton australis* (Schott & Endl.) A.Terracc.	Malvaceae	Broad Leaved Bottle Tree	Tree	Ph
68	*Brassica campestris* var. sarson Prain	Brassicaceae	Yellow Sarson, Sarson	Herb	Th
69	*Brassica juncea* (L.) Czern.	Brassicaceae	Indian Mustard, Brown Mustard, Rai	Herb	Th
70	*Brassica oleracea* var. botrytis L.	Brassicaceae	Cauliflower, Phool Gobhi	Herb	Th
71	*Brassica oleracea* var. capitata L.	Brassicaceae	Cabbage, Band Gobhi, Patta Gobhi	Herb	Th
72	*Brassica oleracea* var. gongylodes L.	Brassicaceae	Kohlrabi, Knol Khol, Ganthgobhi	Herb	G
73	*Brassica oleracea* var. italica Plenck	Brassicaceae	Broccoli, Hari Gobhi	Herb	Th
74	*Brassica oleracea* var. sabellica L.	Brassicaceae	Ornamental Cabbage, Ornamental Kale	Herb	Th
75	*Brassica rapa* L.	Brassicaceae	Turnip, Shaljam	Herb	Th
76	*Buddleja madagascariensis* Lam.	Scrophulariaceae	Madagascar Butterfly Bush	Shrub	Ph
77	*Butea monosperma* (Lam.) Kuntze	Fabaceae	Flame of the Forest, Dhak, Palash	Tree	Ph
78	*Calceolaria × herbeohybrida* Voss	Calceolariaceae	Lady's Purse, Pocketbook Plant	Herb	Th
79	*Calendula officinalis* L.	Asteraceae	Calendula, Pot Marigold, Gul-e-Ashrafi	Herb	Th
80	*Calliandra haematocephala* Hassk.	Fabaceae	Red Powder Puff	Shrub	Ph
81	*Calotropis gigantea* (L.) W.T.Aiton	Apocynaceae	Crown Flower, Safed Aak	Shrub	Ch
82	*Calotropis procera* (Aiton) W.T.Aiton	Apocynaceae	Rubber Bush, Sodom Apple, Aak, Madar	Shrub	Ch
83	*Calyptocarpus vialis* Less.	Asteraceae	Straggler Daisy, Sprawling Horseweed	Herb	Th
84	*Campsis radicans* (L.) Seem. ex Bureau	Bignoniaceae	Trumpet Vine	Climber	L
85	*Cannabis sativa* L.	Cannabaceae	Marijuana, Hemp, Bhang	Shrub	Ch
86	*Capparis decidua* (Forssk.) Edgew.	Capparaceae	Bare Caper, Kair, Kareel	Tree	Ph
87	*Capparis sepiaria* L.	Capparaceae	Wild Caper Bush, Hedge Caper, Kanthari	Shrub	Ch
88	*Capsella bursa-pastoris* (L.) Medik.	Brassicaceae	Shepherd's Purse	Herb	Th
89	*Capsicum annuum* L.	Solanaceae	Chilli, Paprika, Mirch	Herb	Th
90	*Cardamine flexuosa* With.	Brassicaceae	Wood Bitter Cress, Wavy Bitter Cress	Herb	Th
91	*Carica papaya* L.	Caricaceae	Papaya, Melon Tree, Papita	Tree	Ph
92	*Carissa carandas* L.	Apocynaceae	Karanda, Karonda	Shrub	Ph
93	*Carissa spinarum* L.	Apocynaceae	Wild Karanda, Jangli Karonda	Shrub	Ph
94	*Cascabela thevetia* (L.) Lippold	Apocynaceae	Yellow Oleander, Peeli Kaner	Tree	Ph
95	*Cassia fistula* L.	Fabaceae	Golden Shower Tree, Amaltas	Tree	Ph
96	*Cassia javanica* L.	Fabaceae	Java Cassia, Pink Shower	Tree	Ph
97	*Casuarina equisetifolia* L.	Casuarinaceae	Whistling Pine, Jangli Saru	Tree	Ph
98	*Catharanthus roseus* (L.) G.Don	Apocynaceae	Periwinkle, Sadabahar	Undershrub	Ch
99	*Ceiba speciosa* (A.St.-Hil., A.Juss. & Cambess.) Ravenna	Malvaceae	Silk Floss Tree, Kapok, Resham Rui	Tree	Ph
100	*Celastrus paniculatus* Willd.	Celastraceae	Intellect Plant, Malkangani	Liana	L
101	*Celosia cristata* L.	Amaranthaceae	Cockscomb, Lalmurga	Herb	Th
102	*Celtis tetrandra* Roxb.	Cannabaceae	Nilgiri Elm, Khirk	Tree	Ph
103	*Centaurea cyanus* L.	Asteraceae	Cornflower, Bachelor's Button	Herb	Th
104	*Centella asiatica* (L.) Urb.	Apiaceae	Indian Pennywort, Ballari, Manduki	Herb	H
105	*Cestrum diurnum* L.	Solanaceae	King of the Day, Din ka Raja	Shrub	Ph
106	*Cestrum nocturnum* L.	Solanaceae	Lady of the Night, Rat ki Rani	Shrub	Ph

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Table 2. Vascular Plants of the Rashtrapati Bhavan Estate, New Delhi, India

S. No.	Botanical name	Family	Common name	Habit	Life Form
107	*Chenopodiastrum murale* (L.) S.Fuentes, Uotila & Borsch	Amaranthaceae	Nettle-Leaved Goosefoot, Goyalo, Khartua	Herb	Th
108	*Chenopodium album* L.	Amaranthaceae	White Goosefoot, Bathua	Herb	Th
109	*Chrysanthemum indicum* L.	Asteraceae	Indian Chrysanthemum, Chandramallika	Herb	Th
110	*Chukrasia tabularis* A.Juss.	Meliaceae	Chittagong Wood, Indian Redwood, Chikrasi	Tree	Ph
111	*Cicer arietinum* L.	Fabaceae	Chickpea, Gram, Chana	Herb	Th
112	*Cinnamomum camphora* (L.) J.Presl	Lauraceae	Camphor Tree, Kapur	Tree	Ph
113	*Cinnamomum verum* J.Presl	Lauraceae	Cinnamon, Dalchini	Tree	Ph
114	*Cirsium arvense* (L.) Scop.	Asteraceae	Creeping Thistle, Field Thistle	Herb	Th
115	*Cissampelos pareira* L.	Menispermaceae	Velvet Leaf, Akanadi	Climber	L
116	*Cissus quadrangularis* L.	Vitaceae	Veldt Grape, Bone Setter, Hadjod	Climber	L
117	*Citrus* × *aurantiifolia* (Christm.) Swingle	Rutaceae	Lime, Kaghzi Nimbu	Tree	Ph
118	*Citrus* × *limon* (L.) Osbeck	Rutaceae	Lemon, Nimbu, Bada Nimbu	Tree	Ph
119	*Citrus* × *reticulata* Blanco	Rutaceae	Mandarin Orange, Orange, Santara	Tree	Ph
120	*Citrus* × *sinensis* (L.) Osbeck	Rutaceae	Sweet Orange, Mosambi	Tree	Ph
121	*Citrus japonica* Thunb.	Rutaceae	Round Kumquat	Tree	Ph
122	*Citrus maxima* (Burm.) Merr.	Rutaceae	Pomelo, Chinese Grapefruit, Chakotara	Tree	Ph
123	*Citrus reticulata cv. kinnow Blanco.*	Rutaceae	Kinnow	Tree	Ph
124	*Clarkia unguiculata* Lindl.	Onagraceae	Elegant Clarkia, Mountain Garland	Herb	Th
125	*Cleistocactus winteri* D.R.Hunt	Cactaceae	-	Shrub	Ch
126	*Clematis flammula* L.	Ranunculaceae	Fragrant Virgin's Bower, Fragrant Clematis	Climber	L
127	*Cleretum bellidiforme* (Burm.f.) G.D.Rowley	Aizoaceae	Ice Plant, Livingston Daisy, Burf Pushp	Herb	Th
128	*Clerodendrum indicum* (L.) Kuntze	Lamiaceae	Tubeflower, Bharangi	Shrub	Ch
129	*Clerodendrum phlomidis* L.f.	Lamiaceae	Sage Glory Bower, Arni	Shrub	Ch
130	*Clerodendrum splendens* G.Don	Lamiaceae	Flaming Glorybower, Pagoda Flower	Climber	L
131	*Clitoria ternatea* L.	Fabaceae	Butterfly Pea, Aparajita	Climber	L
132	*Coccinia grandis* (L.) Voigt	Cucurbitaceae	Ivy Gourd, Kanduri, Kundru	Climber	L
133	*Cocculus hirsutus* (L.) W.Theob.	Menispermaceae	Broom Creeper, Jaljamni, Patala Garudi	Climber	L
134	*Coleus scutellarioides* (L.) Benth.	Lamiaceae	Coleus	Herb	Th
135	*Combretum indicum* (L.) DeFilipps	Combretaceae	Rangoon Creeper, Madhu Malati	Liana	L
136	*Commiphora madagascariensis* Jacq.	Burseraceae	Madagascar Corkwood	Tree	Ph
137	*Commiphora wightii* (Arn.) Bhandari	Burseraceae	Indian Bdellium Tree, Guggul	Tree	Ph
138	*Convolvulus arvensis* L.	Convolvulaceae	Field Bindweed, Hiranpug	Herb	Th
139	*Convolvulus prostratus* Forssk.	Convolvulaceae	Prostrate Bindweed, Shankh Pushpi	Herb	Th
140	*Corchorus olitorius* L.	Malvaceae	Nalta Jute, Jew's Mallow, Pat	Herb	Th
141	*Cordia dichotoma* G.Forst.	Boraginaceae	Indian Cherry, Fragrant Manjack, Lasora	Tree	Ph
142	*Coreopsis auriculata* L.	Asteraceae	Mouse Ear Tickseed	Herb	Th
143	*Coriandrum sativum* L.	Apiaceae	Coriander, Dhaniya	Herb	Th
144	*Corymbia citriodora* (Hook.) K.D.Hill & L.A.S.Johnson	Myrtaceae	Lemon Scented Gum, Lemon Eucalyptus, Safeda	Tree	Ph
145	*Cosmos sulphureus* Cav.	Asteraceae	Sulphur Cosmos, Orange Cosmos	Herb	Th
146	*Cotula australis* Hook.f.	Asteraceae	Australian Buttonweed	Herb	Th

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S. No.	Botanical name	Family	Common name	Habit	Life Form
147	*Crateva adansonii* subsp. odora (Buch.-Ham.) Jacobs	Capparaceae	Garlic Pear Tree, Barna, Barni	Tree	Ph
148	*Crescentia alata* Kunth	Bignoniaceae	Winged Calabash, Kamandal	Tree	Ph
149	*Crossandra infundibuliformis* (L.) Nees	Acanthaceae	Firecracker Flower, Priyadarsha	Shrub	Ch
150	*Cucurbita maxima* Duchesne	Cucurbitaceae	Giant Pumpkin, Red Pumpkin, Kaddu	Climber	L
151	*Cullen corylifolium* (L.) Medik.	Fabaceae	Scurfy Pea, Babachi, Bakuchi	Herb	Th
152	*Cuscuta campestris* Yunck.	Convolvulaceae	Golden Dodder, Field Dodder	Climber	L
153	*Cuscuta reflexa* Roxb.	Convolvulaceae	Giant Dodder, Amarbel, Akashbel	Climber	L
154	*Cyamopsis tetragonoloba* (L.) Taub.	Fabaceae	Guar, Gum Bean, Gavar	Herb	Th
155	*Cyanthillium cinereum* (L.) H.Rob.	Asteraceae	Little Ironweed, Sahadevi	Herb	Th
156	*Dahlia imperialis* Roezl ex Ortgies	Asteraceae	Tree Dahlia	Herb	G
157	*Dahlia pinnata* Cav.	Asteraceae	Garden Dahlia	Herb	G
158	*Dalbergia sissoo* Roxb. ex DC.	Fabaceae	Indian Rosewood, Shisham	Tree	Ph
159	*Datura metel* L.	Solanaceae	Devil's Trumpet, Dhatura	Undershrub	Ch
160	*Daucus carota* subsp. sativus (Hoffm.) Schübl. & G.Martens	Apiaceae	Carrot, Gajar	Herb	G
161	*Delonix regia* (Bojer ex Hook.) Raf.	Fabaceae	Flame Tree, Gulmohar	Tree	Ph
162	*Delphinium ajacis* L.	Ranunculaceae	Larkspur, Rocket larkspur, Annual Delphinium	Herb	Th
163	*Delphinium elatum* L.	Ranunculaceae	Alpine Delphinium, Candle Larkspur	Herb	Th
164	*Dianthus barbatus* L.	Caryophyllaceae	Sweet William	Herb	Th
165	*Dianthus chinensis* L.	Caryophyllaceae	Chinese Pink, Rainbow Pink	Herb	Th
166	*Dichrostachys cinerea* (L.) Wight & Arn.	Fabaceae	Sickle Bush Ashy Babool, Kheri	Tree	Ph
167	*Dicliptera paniculata* (Forssk.) I.Darbysh.	Acanthaceae	Panicled Foldwing, Kakajangha	Herb	Th
168	*Dillenia indica* L.	Dilleniaceae	Elephant Apple, Chalta	Tree	Ph
169	*Dimorphotheca pluvialis* (L.) Moench	Asteraceae	White African Daisy, Rain Daisy	Herb	Th
170	*Diospyros malabarica* (Desr.) Kostel.	Ebenaceae	Gaub, Malabar Ebony, Gaab, Kala Tendu	Tree	Ph
171	*Diospyros montana* Roxb.	Ebenaceae	Bombay Ebony, Bistendu	Tree	Ph
172	*Dombeya spectabilis* Bojer	Malvaceae	Dombey, Showy Dombeya	Tree	Ph
173	*Duranta erecta* L.	Verbenaceae	Sky Flower, Pigeon Berry, Nilkanta	Shrub	Ph
174	*Echinopsis famatimensis* (Speg.) Werderm.	Cactaceae	-	Shrub	Ch
175	*Echinopsis oxygona* (Link) Zucc. ex Pfeiff. & Otto	Cactaceae	-	Shrub	Ch
176	*Eclipta prostrata* (L.) L.	Asteraceae	False Daisy, Bhringaraj	Herb	Th
177	*Ehretia acuminata* R.Br.	Boraginaceae	Koda Tree, Brown Cedar, Bakli, Pania	Tree	Ph
178	*Ehretia laevis* Roxb.	Boraginaceae	Chamror, Datranga, Tamoriya	Tree	Ph
179	*Ehretia microphylla* Lam.	Boraginaceae	Fukien Tea, Carmona, Pala	Shrub	Ph
180	*Elaeocarpus angustifolius* Blume	Elaeocarpaceae	Blue Marble Tree, Rudraksh	Tree	Ph
181	*Eriobotrya japonica* (Thunb.) Lindl.	Rosaceae	Loquat, Lokat	Tree	Ph
182	*Erysimum × cheiri* (L.) Crantz	Brassicaceae	Common Wallflower	Herb	Th
183	*Erythrina variegata* L.	Fabaceae	Indian Coral Tree, Tiger Claw, Pangar	Tree	Ph
184	*Eschscholzia californica* Cham.	Papaveraceae	California Poppy, Golden Poppy	Herb	Th
185	*Eucalyptus camaldulensis* Dehnh.	Myrtaceae	River Red Gum, Longbeak Eucalyptus	Tree	Ph

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Table 2. Vascular Plants of the Rashtrapati Bhavan Estate, New Delhi, India

S. No.	Botanical name	Family	Common name	Habit	Life Form
186	*Euphorbia helioscopia* L.	Euphorbiaceae	Sun Spurge, Hirruseeah, Dudhya	Herb	Th
187	*Euphorbia hirta* L.	Euphorbiaceae	Common Spurge, Asthma Weed, Bada Dudhi	Herb	Th
188	*Euphorbia milii* Des Moul.	Euphorbiaceae	Giant Crown of Thorns	Undershrub	Ch
189	*Euphorbia neriifolia* L.	Euphorbiaceae	Indian Spurge Tree, Danda Thor, Sehund	Shrub	Ph
190	*Euphorbia prostrata* Aiton	Euphorbiaceae	Prostrate Spurge, Prostrate Sandmat	Herb	Th
191	*Euphorbia pulcherrima* Willd. ex Klotzsch	Euphorbiaceae	Poinsettia	Shrub	Ph
192	*Euphorbia serpens* Kunth	Euphorbiaceae	Matted Sandmat, Roundleaf Spurge, Dudhi	Herb	Th
193	*Euphorbia tithymaloides* L.	Euphorbiaceae	Devil's Backbone, Slipper Spurge, Redbird Cactus	Undershrub	Ch
194	*Evolvulus nummularius* (L.) L.	Convolvulaceae	Roundleaf Bindweed, Safed shankhpushpi, Musakarni	Herb	H
195	*Fernandoa adenophylla* (Wall. ex G.Don) Steenis	Bignoniaceae	Katsagon, Marodphali	Tree	Ph
196	*Ferocactus latispinus* (Haw.) Britton & Rose	Cactaceae	-	Shrub	Ch
197	*Ficus altissima* Blume	Moraceae	Lofty Fig, Council Tree	Tree	Ph
198	*Ficus amplissima* Sm.	Moraceae	Indian Bat Fig, Pipri, Pakri	Tree	Ph
199	*Ficus auriculata* Lour.	Moraceae	Elephant Ear Fig, Roxburgh Fig, Fagoora, Timla	Tree	Ph
200	*Ficus benghalensis* L.	Moraceae	Banyan Tree, Bargad, Bad	Tree	Ph
201	*Ficus benjamina* L.	Moraceae	Weeping Fig, Benjamin's Fig, Pukar	Tree	Ph
202	*Ficus carica* L.	Moraceae	Common Fig, Anjeer	Tree	Ph
203	*Ficus elastica* Roxb. ex Hornem.	Moraceae	Indian Rubber Tree, Rubber Fig	Tree	Ph
204	*Ficus krishnae* C.DC.	Moraceae	Krishna's Butter Cup, Makhan Katori, Krisna Badh	Tree	Ph
205	*Ficus lyrata* Warb.	Moraceae	Fiddle Leaf Fig	Tree	Ph
206	*Ficus maclellandii* King	Moraceae	Willow Fig, Alii Fig, Banana-leaf Fig	Tree	Ph
207	*Ficus microcarpa* L.f.	Moraceae	Laurel Fig, Indian Laurel, Kamarup	Tree	Ph
208	*Ficus palmata* subsp. virgata Browicz	Moraceae	Punjab Fig, Anjiri, Bedu, Jangli Anjir	Tree	Ph
209	*Ficus racemosa* L.	Moraceae	Cluster Fig, Gular, Umar	Tree	Ph
210	*Ficus religiosa* L.	Moraceae	Holy Fig Tree, Peepal	Tree	Ph
211	*Ficus virens* Aiton	Moraceae	White Fig, Pilkhan, Pakhad	Tree	Ph
212	*Flacourtia indica* (Burm.f.) Merr.	Salicaceae	Governor's Plum, Bilangada	Tree	Ph
213	*Fragaria × ananassa* (Duchesne ex Weston) Duchesne ex Rozier	Rosaceae	Strawberry, Alpine Strawberry	Herb	Th
214	*Fumaria indica* (Hausskn.) Pugsley	Papaveraceae	Indian Fumitory, Pit Papra	Herb	Th
215	*Gamochaeta pensylvanica* (Willd.) Cabrera	Asteraceae	Pennsylvania Cudweed	Herb	Th
216	*Gardenia jasminoides* J.Ellis	Rubiaceae	Cape Jasmine, Gardenia, Gandhraj	Shrub	Ch
217	*Gazania rigens* (L.) Gaertn.	Asteraceae	-	Herb	Th
218	*Glebionis coronaria* (L.) Cass. ex Spach	Asteraceae	Crown Daisy, Guldaudi	Herb	Th
219	*Glycyrrhiza glabra* L.	Fabaceae	Liquorice, Mulhatti	Undershrub	Th
220	*Gomphrena celosioides* Mart.	Amaranthaceae	Cockscomb Gomphrena, Soft Khakiweed, Kasia	Herb	Th
221	*Grevillea robusta* A.Cunn. ex R.Br.	Proteaceae	Silver Oak, Silk Oak	Tree	Ph

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S. No.	Botanical name	Family	Common name	Habit	Life Form
222	*Grewia subinaequalis* DC.	Malvaceae	Phalsa, Falsa	Tree	Ph
223	*Grewia tenax* (Forssk.) Fiori	Malvaceae	White Crossberry, Gondni, Chabeni	Shrub	Ph
224	*Grona triflora* (L.) H.Ohashi & K.Ohashi	Fabaceae	Creeping Tick Trefoil, Kudaliya	Herb	Ch
225	*Guilandina bonduc* L.	Fabaceae	Yellow Nicker, Fever Nut, Katkaranj	Shrub	Ph
226	*Gymnema sylvestre* (Retz.) R.Br. ex Sm.	Apocynaceae	Cowplant, Gurmar	Climber	L
227	*Gymnocalycium mihanovichii* (Fric ex Gürke) Britton & Rose	Cactaceae	-	Shrub	Ch
228	*Gymnocalycium stenopleurum* F.Ritter	Cactaceae	-	Shrub	Ch
229	*Gypsophila elegans* M.Bieb.	Caryophyllaceae	Baby's Breath	Herb	Th
230	*Hamelia patens* Jacq.	Rubiaceae	Firebush, Hummingbird Bush	Shrub	Ch
231	*Handroanthus impetiginosus* (Mart. ex DC.) Mattos	Bignoniaceae	Pink Trumpet Tree, Basant Rani	Tree	Ph
232	*Hardwickia binata* Roxb.	Fabaceae	Indian Blackwood, Anjan	Tree	Ph
233	*Hemidesmus indicus* (L.) R.Br.	Apocynaceae	Indian Sarsaparilla, Anantamul	Climber	L
234	*Heptapleurum arboricola* Hayata	Araliaceae	Dwarf Umbrella Tree, Dwarf Schefflera	Shrub	Ch
235	*Hibiscus mutabilis* L.	Malvaceae	Confederate Rose, Cotton Rose, Sthalkamal	Shrub	Ch
236	*Hibiscus rosa-sinensis* L.	Malvaceae	China Rose, Gurhal, Japaa	Shrub	Ph
237	*Hibiscus sabdariffa* L.	Malvaceae	Roselle, Lal Ambari, Patwa	Herb	Ch
238	*Hiptage benghalensis* (L.) Kurz	Malpighiaceae	Helicopter Flower, Madhavi Lata	Liana	L
239	*Holoptelea integrifolia* (Roxb.) Planch.	Ulmaceae	Kanju, Chilbil, Indian Elm	Tree	Ph
240	*Iberis amara* L.	Brassicaceae	Candytuft	Herb	Th
241	*Ipomoea aitonii* Lindl.	Convolvulaceae	-	Climber	L
242	*Ipomoea aquatica* Forssk.	Convolvulaceae	Water Morning Glory, Kalmi Sag, Nali	Climber	L
243	*Ipomoea batatas* (L.) Lam.	Convolvulaceae	Sweet Potato, Shakarkand	Herb	G
244	*Ipomoea cairica* (L.) Sweet	Convolvulaceae	Railway Creeper, Neeli Bel	Climber	L
245	*Ipomoea nil* (L.) Roth	Convolvulaceae	Blue Morning Glory, Neelkalmi	Climber	L
246	*Ipomoea obscura* (L.) Ker Gawl.	Convolvulaceae	Obscure Morning Glory, Lakshmana	Climber	L
247	*Ixora finlaysoniana* Wall. ex G.Don	Rubiaceae	Fragrant Ixora, White Jungle Flame	Shrub	Ch
248	*Ixora pavetta* Andrews	Rubiaceae	Torch Tree	Shrub	Ch
249	*Jacaranda mimosifolia* D.Don	Bignoniaceae	Blue Jacaranda, Neeli Gulmohur	Tree	Ph
250	*Jacquemontia pentanthos* (Jacq.) G.Don	Convolvulaceae	Skyblue Clustervine	Climber	L
251	*Jasminum elongatum* (P.J.Bergius) Willd.	Oleaceae	Red Kund, Ear-leaf Jasmine	Shrub	Ch
252	*Jasminum grandiflorum* L.	Oleaceae	Royal Jasmine, Chameli, Jati	Shrub	Ch
253	*Jasminum mesnyi* Hance	Oleaceae	Primrose Jasmine, Japanese Jasmine, Japani Chameli	Climber	L
254	*Jasminum sambac* (L.) Aiton	Oleaceae	Arabian Jasmine, Mogra, Bela	Shrub	Ch
255	*Jatropha curcas* L.	Euphorbiaceae	Physic Nut, Barbados Nut, Ratanjot	Shrub	Ph
256	*Jatropha integerrima* Jacq.	Euphorbiaceae	Peregrina, Spicy Jatropha	Shrub	Ch
257	*Justicia adhatoda* L.	Acanthaceae	Malabar Nut, Arusa, Bansa	Shrub	Ch
258	*Kalanchoe beharensis* Drake	Crassulaceae	Feltbush Kalanchoe, Elephant's Ear Kalanchoe	Shrub	Ch
259	*Kalanchoe blossfeldiana* Poelln.	Crassulaceae	Kalanchoe, Flaming Katy	Herb	Ch

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S. No.	Botanical name	Family	Common name	Habit	Life Form
260	*Kalanchoe pinnata* (Lam.) Pers.	Crassulaceae	Air Plant, Leaf of Life, Amar Poi	Herb	Ch
261	*Kigelia africana* (Lam.) Benth.	Bignoniaceae	Sausage Tree, Balam Khira	Tree	Ph
262	*Koelreuteria bipinnata* Franch.	Sapindaceae	Chinese Golden Rain Tree	Tree	Ph
263	*Koelreuteria paniculata* Laxm.	Sapindaceae	Golden Rain Tree, Varnish Tree	Tree	Ph
264	*Kroenleinia grusonii* (Hildm.) Lodé	Cactaceae	-	Shrub	Ch
265	*Lablab purpureus* (L.) Sweet	Fabaceae	Lablab Bean, Hyacinth Bean, Sem	Climber	L
266	*Lactuca sativa* L.	Asteraceae	Lettuce, Salad	Herb	Th
267	*Lagerstroemia indica* L.	Lythraceae	Common Crape Myrtle, Sawani	Shrub	Ph
268	*Lagerstroemia speciosa* (L.) Pers.	Lythraceae	Pride of India, Queen Crape Myrtle, Jarul	Tree	Ph
269	*Lagerstroemia tomentosa* C.Presl	Lythraceae	White Crape Myrtle, Leza	Tree	Ph
270	*Lantana camara* L.	Verbenaceae	Common Lantana, Wild Sage, Raimuniya	Shrub	Ch
271	*Lathyrus odoratus* L.	Fabaceae	Sweet Pea	Herb	Th
272	*Lathyrus oleraceus* Lam.	Fabaceae	Pea, Matar	Herb	Th
273	*Lathyrus sativus* L.	Fabaceae	Grass Pea, Khesari, Latari	Herb	Th
274	*Rosmarinus officinalis* L.	Lamiaceae	Rosemary	Shrub	Ch
275	*Lawsonia inermis* L.	Lythraceae	Henna, Mehendi	Shrub	Ch
276	*Lepidium didymum* L.	Brassicaceae	Lesser Swinecress, Wart Cress, Jangli Hala	Herb	Th
277	*Leucaena leucocephala* (Lam.) de Wit	Fabaceae	Wild Tamarind, Safed Babool	Tree	Ph
278	*Leucophyllum frutescens* (Berland.) I.M.Johnst.	Scrophulariaceae	Texas Barometer-bush, Silver-leaf Purple Sage	Shrub	Ch
279	*Leucostele atacamensis* (Phil.) Schlumpb.	Cactaceae	-	Shrub	Ch
280	*Linaria maroccana* Hook.f.	Plantaginaceae	Moroccan Toadflax, Baby Snapdragon	Herb	Th
281	*Linum grandiflorum* Desf.	Linaceae	Scarlet Flax, Flowering Flax	Herb	Th
282	*Litchi chinensis* Sonn.	Sapindaceae	Leechee, Litchi, Lichi	Tree	Ph
283	*Litsea glutinosa* (Lour.) C.B.Rob.	Lauraceae	Indian Laurel, Meda, Chandna	Tree	Ph
284	*Lobularia maritima* (L.) Desv.	Brassicaceae	Sweet Alyssum	Herb	Th
285	*Lophocereus schottii* (Engelm.) Britton & Rose	Cactaceae	-	Shrub	Ch
286	*Lophophora williamsii* (Lem.) J.M.Coult.	Cactaceae	-	Shrub	Ch
287	*Luffa cylindrica* (L.) M.Roem.	Cucurbitaceae	Sponge Gourd, Ghia Torai	Climber	L
288	*Lysimachia arvensis* var. *caerulea* (L.) Turland & Bergmeier	Primulaceae	Blue Pimpernel, Neel, Dharti Dhak	Herb	Th
289	*Madhuca longifolia* var. *latifolia* (Roxb.) A.Chev.	Sapotaceae	Indian Butter Tree, Honey Tree, Mahua	Tree	Ph
290	*Madhuca longifolia* (J.Koenig ex L.) J.F.Macbr.	Sapotaceae	South Indian Mahua, Mahua	Tree	Ph
291	*Maerua oblongifolia* (Forssk.) A.Rich.	Capparaceae	Desert Caper, Hemkand	Shrub	Ch
292	*Magnolia champaca* (L.) Baill. ex Pierre	Magnoliaceae	Golden Champa, Champa, Son Champa	Tree	Ph
293	*Magnolia grandiflora* L.	Magnoliaceae	Southern Magnolia, Bull Bay, Him Champa	Tree	Ph
294	*Malus domestica* (Suckow) Borkh.	Rosaceae	Apple, Seb	Tree	Ph
295	*Malva parviflora* L.	Malvaceae	Cheeseweed, Egyptian Mallow, Panirak	Herb	Th
296	*Malvastrum coromandelianum* (L.) Garcke	Malvaceae	False Mallow, Bariara, Kharenti	Herb	Th
297	*Malvaviscus arboreus* Dill. ex Cav.	Malvaceae	Sleeping Hibiscus, Turk's Cap	Shrub	Ch

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S. No.	Botanical name	Family	Common name	Habit	Life Form
298	*Mammillaria baumii* Boed.	Cactaceae	-	Shrub	Ch
299	*Mammillaria elongata* DC.	Cactaceae	-	Shrub	Ch
300	*Mammillaria longimamma* DC.	Cactaceae	-	Shrub	Ch
301	*Mammillaria rhodantha* Link & Otto	Cactaceae	-	Shrub	Ch
302	*Mangifera indica* L.	Anacardiaceae	Mango, Aam	Tree	Ph
303	*Manihot esculenta* Crantz	Euphorbiaceae	Tapioca, Para Arrowroot, Cassava	Shrub	G
304	*Manilkara hexandra* (Roxb.) Dubard	Sapotaceae	Ceylon Iron Wood, Milk Tree, Khirni	Tree	Ph
305	*Manilkara zapota* (L.) P.Royen	Sapotaceae	Sapodilla, Noseberry, Chikoo	Tree	Ph
306	*Mansoa alliacea* (Lam.) A.H.Gentry	Bignoniaceae	Garlic Vine, Lahsun Bel	Climber	L
307	*Matricaria chamomilla* L.	Asteraceae	Chamomile, Chamomilla	Herb	Th
308	*Matthiola incana* (L.) W.T.Aiton	Brassicaceae	Common Stock	Herb	Th
309	*Matucana paucicostata* F.Ritter	Cactaceae	-	Shrub	Ch
310	*Mazus pumilus* (Burm.f.) Steenis	Mazaceae	Japanese Mazus	Herb	Th
311	*Medicago polymorpha* L.	Fabaceae	Bur Clover, Chandansi	Herb	Th
312	*Melaleuca bracteata* F.Muell.	Myrtaceae	Golden Bottle Brush, River Tea Tree	Tree	Ph
313	*Melaleuca viminalis* (Sol. ex Gaertn.) Byrnes	Myrtaceae	Weeping Bottle Brush, Cheel	Tree	Ph
314	*Melia azedarach* L.	Meliaceae	Chinaberry Tree, Bakain, Mahanimb	Tree	Ph
315	*Melilotus indicus* (L.) All.	Fabaceae	Indian Sweet Clover, Ban Methi	Herb	Th
316	*Melocactus levitestatus* Buining & Brederoo	Cactaceae	-	Shrub	Ch
317	*Melochia corchorifolia* L.	Malvaceae	Chocolate Weed, Redweed, Chitrabeej	Herb	Th
318	*Mentha × piperita* L.	Lamiaceae	Pepper Mint, Vilayati Pudina	Herb	H
319	*Mentha aquatica* L.	Lamiaceae	Water Mint	Herb	H
320	*Mentha arvensis* L.	Lamiaceae	Field Mint, Wild Mint, Ban Pudina	Herb	H
321	*Mentha spicata* L.	Lamiaceae	Garden Mint, Pahari Pudina	Herb	H
322	*Miliusa velutina* (Dunal) Hook.f. & Thomson	Annonaceae	Velvety Miliusa, Chopar Chilla, Domsal	Tree	Ph
323	*Millettia peguensis* Ali	Fabaceae	Moulmein Rosewood	Tree	Ph
324	*Millingtonia hortensis* L.f.	Bignoniaceae	Indian Cork Tree, Tree Jasmine, Neem Chameli	Tree	Ph
325	*Mimosa pudica* L.	Fabaceae	Touch-me-not, Chui-mui, Lajwanti	Undershrub	Ch
326	*Mimusops elengi* L.	Sapotaceae	Spanish Cherry, Maulsari, Bakul	Tree	Ph
327	*Mirabilis jalapa* L.	Nyctaginaceae	Four O'clock, Gul Abbas	Herb	Th
328	*Mitragyna parvifolia* (Roxb.) Korth.	Rubiaceae	Kaim, Kadamb, Bhumi Kadamb	Tree	Ph
329	*Momordica charantia* L.	Cucurbitaceae	Bitter Gourd, Karela	Climber	L
330	*Monoon longifolium* (Sonn.) B.Xue & R.M.K.Saunders	Annonaceae	False Ashok, Ashok	Tree	Ph
331	*Moringa oleifera* Lam.	Moringaceae	Drumstick Tree, Sahjan	Tree	Ph
332	*Morus alba* L.	Moraceae	Silkworm Mulberry, Tutri, Toot	Tree	Ph
333	*Morus macroura* Miq.	Moraceae	Himalayan Mulberry, Shahtoot	Tree	Ph
334	*Murraya exotica* L.	Rutaceae	Mock Orange, Badi Kamini	Tree	Ph
335	*Murraya koenigii* (L.) Spreng.	Rutaceae	Curry Leaf, Kadhi Patta, Meetha Neem	Shrub	Ch
336	*Murraya paniculata* (L.) Jack	Rutaceae	Orange Jasmine, Kamini	Shrub	Ch
337	*Naringi crenulata* (Roxb.) Nicolson	Rutaceae	Toothed-Leaf Limonia, Beli	Tree	Ph

Cont...

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S. No.	Botanical name	Family	Common name	Habit	Life Form
338	*Nemesia strumosa* Benth.	Scrophulariaceae	Pouch Nemesia, Capejewels	Herb	Th
339	*Neolamarckia cadamba* (Roxb.) Bosser	Rubiaceae	Burflower Tree, Kadam, Kadamb	Tree	Ph
340	*Nerium oleander* L.	Apocynaceae	Oleander, Kaner	Shrub	Ph
341	*Nicotiana plumbaginifolia* Viv.	Solanaceae	Tex Mex Tobacco, Ban Tamaku	Herb	Th
342	*Nyctanthes arbor-tristis* L.	Oleaceae	Coral Jasmine, Har Singar, Parijat	Tree	Ph
343	*Nymphaea nouchali* Burm.f.	Nymphaeaceae	Blue Water Lily, Neelkamal	Aquatic Herb	G
344	*Ocimum basilicum* L.	Lamiaceae	Sweet Basil, Ram Tulsi, Babui Tulsi	Herb	Ch
345	*Ocimum gratissimum* L.	Lamiaceae	Wild Basil, Clove Basil, Ban Tulsi	Undershrub	Ch
346	*Ocimum kilimandscharicum* Gürke	Lamiaceae	Camphor Basil, Kilimanjaro Basil, Kapur Tulsi	Herb	Ch
347	*Ocimum tenuiflorum* L.	Lamiaceae	Holy Basil, Tulsi	Undershrub	Ch
348	*Oenothera biennis* L.	Onagraceae	Common Evening Primrose	Herb	Th
349	*Oldenlandia corymbosa* L.	Rubiaceae	Diamond Flower, Daman Pappar, Parpatah	Herb	Th
350	*Olea europaea* L.	Oleaceae	European Olive, Olive, Zaitun	Tree	Ph
351	*Oroxylum indicum* (L.) Kurz	Bignoniaceae	Broken Bones Tree, Shyonak	Tree	Ph
352	*Ouret lanata* (L.) Kuntze	Amaranthaceae	Mountain Knot Grass, Gorakhganja	Herb	Ch
353	*Oxalis corniculata* L.	Oxalidaceae	Creeping Wood Sorrel, Tinpatiya	Herb	H
354	*Oxalis debilis* Kunth	Oxalidaceae	Pink Wood Sorrel	Herb	Th
355	*Oxalis pes-caprae* L.	Oxalidaceae	Bermuda Buttercup, Cape Sorrel	Herb	Th
356	*Oxystelma esculentum* (L.f.) Sm.	Apocynaceae	Rosy Milkweed Vine, Dudhiya Lata	Climber	L
357	*Paederia foetida* L.	Rubiaceae	Skunk Vine, Gandhali, Gandha Prasarini	Climber	L
358	*Papaver rhoeas* L.	Papaveraceae	Common Poppy, Field Poppy, Lalpost	Herb	Th
359	*Papaver somniferum* L.	Papaveraceae	Opium Poppy, Afim, Posta, Khash-khash	Herb	Th
360	*Parodia scopa* (Spreng.) N.P.Taylor	Cactaceae	-	Shrub	Ch
361	*Parthenium hysterophorus* L.	Asteraceae	Carrot Grass, Congress Grass, Gajar Ghas	Herb	Th
362	*Passiflora* sp.	Passifloraceae	Lady Margaret Passion Flower	Climber	L
363	*Paulownia tomentosa* (Thunb.) Steud.	Paulowniaceae	Empress Tree, Princess Tree, Foxglove Tree	Tree	Ph
364	*Pelargonium graveolens* L'Hér.	Geraniaceae	Rose Geranium, Rose-Scented Geranium	Undershrub	Th
365	*Peltophorum pterocarpum* (DC.) Backer ex K.Heyne	Fabaceae	Copperpod, Peela Gulmohar	Tree	Ph
366	*Pergularia daemia* (Forssk.) Chiov.	Apocynaceae	Stinking Swallow Wort, Menda Singi, Gadaria Ki Bel	Climber	L
367	*Pericallis × hybrida* (Bosse) B.Nord.	Asteraceae	Cineraria, Florist's Cineraria	Herb	Th
368	*Petrea volubilis* L.	Verbenaceae	Purple Wreath, Sandpaper Vine, Nilmani Lata	Liana	L
369	*Petroselinum crispum* (Mill.) Fuss	Apiaceae	Parsley	Herb	Th
370	*Petunia × atkinsiana* (Sweet) D.Don ex W.H.Baxter	Solanaceae	-	Herb	Th
371	*Phlox drummondii* Hook.	Polemoniaceae	Annual Phlox, Drummond's Phlox	Herb	Th
372	*Phyla nodiflora* (L.) Greene	Verbenaceae	Frog Fruit, Bukkan, Jalbuti	Herb	Th
373	*Phyllanthus amarus* Schumach. & Thonn.	Phyllanthaceae	Gale of Wind, Stone Breaker, Bhui Aonla	Herb	Th
374	*Phyllanthus emblica* L.	Phyllanthaceae	Indian Gooseberry, Amla	Tree	Ph
375	*Phyllanthus fraternus* G.L.Webster	Phyllanthaceae	Gulf Leaf-Flower, Bhuinanvalah, Nunki	Herb	Th

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376	*Phyllanthus reticulatus* Poir.	Phyllanthaceae	Black-berried Featherfoil, Kale Madhu ka	Shrub	Ch
377	*Pilosocereus leucocephalus* (Poselg.) Byles & G.D.Rowley	Cactaceae	-	Shrub	Ch
378	*Pimenta dioica* (L.) Merr.	Myrtaceae	Allspice, Myrtle Pepper, Pimento	Tree	Ph
379	*Piper longum* L.	Piperaceae	Indian Long Pepper, Pipli, Peepar	Climber	L
380	*Pistacia chinensis* subsp. integerrima (J.L.Stewart) Rech.f.	Anacardiaceae	Kakkar, Kakar Singhi, Kakra	Tree	Ph
381	*Pithecellobium dulce* (Roxb.) Benth.	Fabaceae	Sweet Tamarind, Jangal Jalebi	Tree	Ph
382	*Plantago ovata* Forssk.	Plantaginaceae	Blond Plantain, Psyllium, Isabgol	Herb	Th
383	*Platanus orientalis* L.	Platanaceae	Oriental Plane, Chinar	Tree	Ph
384	*Pleurolobus gangeticus* (L.) J.St.-Hil. ex H.Ohashi & K.Ohashi	Fabaceae	Sal Leaved Desmodium, Shalparni	Undershrub	Ch
385	*Pluchea lanceolata* (DC.) C.B.Clarke	Asteraceae	Rasna, Phaar	Herb	Th
386	*Plumbago zeylanica* L.	Plumbaginaceae	White leadwort, Chitrak, Catawar	Undershrub	Ch
387	*Plumeria obtusa* L.	Apocynaceae	White Frangipani, Gulchin	Tree	Ph
388	*Plumeria rubra* L.	Apocynaceae	Red Frangipani, Lal Gulchin	Tree	Ph
389	*Pongamia pinnata* (L.) Pierre	Fabaceae	Pongam Tree, Karanj	Tree	Ph
390	*Populus deltoides* W.Bartram ex Marshall	Salicaceae	Eastern Cottonwood, Poplar	Tree	Ph
391	*Portulaca grandiflora* Hook.	Portulacaceae	Moss Rose, Nonia, Lunia	Herb	Th
392	*Portulaca quadrifida* L.	Portulacaceae	Wild Purslane, Chhota Lunia	Herb	Th
393	*Portulacaria afra* Jacq.	Didiereaceae	Elephant Bush, Dwarf Jade Plant	Shrub	Ch
394	*Primula vulgaris* Huds.	Primulaceae	Common Primrose	Herb	Th
395	*Prosopis cineraria* (L.) Druce	Fabaceae	Khejri Tree, Shami, Khejri	Tree	Ph
396	*Prosopis juliflora* (Sw.) DC.	Fabaceae	Algaroba, Mesquite, Vilayati Babul	Tree	Ph
397	*Prunus domestica* L.	Rosaceae	Plum, Alubukhara, Alucha	Tree	Ph
398	*Prunus persica* (L.) Batsch	Rosaceae	Peach, Adoo	Tree	Ph
399	*Psidium guajava* L.	Myrtaceae	Guava, Amrood	Tree	Ph
400	*Pterospermum acerifolium* (L.) Willd.	Malvaceae	Maple-leaved Bayur Tree, Kanak Champa, Muchkund	Tree	Ph
401	*Pterygota alata* (Roxb.) R.Br.	Malvaceae	Buddha's Coconut Tree	Tree	Ph
402	*Punica granatum* L.	Lythraceae	Pomegranate, Anar	Tree	Ph
403	*Pupalia lappacea* (L.) Juss.	Amaranthaceae	Forest Burr, Bhurat	Herb	Th
404	*Putranjiva roxburghii* Wall.	Putranjivaceae	Putranjiva, Lucky Bean Tree, Putrajeev	Tree	Ph
405	*Pyrostegia venusta* (Ker Gawl.) Miers	Bignoniaceae	Flaming Trumpet, Golden Shower Trumpet	Climber	L
406	*Pyrus communis* L.	Rosaceae	Pear, Nashpati	Tree	Ph
407	*Ranunculus sceleratus* L.	Ranunculaceae	Cursed Buttercup, Jaldhaniya	Herb	Th
408	*Raphanus raphanistrum* subsp. sativus (L.) Domin	Brassicaceae	Radish, Muli	Herb	G
409	*Rauvolfia serpentina* (L.) Benth. ex Kurz	Apocynaceae	Indian Snakeroot, Sarpagandha	Shrub	Ch
410	*Rauvolfia tetraphylla* L.	Apocynaceae	Wild Snake Root, Bada Chandrika	Shrub	Ch
411	*Rebutia arenacea* Cárdenas	Cactaceae	-	Shrub	Ch
412	*Rebutia heliosa* Rausch	Cactaceae	-	Shrub	Ch
413	*Rebutia mentosa* (F.Ritter) Donald	Cactaceae	-	Shrub	Ch

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Table 2. Vascular Plants of the Rashtrapati Bhavan Estate, New Delhi, India

S. No.	Botanical name	Family	Common name	Habit	Life Form
414	*Rebutia pygmaea* (R.E.Fr.) Britton & Rose	Cactaceae	-	Shrub	Ch
415	*Ricinus communis* L.	Euphorbiaceae	Castor Bean, Arandi	Tree	Ph
416	*Rondeletia odorata* Jacq.	Rubiaceae	Cleveland Sunrise, Panama Rose	Shrub	Ch
417	*Rosa chinensis* f. viridiflora (Lavall,e) C.K.Schneid.	Rosaceae	Green Rose, Hara Gulab	Shrub	Ch
418	*Rosa indica* L.	Rosaceae	Indian Fragrant Rose, Desi Gulab	Shrub	Ch
419	*Ruellia patula* Jacq.	Acanthaceae	Spreading Ruellia	Undershrub	Th
420	*Ruellia prostrata* Poir.	Acanthaceae	Bell Weed, Prostrate Wild Petunia	Herb	Th
421	*Ruellia simplex* C.Wright	Acanthaceae	Desert Petunia, Mexican Petunia	Herb	Th
422	*Rumex dentatus* L.	Polygonaceae	Toothed Dock, Jangli Palak	Herb	Th
423	*Salvadora persica* L.	Salvadoraceae	Toothbrush Tree, Mustard Tree, Meswak, Pilu	Tree	Ph
424	*Salvia splendens* Sellow ex Nees	Lamiaceae	Scarlet Sage	Herb	Th
425	*Santalum album* L.	Santalaceae	Indian Sandalwood, Chandan, Safed Chandan	Tree	Ph
426	*Sapindus mukorossi* Gaertn.	Sapindaceae	North Indian Soapnut, Indian Soapberry, Reetha	Tree	Ph
427	*Saraca asoca* (Roxb.) W.J.de Wilde	Fabaceae	Sorrowless Tree, Ashok, Sita Ashok	Tree	Ph
428	*Schleichera oleosa* (Lour.) Oken	Sapindaceae	Ceylon Oak, Lac Tree, Kusum	Tree	Ph
429	*Selenicereus grandiflorus* subsp. donkelaarii (Salm-Dyck) Ralf Bauer	Cactaceae	-	Shrub	Ch
430	*Senegalia catechu* (L.f.) P.J.H.Hurter & Mabb.	Fabaceae	Black Catechu, Cutch Tree, Khair	Tree	Ph
431	*Senegalia ferruginea* (DC.) Pedley	Fabaceae	Rusty Acacia, Kaigar, Safed Khair, Son Khair	Tree	Ph
432	*Senegalia modesta* (Wall.) P.J.H.Hurter	Fabaceae	Amritsar Gum, Phulai	Tree	Ph
433	*Senegalia rugata* (Lam.) Britton & Rose	Fabaceae	Soap-pod, Shikakai	Liana	L
434	*Senegalia senegal* (L.) Britton	Fabaceae	Gum Senegal Tree, Kumttha, Kumat	Tree	Ph
435	*Senna alexandrina* Mill.	Fabaceae	Indian Senna, Hind Senna	Shrub	Ch
436	*Senna occidentalis* (L.) Link	Fabaceae	Coffee Senna, Kasunda	Undershrub	Th
437	*Senna pallida* (Vahl) H.S.Irwin & Barneby	Fabaceae	Twin Flowered Cassia	Tree	Ph
438	*Senna siamea* (Lam.) H.S.Irwin & Barneby	Fabaceae	Siamese Senna, Kassod	Tree	Ph
439	*Sida cordata* (Burm.f.) Borss.Waalk.	Malvaceae	Flannel Weed, Bhumi-Bariara, Rajbala	Herb	Th
440	*Sideroxylon grandiflorum* A.DC.	Sapotaceae	Dodo Tree, Tambalacoque	Tree	Ph
441	*Silybum marianum* (L.) Gaertn.	Asteraceae	Milk Thistle, Mary Thistle	Herb	Th
442	*Simarouba glauca* DC.	Simaroubaceae	Paradise Tree, Lakshmi Taru	Tree	Ph
443	*Sisymbrium irio* L.	Brassicaceae	London Rocket, Asalio, Khubkhala	Herb	Th
444	*Solanum lycopersicum* L.	Solanaceae	Tomato, Tamatar	Herb	Th
445	*Solanum melongena* L.	Solanaceae	Brinjal, Egg plant, Baingan	Undershrub	Th
446	*Solanum nigrum* L.	Solanaceae	Black Nightshade, Makoy, Makoh	Herb	Th
447	*Solanum torvum* Sw.	Solanaceae	Turkey Berry, Bhankatiya, Bhurat	Shrub	Ch
448	*Solanum tuberosum* L.	Solanaceae	Potato, Alu	Herb	G
449	*Solanum villosum* Mill.	Solanaceae	Hairy Nightshade, Red Nightshade, Laal Makoy	Herb	Th
450	*Sonchus oleraceus* L.	Asteraceae	Hare's Lettuce, Peeli Dudhi	Herb	Th

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S. No.	Botanical name	Family	Common name	Habit	Life Form
451	*Spathodea campanulata* P.Beauv.	Bignoniaceae	African Tulip Tree, Rugtoora	Tree	Ph
452	*Spergularia flaccida* (Madden) I.M.Turner	Caryophyllaceae	Flaccid Leaf Spergularia	Herb	Th
453	*Sphagneticola trilobata* (L.) Pruski	Asteraceae	Yellow Dots, Wedelia	Herb	H
454	*Spinacia oleracea* L.	Amaranthaceae	Spinach, Palak	Herb	Th
455	*Stellaria aquatica* (L.) Scop.	Caryophyllaceae	Giant Chickweed	Herb	Th
456	*Stellaria media* (L.) Vill.	Caryophyllaceae	Chickweed, Buchbucha	Herb	Th
457	*Sterculia foetida* L.	Malvaceae	Java Olive, Poon Tree, Jangli Badam	Tree	Ph
458	*Stevia rebaudiana* (Bertoni) Bertoni	Asteraceae	Stevia, Sweet Honey Leaf	Herb	Th
459	*Strychnos nux-vomica* L.	Loganiaceae	Nux Vomica, Poison Nut, Kuchala	Tree	Ph
460	*Swietenia mahagoni* (L.) Jacq.	Meliaceae	Cuban Mahogany, West Indian Mahogany, Mahogany	Tree	Ph
461	*Syzygium cumini* (L.) Skeels	Myrtaceae	Java Plum, Black Plum, Jamun	Tree	Ph
462	*Syzygium jambos* (L.) Alston	Myrtaceae	Rose Apple, Malabar Plum, Gulab Jamun	Tree	Ph
463	*Syzygium nervosum* A.Cunn. ex DC.	Myrtaceae	Rai Jamun, Paiman	Tree	Ph
464	*Tabebuia aurea* (Silva Manso) Benth. & Hook.f. ex S.Moore	Bignoniaceae	Caribbean Trumpet Tree, Yellow Tabebuia	Tree	Ph
465	*Tabernaemontana divaricata* (L.) R.Br. ex Roem. & Schult.	Apocynaceae	Crape Jasmine, Chandni	Shrub	Ph
466	*Tagetes erecta* L.	Asteraceae	Marigold, Genda	Herb	Th
467	*Tamarindus indica* L.	Fabaceae	Tamarind, Imli	Tree	Ph
468	*Tamarix aphylla* (L.) H.Karst.	Tamaricaceae	Athel Pine, Athel Tamarisk, Lal-jhar, Lal Jhau	Tree	Ph
469	*Tecoma castanifolia* (D.Don) Melch.	Bignoniaceae	Chestnutleaf Trumpetbush	Tree	Ph
470	*Tecoma stans* (L.) Juss. ex Kunth	Bignoniaceae	Yellow Bells, Yellow Trumpet, Piliya	Shrub	Ph
471	*Tecomella undulata* (Sm.) Seem.	Bignoniaceae	Honey Tree, Desert Teak, Roheda	Tree	Ph
472	*Tectona grandis* L.f.	Lamiaceae	Teak, Sagon	Tree	Ph
473	*Telosma pallida* (Roxb.) Craib	Apocynaceae	Telosma Vine, Surkilla	Climber	L
474	*Tephrosia purpurea* (L.) Pers.	Fabaceae	Wild Indigo, Sharpunkha	Herb	Th
475	*Terminalia arjuna* (Roxb. ex DC.) Wight & Arn.	Combretaceae	Arjun Tree, Arjun	Tree	Ph
476	*Terminalia bellirica* (Gaertn.) Roxb.	Combretaceae	Belliric Myrobalan, Beach almond, Baheda	Tree	Ph
477	*Thespesia populnea* (L.) Sol. ex Corrêa	Malvaceae	Indian Tulip Tree, Portia Tree, Paras Pipal	Tree	Ph
478	*Thunbergia grandiflora* Roxb.	Acanthaceae	Bengal Trumpet Vine, Blue Sky Flower, Neel Lata	Climber	L
479	*Thymophylla tenuiloba* (DC.) Small	Asteraceae	Dahlberg Daisy, Golden Fleece	Herb	Th
480	*Thymus serpyllum* L.	Lamiaceae	Thyme	Herb	Th
481	*Tinospora cordifolia* (Willd.) Hook.f. & Thomson	Menispermaceae	Heart-leaved Moonseed, Giloy, Guduchi	Climber	L
482	*Toona hexandra* (Wall.) M.Roem.	Meliaceae	Indian Mahogany, Red Cedar, Toon	Tree	Ph
483	*Trachelospermum jasminoides* (Lindl.) Lem.	Apocynaceae	Confederate Jasmine, Star Jasmine	Climber	L
484	*Trianthema portulacastrum* L.	Aizoaceae	Giant Pigweed, Horse-Purslane, Sabuni, Santhi	Herb	Th
485	*Tribulus terrestris* L.	Zygophyllaceae	Puncture Vine, Small Caltrop, Gokhuru	Herb	Th

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S. No.	Botanical name	Family	Common name	Habit	Life Form
486	*Trichosanthes cucumerina* var. *anguina* (L.) Haines	Cucurbitaceae	Snake Gourd, Chachinda, Chichonda	Climber	L
487	*Tridax procumbens* L.	Asteraceae	Tridax Daisy, Coat Buttons, Kanphuli	Herb	Th
488	*Trigonella balansae* Boiss. & Reut.	Fabaceae	Cultivated Fenugreek, Kasuri Methi	Herb	Th
489	*Trigonella foenum-graecum* L.	Fabaceae	Fenugreek, Methi	Herb	Th
490	*Tropaeolum majus* L.	Tropaeolaceae	Garden Nasturtium, Indian Cress	Herb	Th
491	*Tylophora indica* (Burm.f.) Merr.	Apocynaceae	Indian Ipecac, Antamul, Latakshiri	Climber	L
492	*Vachellia leucophloea* (Roxb.) Maslin, Seigler & Ebinger	Fabaceae	White Bark Acacia, Safed Babul	Tree	Ph
493	*Vachellia nilotica* subsp. *indica* (Benth.) Kyal. & Boatwr.	Fabaceae	Gum Arabic, Babool, Kikar	Tree	Ph
494	*Vallaris solanacea* (Roth) Kuntze	Apocynaceae	Bread Flower, Dudhi Ki Bel	Climber	L
495	*Veronica agrestis* L.	Plantaginaceae	Green Field-Speedwell	Herb	Th
496	*Veronica anagallis-aquatica* L.	Plantaginaceae	Water Speedwell, Sada	Herb	Th
497	*Vicia sativa* L.	Fabaceae	Common Vetch, Akra, Matari	Herb	Th
498	*Vigna unguiculata* (L.) Walp.	Fabaceae	Cowpea, Lobiya	Climber	L
499	*Vincetoxicum spirale* (Forssk.) D.Z.Li	Apocynaceae	-	Climber	L
500	*Viola tricolor* L.	Violaceae	Wild Pansy, Heartsease	Herb	Th
501	*Vitex negundo* L.	Lamiaceae	Chaste Tree, Nirgundi	Shrub	Ch
502	*Vitis vinifera* L.	Vitaceae	Grapes, Angur	Climber	L
503	*Volkameria inermis* L.	Lamiaceae	Glory Bower, Binjoan, Sankuppi	Shrub	Ch
504	*Wattakaka volubilis* (L.f.) Stapf	Apocynaceae	Green Milkweed Climber, Nakchhikni	Climber	L
505	*Withania somnifera* (L.) Dunal	Solanaceae	Winter Cherry, Indian Ginseng, Ashwagandha	Shrub	Ch
506	*Wrightia tinctoria* (Roxb.) R.Br.	Apocynaceae	Sweet Indrajao, Kapar, Dudhi, Sveta Kutaja	Tree	Ph
507	*Xerochrysum bracteatum* (Vent.) Tzvelev	Asteraceae	Paper Daisy, Strawflower	Herb	Th
508	*Youngia japonica* (L.) DC.	Asteraceae	Oriental Hawkweed	Herb	Th
509	*Ziziphus mauritiana* Lam.	Rhamnaceae	Indian Jujube, Indian Plum, Ber	Tree	Ph
510	*Ziziphus xylopyrus* (Retz.) Willd.	Rhamnaceae	Kath Ber, Bada Ber	Tree	Ph
Angiosperms (Monocotyledons)					
1	*Acorus calamus* L.	Acoraceae	Sweet Flag, Bach, Vach, Ghorvach	Herb	G
2	*Agave angustifolia* Haw.	Asparagaceae	Caribbean Agave, Narrow-leaved Century Plant	Shrub	Ph
3	*Agave decipiens* Baker	Asparagaceae	False Sisal, Florida Agave	Shrub	Ph
4	*Agave demeesteriana* Jacobi	Asparagaceae	Smooth Agave, Smooth Century Plant	Shrub	Ph
5	*Allium ampeloprasum* L.	Amaryllidaceae	Elephant Garlic, Wild Leek, Levant Garlic	Herb	G
6	*Allium cepa* L.	Amaryllidaceae	Onion, Pyaz, Piyaz	Herb	G
7	*Allium sativum* L.	Amaryllidaceae	Garlic, Lahsun, Lahsan, Rason	Herb	G
8	*Aloe vera* (L.) Burm.f.	Asphodelaceae	Indian Aloe, Gheekunwar, Gwarpatha, Ghritkumari	Herb	Ch
9	*Alpinia calcarata* Roscoe	Zingiberaceae	Cardamon Ginger, Kulanjan	Herb	G
10	*Amorphophallus paeoniifolius* (Dennst.) Nicolson	Araceae	Elephant Foot Yam, Zaminkand, Oal, Suran	Herb	G
11	*Asparagus aethiopicus* L.	Asparagaceae	Ground Asparagus, Basket Asparagus	Undershrub	Th
12	*Asparagus densiflorus* (Kunth) Jessop	Asparagaceae	Foxtail Asparagus, Sprenger's Asparagus, Plume Asparagus	Undershrub	G

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13	*Asparagus racemosus* Willd.	Asparagaceae	Wild Asparagus, Satavar, Shatavari, Shatamuli	Climber	G
14	*Aspidistra elatior* Blume	Asparagaceae	Bar-room Plant, Cast-iron Plant	Herb	Th
15	*Bambusa oldhamii* Munro	Poaceae	Giant Timber Bamboo, Oldham's Bamboo	Woody Grass	Ph
16	*Bambusa vulgaris* cv wamin McClure	Poaceae	Buddha Bamboo, Giant Buddha's Belly	Woody Grass	Ph
17	*Bambusa vulgaris* Schrad. ex J.C.Wendl.	Poaceae	Golden Bamboo, Striped Bamboo, Bans	Woody Grass	Ph
18	*Beaucarnea recurvata* (K.Koch & Fintelm.) Lem.	Asparagaceae	Elephant's Foot, Ponytail Palm	Tree	Ph
19	*Bismarckia nobilis* Hildebrandt & H.Wendl.	Arecaceae	Bismarck Palm	Tree	Ph
20	*Canna* × *generalis* L.H.Bailey	Cannaceae	Canna Hybrid Plant, Common Garden Canna	Herb	Ch
21	*Canna flaccida* Salisb.	Cannaceae	Golden Canna, Bandanna of the Everglades	Herb	Ch
22	*Canna indica* L.	Cannaceae	Indian Shot, Wild Canna, Sarvajjaya	Herb	Ch
23	*Caryota urens* L.	Arecaceae	Fishtail Palm, Jaggery Palm	Tree	Ph
24	*Cenchrus americanus* (L.) Morrone	Poaceae	Pearl Millet, Bajra	Herb	Th
25	*Cenchrus biflorus* Roxb.	Poaceae	Indian Sandbur, Burgrass, Bhurat	Herb	Th
26	*Cenchrus orientalis* (Rich.) Morrone	Poaceae	Oriental Fountain Grass	Herb	Th
27	*Chamaedorea seifrizii* Burret	Arecaceae	Bamboo Palm, Reed Palm, Cane Palm	Shrub	Ch
28	*Chloris virgata* Sw.	Poaceae	Feather Finger Grass, Blue Grass	Herb	Th
29	*Chlorophytum borivilianum* Santapau & R.R.Fern.	Asparagaceae	Musli, Safed Musli, Sweta Musli, Dhavalmuli	Herb	G
30	*Chlorophytum comosum* (Thunb.) Jacques	Asparagaceae	Spider Plant, Ribbon Plant, Musli	Herb	G
31	*Chrysopogon zizanioides* (L.) Roberty	Poaceae	Vetiver, Khas, Khus-khus, Gandar, Jhaund	Herb	Ch
32	*Colocasia esculenta* (L.) Schott	Araceae	Taro, Elephant's Ear, Arabi, Ghuiyan	Herb	G
33	*Commelina benghalensis* L.	Commelinaceae	Bengal Dayflower, Kana, Kankawa	Herb	Th
34	*Cordyline fruticosa* (L.) A.Chev.	Asparagaceae	Hawaiian Ti Plant, Good Luck Plant, Ti Plant	Shrub	Ch
35	*Curcuma aromatica* Salisb.	Zingiberaceae	Wild Turmeric, Aromatic Turmeric, Jangli Haldi	Herb	G
36	*Curcuma longa* L.	Zingiberaceae	Turmeric, Haldi	Herb	G
37	*Cymbopogon citratus* (DC.) Stapf	Poaceae	Lemon Grass, Citronella	Herb	G
38	*Cymbopogon martini* (Roxb.) W.Watson	Poaceae	Palmarosa Grass, Rusha Grass, Gandhej-ghas, Makora	Herb	G
39	*Cynodon dactylon* (L.) Pers.	Poaceae	Bermuda Grass, Doob, Dobri	Herb	H
40	*Cyperus pangorei* Rottb.	Cyperaceae	Mat Sedge, Korai	Herb	G
41	*Cyperus rotundus* L.	Cyperaceae	Common Nut Sedge, Purple Nut Sedge, Motha	Herb	G
42	*Dactyloctenium aegyptium* (L.) Willd.	Poaceae	Crowfoot Grass, Four-finger Grass, Makra	Herb	H
43	*Dianella tasmanica* Hook.f.	Asphodelaceae	Blue Flax Lily, Tasman Flax lily, Variegated Flax Lily	Herb	Th
44	*Digitaria setigera* Roth	Poaceae	East Indian Crabgrass, Kiwai	Herb	H
45	*Dracaena fragrans* (L.) Ker Gawl.	Asparagaceae	Corn Palm, Fragrant Dracaena, Palmillo	Shrub	Ch
46	*Dracaena reflexa* Lam.	Asparagaceae	Song of India, Song of Jamaica, Pleomele	Shrub	Ch
47	*Dracaena reflexa* var. *angustifolia* Baker	Asparagaceae	Silhouette Plant, Rainbow Tree	Shrub	Ch

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48	*Dracaena trifasciata* (Prain) Mabb.	Asparagaceae	Snake Plant, Mother-in-law's tongue, Saas ki Zaban	Herb	Ch
49	*Drimia indica* (Roxb.) Jessop	Asparagaceae	Indian Squill, Jangli Pyaz, Kolkand	Herb	G
50	*Dypsis lutescens* (H.Wendl.) Beentje & J.Dransf.	Arecaceae	Golden Cane Palm, Areca Palm, Butterfly Palm	Tree	Ph
51	*Echinochloa colonum* (L.) Link	Poaceae	Jungle Rice, Shama Millet, Jangli Jhangora	Herb	H
52	*Eleusine indica* (L.) Gaertn.	Poaceae	Indian Goosegrass, Malankuri, Balraja	Herb	H
53	*Epipremnum aureum* (Linden & André) G.S.Bunting	Araceae	Money Plant, Golden Pothos, Ivy Arum	Climber	L
54	*Epipremnum pinnatum* (L.) Engl.	Araceae	Centipede Tongavine, Dragon-tail Plant	Climber	L
55	*Eragrostis tenella* (L.) P.Beauv. ex Roem. & Schult.	Poaceae	Feather Lovegrass, Bharbhusi	Herb	H
56	*Freesia corymbosa* (Burm.f.) N.E.Br.	Iridaceae	Common Freesia	Herb	G
57	*Furcraea foetida* (L.) Haw.	Asparagaceae	Giant Cabuya, Mauritius-hemp	Shrub	Ch
58	*Furcraea selloa* K.Koch	Asparagaceae	False Agave, Maguey, Sword Lily, Wild Sisal	Shrub	Ch
59	*Gladiolus dalenii* Van Geel	Iridaceae	Gladiolus, Dragon's-head Lily, Natal Lily	Herb	G
60	*Gloriosa superba* L.	Colchicaceae	Glory Lily, Flame Lily, Kalihari	Climber	G
61	*Heliconia rostrata* Ruiz & Pav.	Heliconiaceae	Lobster Claw, Hanging Heliconia	Herb	G
62	*Hellenia speciosa* (J.Koenig) S.R.Dutta	Costaceae	Spiral Flag, Spiral Ginger, Kevuk, Keokand	Herb	G
63	*Hymenocallis caribaea* (L.) Herb.	Amaryllidaceae	Caribbean Spider Lily	Herb	G
64	*Iris* × *hollandica* H.R.Wehrh.	Iridaceae	Dutch Iris	Herb	G
65	*Kaempferia galanga* L.	Zingiberaceae	Aromatic Ginger, Lesser Galangal, Chandramula	Herb	G
66	*Lilium* × *asiaticum*	Liliaceae	Asiatic Hybrid Lily	Herb	G
67	*Lilium maculatum* Thunb.	Liliaceae	Lily, See-through Lily	Herb	G
68	*Livistona chinensis* (Jacq.) R.Br. ex Mart.	Arecaceae	Chinese Fan Palm, Fountain Palm	Tree	Ph
69	*Maranta arundinacea* L.	Marantaceae	West-Indian Arrowroot, Tikhor, Tikkor	Herb	G
70	*Monstera deliciosa* Liebm.	Araceae	Ceriman, Swiss Cheese Plant	Climber	L
71	*Musa* × *paradisiaca* L.	Musaceae	Banana, Kela, Kadali	Herb	G
72	*Ophiopogon jaburan* (Siebold) G.Lodd.	Asparagaceae	Lilyturf, Giant Striped Mondo Grass	Herb	G
73	*Ophiopogon japonicus* (Thunb.) Ker Gawl.	Asparagaceae	Dwarf Lilyturf, Mondo Grass	Herb	G
74	*Phalaris minor* Retz.	Poaceae	Dwarf Canary Grass, Lesser Canary Grass	Herb	Th
75	*Phoenix acaulis* Roxb.	Arecaceae	Dwarf Palm, Jangli Chhina	Shrub	Ch
76	*Phoenix roebelenii* O'Brien	Arecaceae	Dwarf Date Palm, Pygmy Date Palm	Shrub	Ch
77	*Phoenix sylvestris* (L.) Roxb.	Arecaceae	Indian Wild Date, Silver Date Palm, Khajur, Khajuri	Tree	Ph
78	*Phragmites karka* (Retz.) Trin. ex Steud.	Poaceae	Tall Reed, Narkul, Nal, Doka-ghas	Herb	Th
79	*Polianthes tuberosa* L.	Asparagaceae	Mexican Tuberose, Tuberose, Rajanigandha	Herb	G
80	*Polypogon monspeliensis* (L.) Desf.	Poaceae	Annual Beard Grass	Herb	Th
81	*Rhapis excelsa* (Thunb.) A.Henry	Arecaceae	Broadleaf Lady Palm	Shrub	Ph
82	*Roystonea regia* (Kunth) O.F.Cook	Arecaceae	Bottle Palm, Royal Palm	Tree	Ph
83	*Saccharum officinarum* L.	Poaceae	Sugarcane, Eekh, Ganna	Herb	Ch
84	*Sansevieria roxburghiana* Schult. & Schult.f.	Asparagaceae	Indian Bowstring Hemp, Bowstring Hemp, Marul	Herb	Ch

Cont...

Table 2. Vascular Plants of the Rashtrapati Bhavan Estate, New Delhi, India

S. No.	Botanical name	Family	Common name	Habit	Life Form
85	*Setaria flavida* (Retz.) Veldkamp	Poaceae	Yellow Watercrown Grass	Herb	Th
86	*Setaria verticillata* (L.) P.Beauv.	Poaceae	Bristly Foxtail, Barchitta	Herb	Th
87	*Sorghum halepense* (L.) Pers.	Poaceae	Aleppo Grass, Baru, Chinna, Jangli Jowar	Herb	Th
88	*Strelitzia reginae* Banks	Strelitziaceae	Bird of Paradise, Crane Flower	Herb	G
89	*Syngonium podophyllum* Schott	Araceae	Arrowhead Plant, Arrowhead Vine	Climber	L
90	*Tradescantia pallida* (Rose) D.R.Hunt	Commelinaceae	Purple Heart, Wandering Jew, Purple Queen	Herb	Th
91	*Tulipa gesneriana* L.	Liliaceae	Didier's Tulip, Garden Tulip	Herb	G
92	*Typha domingensis* Pers.	Typhaceae	Elephant Grass, Small Bulrush, Patera, Pater	Herb	G
93	*Urochloa ramosa* (L.) T.Q.Nguyen	Poaceae	Browntop Millet, Makra, Murat	Herb	H
94	*Urochloa reptans* (L.) Stapf	Poaceae	Creeping Panic Grass, Para Grass, Para Ghas	Herb	H
95	*Wodyetia bifurcata* A.K.Irvine	Arecaceae	Foxtail Palm, Wodyetia Palm	Tree	Ph
96	*Yucca aloifolia* L.	Asparagaceae	Spanish Dagger, Adam's Needle	Shrub	Ch
97	*Yucca gloriosa* L.	Asparagaceae	Adam's Needle, Glorious Yucca	Shrub	Ch
98	*Zea mays* L.	Poaceae	Maize, Corn, Makka, Makai, Bhutta	Herb	Th
99	*Zephyranthes citrina* Baker	Amaryllidaceae	Yellow Rain Lily, Yellow Fairy Lily	Herb	G

of Delhi containing 377 genera and 551 species belonging to 90 families. Dicots were represented by 76 families, 299 genera and 448 species whereas monocots were represented by 14 families, 78 genera and 103 species. Again Mishra et al, (2015b) published a plant list of Delhi including 604 species belonging to 92 families and 399 genera from Delhi, some major families were Fabaceae (44 genera and 80 species), Asteraceae (43 genera and 43 species), Malvaceae (16 genera and 30 species), Amaranthaceae (12 genera 21 species), Apocynaceae, Convolvulaceae, Euphorbiaceae contained 20 species each). Also Mishra et al, ($2015_{c\text{-}d}$, 2019) reported several new plant records from Delhi region.

In present study, the generic diversity shows that *Ficus* L. is the largest genus represented by 15 species in the Rashtrapati Bhavan followed by *Brassica* L. and *Euphorbia* L. (08 each), *Citrus* L. (07), *Bauhinia* L., *Ipomoea* L. and *Solanum* L. (06 each), *Senegalia* Raf. (05), *Dracaena* L., *Jasminum* L., *Mammillaria* Haw., *Mentha* L., *Ocimum* L., *Phyllanthus* L. and *Rebutia* K.Schum. (04 each) respectively. The ten dominant families [Fabaceae (including Mimosaceae, Caesalpiniaceae), Asteraceae, Poaceae, Malvaceae (including Bombacaceae, Sterculiaceae, Tiliaceae), Apocynaceae (including Asclepiadaceae), Asparagaceae, Moraceae, Lamiaceae, Brassicaceae and Bignoniaceae respectively] present in the Flora of Rashtrapati Bhavan have been compared with Maheshwari, 1963 [Gramineae (Poaceae), Leguminosae (Fabaceae), Compositae (Asteraceae), Cyperaceae, Acanthaceae, Euphorbiaceae (including Putranjivaceae), Convolvulaceae, Malvaceae, Amaranthaceae and Scrophulariaceae respectively] (The Flora of Delhi) and Mishra et al, 2015a, [Poaceae, Fabaceae, Asteraceae, Malvaceae, Amaranthaceae, Apocynaceae, Convolvulaceae, Euphorbiaceae, Acanthaceae and Lamiaceae respectively] shows that in present study Fabaceae is the largest family while in study of Maheshwari (1963) & Mishra et al, (2015_a) Poaceae was the largest family.

The vascular plants composition has been analyzed in terms of biological spectrum for the life form and it is compared with the normal spectrum of Raunkiaer (1934). The representation of various life forms in spectrum is Phanerophytes (223), Therophytes (174), Chamaephytes (103), Lianas (54), Geophytes (49) and Hemicryptophytes (17). From Table 1 and Figure 1 it is clear that Phanerophytes constitute the highest percentage (36%) which is less than normal spectrum. The life forms next in importance are Therophytes (28 %), Chamaephytes (16%), Lianas (9%), Geophytes (8%) and Hemicryptophytes (3%). The percentage of Therophytes is two times more than normal spectrum. This is natural since annuals with a short span of 2 to 4 months of life cycle are best adopted to evade the unfavourable period as seeds, which are left in the soil. However, the percentage of Phanerophytes does not exceed the corresponding percentage in the normal spectrum while percentage of Chamaephytes and Geophytes exceeds the corresponding percentage in the normal spectrum. While the percentage of Hemicryptophytes is 8.5 times less than normal spectrum. On the basis of life-forms the phytoclimate is Thero-Chamae-Geo-phytic.

Rashtrapati Bhavan Estate is rich in plant diversity and always looks-green due to occurrence of various cultivated plants. But some parts of this Estate covered with Ridge forest is highly diversified in plant diversity. In present study 620 species of vascular plants belonging to 112 families and 444 genera were reported, out of which 01 Pteridophyte, 10 Gymnosperms and 609 species of Angiosperms were present. Fabaceae (including Mimosaceae, Caesalpiniaceae) is the largest family among Dicots and Poaceae is the largest family of Monocots. Earlier, Maheshwari (1963) published *The Flora of Delhi* and *Illustrations of the Flora of Delhi* in 1966 reported 531 indigenous and naturalized species with detail description of 478 species along with their economic importance. During his study Poaceae was the dominant family followed by Leguminosae (Fabaceae) and Compositae (Asteraceae). Later on Dakshini and Vijayaraghavan (1970), Viswanathan et al, (1982, 1984), Viswanathan and Singh (1986), Sharma and Ahmad ($1990_{a,b}$, 1991), Sharma (1994, 1997 & 2002) reported various new species which were addition to Delhi Flora. Lal et al, (2002) studied aquatic vegetation in and around Delhi. Kumar and Yadav (2005) conducted a detailed study on the grasses of Delhi region, where he reported 128 species (excluding bamboos) belonging to 70 genera, of which 24 species, 1 sub-species and 1 variety belonging to 21 genera were new records for this region. Naithani et al, (2006) explored the plants of Ridges of Delhi wherein he reported 414 species of angiosperms belonging to 270 genera and 80 families. Krishen (2006) reported 252 tree species from Delhi. Singh (2007_a) has published the Trees of Rashtrapati Bhavan with the descriptive remarks and uses of 160 tree species introduced or naturally occurring since the establishment of the Rashtrapati Bhavan Estate in 1929. Singh (2007_b) also published a beautiful pictorial book entitled 'Roses of Mughal Garden' described all the varieties of Roses present in Mughal Gardens. Mishra et al, (2015_a) published list a floral diversity of Delhi containing 377 genera and 551 species belonging to 90 angiosperm families. Again Mishra et al, (2015_b) published a plant list of Delhi including 604 species belonging to 92 families and 399 genera from Delhi. During his study Poaceae was the dominant family followed by Fabaceae and Asteraceae. Also Mishra et al, (2015_{c-d}, 2019) reported several new plant records from Delhi region. Baviskar (2016) published a book entitled 'First Garden of The Republic' described important flora and fauna of Rashtrapati Bhavan. On the basis of life-forms the phytoclimate of Rashtrapati Bhavan Estate is Thero-Chamae-Geo-phytic. Similar study was conducted by Soni et al, (2020) in Gargi College campus, University of Delhi and reported 199 plant species of 172 genera and 69 families were recorded, including 2 pteridophytes, 7 gymnosperms and 190 angiosperms (23% monocots and 77% dicots). Phanerophytes were the most abundant life form that constituted 55.28% of the total flora, followed by therophytes (29.15%), chamaephytes (6.53%), geophytes (5.03%) hemicryptophytes (3.02%), and hydrophytes (1.01%). Grisebach (1838) and Drude (1890) have emphasized the dependence of lifeforms on climate and assessed the role of species in vegetation with special reference to duration of protection to the perennating organs and mode of propagation.

ACKNOWLEDGEMENT

The authors are grateful to Sri Ram Nath Kovind Ji, Honorable President of India for the encouragement and facilities provided for this study. Our sincere thanks go to authorities of the President's Secretariat, New Delhi, for their cordinaton during this study. We are also thankful to Param Pujya Swami Ramdev Ji, Patanjali Yogpeeth, Haridwar for providing research facilities in Patanjali Research Institute, Haridwar.

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Received 06 February, 2022; Accepted 22 May, 2022

Indian Journal of Ecology (2022) 49(3) (SI): 1089-1095
DOI: https://doi.org/10.55362/IJE/2022/3636

Manuscript Number: 3636
NAAS Rating: 5.79

Ethnobotanical Study on Medicinal Plants Used Against Chronic Obstructive Pulmonary Disease by Tribal Healers of Uttarakhand, India

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***Abstract*:** Chronic obstructive pulmonary disease (COPD) is one of the most fatal respiratory diseases and affects millions of people every year globally. According to WHO, more than 3 million people die each year from COPD, an estimated 6% of all deaths worldwide and more than 90% of COPD deaths occurs in low-income and middle-income countries. Modern pharmaceuticals are inaccessible ubiquitously and exert several side effects, therefore it is imperative to investigate the traditional knowledge of indigenous medicinal plants as an alternative to contemporary medicine. This study is a pioneering attempt to document the traditional use of medicinal plants of Uttarakhand for treating respiratory diseases including COPD. A Traditional Healing Practices (THP) survey was conducted in selected regions of Dehradun and Pithoragarh districts, Uttarakhand. A semi-structured questionnaire was developed for interviewing 116 tribal healers among them 27 herbal practitioners had the experience of 3-40 years with COPD patients. A total of 23 medicinal species were documented belonging to 21 genera and 17 families, prescribed against COPD. Twenty medicinal plants were effective against cough and *Bergenia ciliata* & *Zingiber officinale* were frequently used among them. Among these, only 12 plants were used in myriad pharmacological investigations. The present study concluded that most of the medicinal plants exhibited traditional implications as well as evidence-based scientific validation against COPD, while there is a huge scope for the researchers to explore pre-clinical and clinical properties of traditionally used herbs for futuristic investigations.

***Keywords*:** COPD, Ethnomedicine, Pharmacology, Tribal healer, Uttarakhand

The respiratory disease poses a serious threat and significant burden on the global health system which claims approximately 92.5 million disability-adjusted life years (DALYs) in 2016 (Simkovich et al 2019). Many symptoms of respiratory diseases are often left undiagnosed which leads to chronic obstructive pulmonary diseases (COPD). COPD is a dominant global health problem that affects people without gender bias with a lifetime risk of approximately 25% and its rampant pervasiveness is becoming prevalent, particularly in developing countries (Barnes 2013), leading to approx. 6% of total deaths and expected to rise upto 30% in the next 10 years, demanding a serious challenge to scientists and policymakers to fight COPD (WHO 2021). COPD is manifested in patients in the form of air trappings and shortness of breath, leading to scarcity of the amount of oxygen delivered by the lungs in the bloodstream which is expressed in the form of physical exertion (Barnes et al 2015).

Considering the rapid prevalence and severity of COPD on global health, the hour demands to quickly extend and execute research in all the relevant branches of medical science including the traditional medical systems like Ayurveda, Unani, Siddha, and Homeopathy that use natural products mainly derived from plant sources. Tremendous encouragement and acceptance from WHO as well as across the world advocates further research and incorporation of traditional and herbal drugs in the national health care program (Hussain et al 2009, Gulati et al 2018, Mownika et al 2021). The effectiveness of traditional and modern herbal drugs has been equally and scientifically validated. Although many herbal drugs are currently used for the treatment of Asthma & COPD. B2-agonists, methylxanthines, anticholinergics and chromones are having a herbal origin (Mukheriee and Wahile 2006). Many countries like India, China, Sri Lanka, Thailand and Cuba have substantiated and incorporated the traditional system of medicines in their official therapeutic alternatives. Over 2,500 plants species are officially recognized in India for medicinal purposes while over 6,000 plants are estimated to be explored in traditional, folk, and herbal medicines (Jain et al 2018). Many of these medicinal plants are found in Garhwal region of Uttarakhand state in India (Singh and Navneet 2016, Varshney and Lohia 2018). Recently, State Medicinal

Plants Board (SMPB) listed 5662 medicinal plants however, 1642 medicinal species are listed as the medicinal and aromatic wealth of Uttarakhand (SMPB 2014).

Plants and their bioactive molecules are key players in the development of novel drugs (Kumari et al 2018, Balkrishna et al 2021, Sharma et al 2021, Sonam et al 2021, Dhatwalia et al 2021). Herbal remedies have a long history of being used in COPD treatment in Asia, particularly in India, China, and other Asian countries (Guo et al 2006). The Kampo formulation *'hochu-ekki-to*' is given against COPD, in Japan as well as *Ocimum sanctum* for bronchitis and colds in India and *Argemone ochroleuca* is used to treat asthma, cough, pneumonia, and bronchitis in Mexico (Ram et al 2011). India is home to about one third of the total tribal population of the world, comprising 2, 91,903 tribal people in Uttarakhand especially in the Himalayan region (Prakash 2015, Kumar et al 2020, Mir and Sehgal 2021). Five major tribal communities are recognized in this state, namely Tharu, Bhotia, Raji, Jaunsari, Buksa and their health care system relies primarily on traditional knowledge of medical practices and medicinal herbs. Tharu tribe uses the leaves of *Balioselia retusa* (Danti / Vanchura) against asthma, and *Basella rubra* (Poy) and *Cassia tora* (Kasonji) against cold and cough. Bhotia tribes use the juice of *Morus alba* to treat cough and cold. They have also applied a fruit paste made from *Myristica fragrans* on the chest or neck to relieve cough. To treat asthma and chest pain, the tribe Jaunsari uses *Abrus precatorius* (ratti) leaf, seed, and root decoctions. In addition, Jaunsari tribe also uses *Evolvulus alsinoides* (Sankhpushpi) and its flower extracts to treat cough, cold, asthma and bronchitis (Prakash 2015). Raji tribe uses the root juice of binait medicinally for cold, cough and asthma. Raji people also use seed powder with warm water to fight cold (Bhatt et al 2013, Prakash 2015). Vanraji tribes in the Kumaun region of Himalaya use an infusion of the flowers and leaves of *Adhatoda vasica* (vasa) to treat common cold and bronchitis. Similarly, they chew leaves of *Colebrookea oppositifolia* and swallowed juice of the leaves to cure old cough. They roasted *Dioscorea bulbifera* tubers in hot ash and then gave them to sick people with salt (Bhatt et al 2013).

The Himalayas are home to a wide range of medicinal plants and are used in traditional medical practices. Local people with limited financial resources can access traditional medicinal plants found in their regions as an alternative to modern medical facilities. Currently, traditional knowledge about medicinal plants in rural areas is gradually fading and disappearing from the countryside, which is of great concern around the world (Pala et al 2010, Prakash 2015). It is vital to document the ethnomedicinal uses of plants in Uttarakhand by tribal communities to conserve and develop this knowledge (Tewari 2021). In present important medicinal plants used by some tribal communities of Uttarakhand against COPD along with the status of preclinical research are documented.

MATERIAL AND METHODS

Study site and data collection: The survey was conducted from 13 to 18 September, 2020, in the Jaunsari & Buksa region (Vikas Nagar, Tyuni, Chakrata and Kalsi subdivisions) of district Dehradun (30° 18' 59.382" N 78° 1' 55.891" E) and Bhotia region of district Pithoragarh (29° 34' 58.296" N 80° 13' 5.4768" E), Uttarakhand. A semi-structured questionnaire was used for interviewing 116 tribal healers. The questionnaire was designed by the Patanjali Herbal Research Department (PHRD) of Patanjali Research Institute, Haridwar, Uttarakhand, India. The criteria for the selection of tribal healers were a purposive sampling method based on their knowledge and experience regarding traditional medicine. Questionnaires were designed to acquire information about medicinal species used to treat different diseases, morphological parts of the plant used, formulations used, mode of administration, etc. Medicinal plants were identified taxonomically by the taxonomist and botanist of PHRD, were allotted collection numbers and submitted in official herbaria of PHRD.

RESULTS AND DISCUSSION

Taxonomic diversity: The total of 23 medicinal species was identified, belonging to 21 genera and 17 families for treating COPD. The reported information was documented along with their botanical name, local name, family, part used, preparation and application (Table 1). In terms of botanical families, Poaceae (17.39%) was mostly cited, followed by Acanthaceae, Combretaceae and Rosaceae (8.69% each).

Plant parts used and mode of preparation: The foremost often used plant components for the preparation of remedies were root (20%), followed by fruit and rhizome (15% each), leaves (13%), grains (5%), latex and cob axis (5% each), seeds (3%), stem and bark (2% each) (Fig. 1). Preparations from plants were mostly prepared in the form of decoctions followed by powders, extracts, and ashes. Most of the preparation was done with water, but honey was sometimes used as well.

Medicinal plants used against COPD and related diseases: The cough (61%) is most common to be treated among COPD-related diseases, followed by throat diseases (12%), nasal sinus, tonsil (9% each), cold (6%), and asthma (3%) (Fig. 2).

Mechanistic approach of traditionally used plant: The 23 plants used in the treatment of respiratory conditions were analyzed along with mechanisms of action however, only 12 plants were scientifically validated as mentioned in various pharmacological investigations (Table 2).

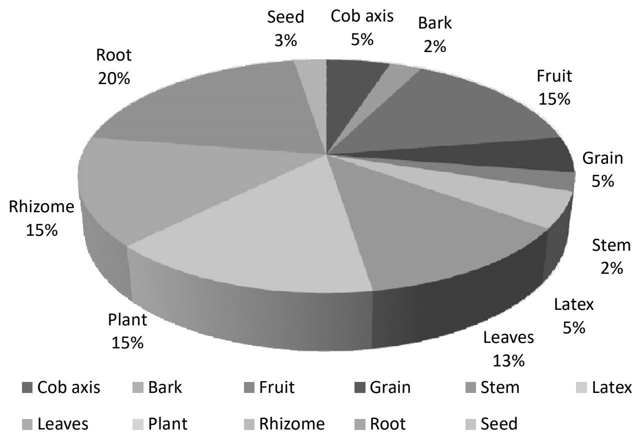

Fig. 1. Plant parts used to treat COPD and related diseases

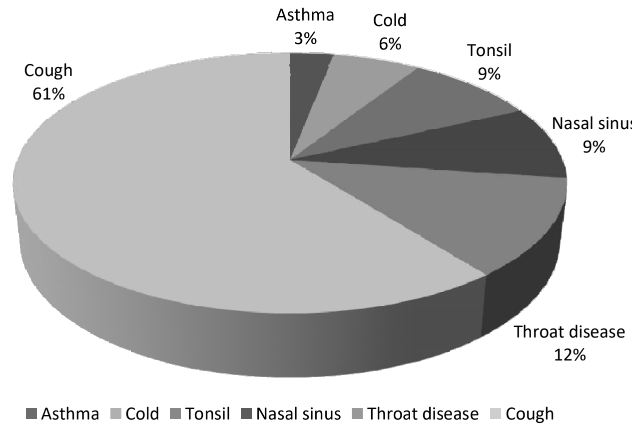

Fig. 2. COPD and related diseases treated by tribal healers of Uttarakhand

Table 1. Medicinal plants used by tribal healers of Uttarakhand against COPD

Disease	Botanical name (Family)	Plant local name	Plant part used	Preparation
Cough	*Ocimum tenuiflorum* L. (Lamiaceae)	Tulsi	Plant, Leaf	Decoction, Powder
	Zingiber officinale Roscoe (Zingiberaceae)	Adrak	Plant, Rhizome	Decoction, Powder
	Zea mays L. (Poaceae)	Makka	Cob axis	Ash with honey
	Zanthoxylum armatum DC. (Rutaceae)	Timbru	Leaf	Decoction
	Terminalia chebula Retz. (Combretaceae)	Harad	Fruit	Powder, Dried to chew
	Justicia gendarussa Burm.f. (Acanthaceae)	KalaVasa	Leaf	Powder
	Piper longum L. (Piperaceae)	Chhoti Pippali	Fruit	Powder
	Justicia adhatoda L. (Acanthaceae)	Basoi	Root, Leaf	Decoction
	Violaodorata L. (Violaceae)	Vanafsa	Leaf	Decoction
	Saccharum officinarum L. (Poaceae)	Gur	Stem juice	Burning
	Terminalia bellirica (Gaertn.) Roxb. (Combretaceae)	Bedara	Bark	Fresh or dry
	Rubus paniculatus Sm. (Rosaceae)	Kavi Achoi	Root	Decoction, fresh or dry
	Potentilla indica (Andrews) Th.Wolf (Rosaceae)	Goli Ousu	Root	Decoction
	Hippophae salicifolia D.Don (Elaeagnaceae)	Seabuck Thorn	Fruit	Decoction
	Swertia chirayita (Roxb.) H.Karst. (Gentianaceae)	Chirayita	Plant	Decoction, Juice
	Bergenia ciliata (Haw.) Sternb. (Saxifragaceae)	Pashanbhea	Root	Decoction, chewed after soaking
Cold	*Polygonatum Verticillatum* (L.) All. (Asparagaceae)	Salam Misri	Seed	_
	Zanthoxylum armatum DC. (Rutaceae)	Timbru	Fruit	Powder
	Eleusine coracana (L.) Gaertn. (Poaceae)	Maduwa	Grain	Powder (cooked)
Throat disease	*Centratherum Anthelminticum* (L.) Gamble (Asteraceae)	Kaljadi	Plant	Powder
	Zingiber officinale Roscoe (Zingiberaceae)	Adrak	Rhizome	Juice after soaking
Nasal sinus	*Calotropis procera (*Aiton) W.T.Aiton (Apocynaceae)	Ak	Latex	Dried
	Oryza sativa L. (Poaceae)	Chawal	Grain	Powder
	Calotropis procera (Aiton) W.T.Aiton (Apocynaceae)	Aak	Latex	Fresh
Tonsil	*Oryza sativa* L. (Poaceae)	Chawal	Grain	Powder
	Musa paradisiaca L. (Musaceae)	Kela	Root	Boiling
	Potentilla indica (Andrews) Th.Wolf (Rosaceae)	Goli Ousu	Root	Decoction
Asthma	*Taxus wallichiana* Zucc. (Taxaceae)	Thunir	Plant	Decoction

Table 2. Mechanism of medicinal plants used by tribal healers of Uttarakhand against COPD

Family	Botanical name	Pharmacological activity	Chemicals	Mechanism of action	References
Asteraceae	*Centratherum anthelminticum* (L.) Gamble	Anti-asthmatic activity	Flavonoids, proteins, saponins, tannins, steroids, glycosides and phenols	*↓ degranulation of mast cells and expressed broncho spasmolytic action	Shah et al (2017)
Acanthaceae	*Justicia adhatoda* L.	Anti-tussive effect	Vasicine and vasicinone	Bronchodilation and mucolytic effects (vasicine)	Barth et al (2015)
		SARS CoV-2 inhibition effect	Alkaloids (vasicoline, vasicolinone, vasicinone, vasicine, adhatodine and anisotine)	#┤ of proteolytic activity of Mpro to block the viral replication	Ghosh et al (2020)
		Anti-tussive effect	Vasicinone and vasicine	Prescence of site of action of Vasicinone and Vasicine (major alkaloids) which suppress coughing by its action on its neuronal system in the medulla.	Kaur et al (2013)
Musaceae	*Musa paradisiaca* L.	Anti-asthmatic activity	Flavonoids, steroids, saponin, terpenoids, lignins, and phenolic compounds	Suppression of antibody production, stabilization of membrane and also #┤ of antigen-induced acetylcholine and histamine	Patro et al (2016)
Lamiaceae	*Ocimum tenuiflorum* L.	Anti-tussive effect	Plant extract	By central action, supposed to be mediated by GABA-ergic system as well as opioid system.	Nadig and Laxmi (2005)
Poaceae	*Oryza sativa* L.	Anti-asthmatic activity	Plant extract [DA-9201]	*↓ total serum and BALF IgE level *↓ eosinophilia in BALF	Lee et al (2006)
		Anti-asthmatic activity	Plant extract	NF-kappaB suppression *↓ airway hyper responsiveness (AHR), *↓ level of IgE in BALF and plasma *↓ IL-2, 4, 13 in BALF along with eosinophils percentage in BALF.	Lee et al (2005)
Piperaceae	*Piper longum* L.	Anti-asthmatic activity	Alkaloid, flavonoids, steroids, glycoside, carbohydrates	H1- receptor antagonistic activity.	Kaushik et al (2012)
Combretaceae	*Terminalia bellirica* (Gaertn.) Roxb	Bronchodilatory effect	Plant extract	Combined blockade of muscarinic receptors and Ca++ influx	Gilaniet al (2008)
Rutaceae	*Zanthoxylum armatum* DC.	Anti-asthmatic activity	Linalool	Blocks the IgE effect by *↓ its serum level *↓ level of total inflammatory cells including neutrophils and eosinophils in the BALF .	Sharma et al (2018)
		Bronchodilatory effects	Plant extract	Blockage of calcium channels and muscarinic receptors antagonists.	Alam and Shah (2019)
Zingiberaceae	*Zingiber officinale* Roscoe	Anti-asthmatic activity	Plant extract	*↓ T2 type cytokines mRNA expression and its protein *↓ the level of serum IgE	Khanet al (2015)
		Anti-asthmatic activity	6-Shogaol	Put down the induction of NF-κB signaling and pro332 inflammatory cytokine as IL-2, TNF α & γ Elevates CD4 cell cAMP concentrations and increase Treg polarization in vitro.	Yocum et al (2020)

Cont...

In some scientific studies, different extracts were used as a whole, while in others, specific phytochemical groups were used. The plants used by tribal healers have shown bronchodilator effects, anti-asthmatic effects, relaxant effects, anti-tussive effects, respiratory ailment preventing effects, SARS-CoV-2 inhibition effects, anti-rhinitis effects and anti-inflammatory action. There are several cellular and molecular mechanisms involved in the expression of these effects including anti-histamine activity & histamine H1-blocking properties, β-adrenergic stimulation activity, opening of potassium channel and inhibition of calcium channel, inhibition of stimulatory nonadrenergic-noncholinergic nervous system (NANC), inhibiting the proteolytic activity of Mpro, decreasing eosinophilia and neutrophils in BALF, bronchodilation & mucolytic effect, anti-tussive effect by central action mediated by opioid and GABA-ergic system, suppression of Th-2 mediated immune response, reduction of degranulation of mast cells and suppression of NF-kappa B (Nuclear factor-kappa β) pathway (Fig. 3).

Table 2. Mechanism of medicinal plants used by tribal healers of Uttarakhand against COPD

Family	Botanical name	Pharmacological activity	Chemicals	Mechanism of action	References
		Anti-asthmatic activity	Hydroalcoholic extract and 6-gingerole	Expression of GATA-3 and ROR-t *↓. T-bet as Th1 transcription factor decrease considerably in the PBMCs	Kardan et al (2019)
		Anti-asthmatic activity	Plant extract	Blockage of plasma memebrane Ca++ channels.	Ghayuret al (2008)
		Anti-asthmatic activity	Gingerol and shogaol	Lowered the Ca21 influx through L-type Ca^{++} channels subside Ca^{++} responses to the Gq-coupled receptor agonists i.e. acetylcholine and bradykinin.	Townsendet al (2013)
Violaceae	*Viola odorata* L.	Antiasthmatic activity	Plant extract	Activated T lymphocytes possibly might be suppressed	Haratiet al (2018)
Gentianaceae	*Swertia chirayita* (Roxb.) H.Karst.	Bronchodilating effect	Crude extract	Ca++ antagonist mechanism	Khanet al (2012)
Saxifragaceae	*Bergenia ciliata* (Haw.) Sternb.	Anti-tussive activity and bronchodilator action	Methanol extract	#┤ histamine and acetylcholine induced contractions on isolated tracheal strips. Delayed the onset time of the histamine and acetylcholine induced bronchospasm	Sinha et al (2001), Kour et al (2019)

*↓- reduced, decreased; #┤ -inhibited, blocked

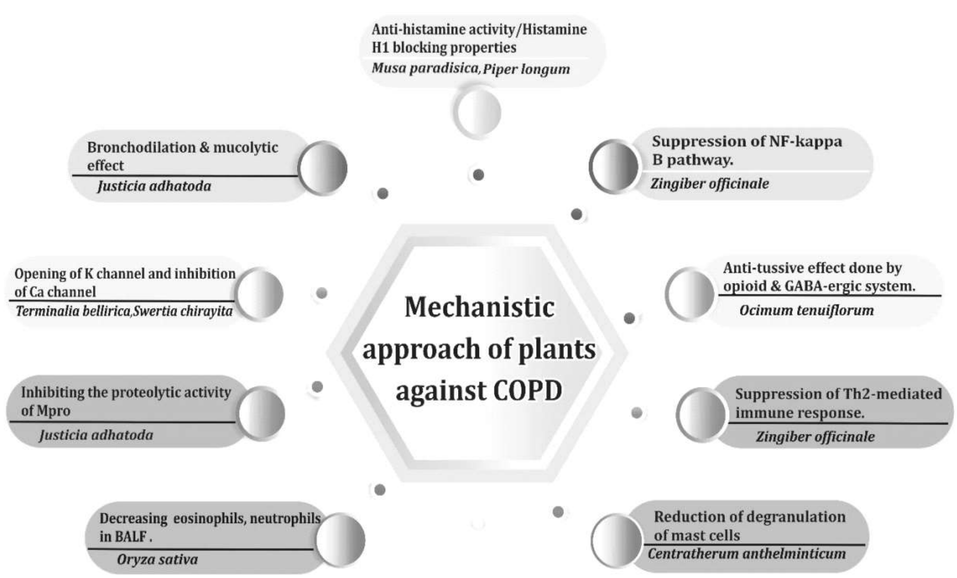

Fig. 3. Mechanistic insight of plants used against COPD-related diseases

CONCLUSION

Uttarakhand is cradle of diverse medicinal plants, which are utilized by the tribal healers for treating variety of ailments. Despite of this, well-documented records of indigenous knowledge via ethnobotanical and ethnomedicine studies are crucial, which is imperative for the conservation of this rich heritage. Tribal healers around the world use several medicinal plants for the treatment of COPD-related diseases, nevertheless the lack of scientific validity of their use is not well explored. Although, there are several surveys conducted in Uttarakhand, India to collect information about the medicinal plants used by the tribal healers without any scientific validation, which is crucial. To support this, the present study documented some important medicinal plants used in some tribal communities of Uttarakhand against COPD, as well as their mode of action, to make them available to mankind. It is necessary to develop specific formulations and dosages of medicinal plants and to conduct preclinical and clinical trials to ensure their safety and efficacy. To elucidate the mechanism of action of the herbs against diseases, further pharmacological or scientific research is needed. This approach would create new avenues to make herbal drugs to treat different respiratory diseases. The finding of this study will not only serve as a benchmark for screening promising COPD plants in Uttarakhand but will also prove useful in conducting phytochemical studies using ethnobotanical indices. Exploration of this indigenous knowledge should be done through the survey in tribes to know the hidden potential of these medicinal plants. Along with this overexploitation of natural resources should be reduced as the non-managed way of using medicinal plants has resulted in the loss of some species in nature. To meet the increasing demand for these plants, it is necessary to conserve them through domestication and cultivation, as well as other ex-situ and in-situ conservation methods, to ensure their long-term viability. Instead of gathering from the wild, a focus on the cultivation of wild forms would assure botanical uniqueness, genetic improvement, quality, and consistency in the wild forms. Such cultivation may need to begin under well-defined settings, such as microclimates that are similar to the niche requirements of different species.

ACKNOWLEDGEMENTS

The authors are thankful to revered Swami Ramdev for his continuous support. The authors are also grateful to Dr. Naval Kapoor, Joint Secretary, MoTA for his continuous support & motivation for tribal development work. Authors are thankful to Dr. Anupam Srivastava for his identification work and to the tribal healers of Pithoragarh and Dehradun of Uttarakhand district for sharing their traditional knowledge and their cooperation during the study.

FUNDING DETAILS

This work is funded by the grant received from the Ministry of Tribal Affairs (MoTA) with project entitled “Tribal Medicine, Healing Practices & Livelihood initiatives in Uttarakhand”.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest regarding this study.

AUTHOR CONTRIBUTIONS

AB designed and supervised the study; BJ and RS conducted the field survey; VA, JS and DS analyzed the data and interpreted the result; JS and DS wrote the manuscript; NR, and AD reviewed and edited the manuscript; all authors approved final version of the manuscript.

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Received 16 January, 2022; Accepted 23 May, 2022

Indian Journal of Ecology (2022) 49(3) (SI): 1096-1102
DOI: https://doi.org/10.55362/IJE/2022/3637

Manuscript Number: 3637
NAAS Rating: 5.79

Conservation Status, Anticancer Compounds and Pharmacological Aspects of *Podophyllum hexandrum* Royle: A Review

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Abstract: *Podophyllum hexandrum* or Himalayan may apple is an endangered medicinal plant. The plant is a major source of anticancer agent, podophyllotoxin. Podophyllotoxin content in *Podophyllum hexandrum* is more (7-15%) as compared with other species, notably *Podophyllum peltatum* (4-8%), the most common species in the American subcontinent. To meet pharmaceutical industry's demand in India, the rhizomes of *Podophyllum hexandrum* are being harvested haphazardly in enormous quantities. Subsequently, the plant is reported as an endangered species in the Himalayan region. This review highlighted various conservation initiatives, and importance of podophyllotoxin and its derivatives. In addition, the plant is reported to be antioxidant, anti-tumerogenic, antimutagenic and radioprotective. Therefore, immediate action should be taken for its conservation through *in vitro* and *in vivo* techniques, and also the genetic diversity of this valuable therapeutic plant must be understood exactly and conserved as early as possible.

Keywords: *Podophyllum hexandrum,* Podophyllotoxin, Conservation, Himalayan may apple, Pharmacology

Plants and their bioactive ingredients are forerunners in the discovery of novel medications (Kumari et al 2018, Balkrishna et al 2021, Sharma et al 2021, Sonam et al 2021, Dhatwalia et al 2021). *Podophyllum hexandrum* is commonly known as 'Aindri', in the Indian Ayurveda. Additionally, it also finds use in traditional Chinese medicine (Wong et al 2000). Further, it is also called as Indian may apple, which is regarded as an endangered medicinal herb of the family *Berberidaceae*. It is mostly found in the Himalayan region, which is the richest source of aromatic and medicinal plant diversity. *P. hexandrum*, an upright, glabrous, succulent herb enjoying moisture and shade, thrives from the Himalayan region at an elevation between 1300-4300 m above sea level. A variety of compounds such as podophyllin, podophyllotoxin, quercetin, 4-dimethypodophyllotoxin, kaempferol, picropodophyllotoxin are present in comprehensive chemical analysis of the *Podophyllum* community (Singh and Shah 1994). The Indian *Podophyllum hexandrum* contains more podophyllotoxin (7-15%) than *Podophyllum peltatum* (the American) with 4-8% (Pandey et al 2007, Qazi et al 2011) adding more importance to the *Podophyllum hexandrum*. The highest content of podophyllotoxin is found in rhizomes. However, it must be considered that *Podophyllum hexandrum*'s podophyllotoxin yield varies greatly with the place of cultivation and the collection season. In addition, the yield is optimum when the plant has entered the stage of flowering (Chatterjee 1952). Due to its efficacy as an anti-mitotic, anticancer, and immunostimulant, podophyllotoxin has gained great importance and high medicinal status (Pugh et al 2001) especially for curing uterine tumors (Macrae and Towers 1984, Richter et al 1987). Semi-synthetic derivatives of podophyllotoxin such as etoposide, etopophos, and teniposide are effective for treating lung cancer, leukemia, and tumors (Schacter 1996, Pandey et al 2007).

The plant has been successfully used in modern allopathic medicine to treat numerous diseases, monocytoid leukemia, and Hodgkin's lymphoma, warts, AIDS-associated Kaposis sarcoma, and cancer of the brain, lung as well as the bladder (Kar 2008, Kokate et al 2009, Shah and Seth 2010). The number of plant products were explored including *P. hexandrum* derived compounds in the search for novel, reliable and non-toxic radio protectants (Goel et al 1998). Interestingly, pre-radiation administration of *P. hexandrum* extracts was found to reduce radiation-induced alternations (Goel et al 2002). Besides this, *P. hexandrum* fruits are used as a cough remedy. While, its resin is a blood purifier, antibiotic medication, and hepatic stimulant, and used to alleviate constipation, skin diseases, and tumors, in addition to its use in the treatment of cancer. Further, it is used to control spindle formation and disperse chromosomes like colchicines (Purohit et al 1998). The plant contains alkaloids, carbohydrates, phenols, glycosides, flavonoids, saponins, steroids, terpenes, and volatile oil (Kumar and Dhillon 2015). Podophyllotoxin is in an increased demand worldwide due to its anti-cancer properties. Complete podophyllotoxin synthesis is an excessive procedure and the availability of natural resource compounds is a key challenge for pharmaceutical players producing these products (Canel et al 2000). At present, the annual supply is projected to be 50-80 tonnes as compared to demand (>100 tonnes). To meet the demand for crude drugs, *P. hexandrum* rhizomes are being harvested on a large scale. As a result, the plant is identified in the Himalayan region as an endangered species. The importance of this valuable plant endeavored us to review the salient morphological features, conservation status concerns, anticancer components, and pharmacological potential of *P. hexandrum*.

Geographical Distribution and Botanical Description

Podophyllum hexandrum is a native to Afghanistan, China, East and West Himalayas, India, Nepal, Pakistan, Tibet and has been introduced into Czechoslovakia as shown in Figure 1 (KewScience-Plants of the World online). *Podophyllum hexandrum* is herbaceous, 15-60 cm tall, erect, glabrous, succulent, with creeping rootstock. Leaves alternate, long petiolate; lamina 6-15 × 3.5-l0 cm, orbicular-reniform, base cuneate, margins serrate, apex acute, pubescent beneath, brownish, palmately divided into 3 broadly elliptic or obovate segments. Flower large, 3.8-5 cm in diameter, white or rose coloured, bisexual; calyx 3-6, petaloid; corolla 6-9; stamen 6; ovules many. Fruit berry, 2.5-5 cm in diameter, elliptic or ovoid, orange or red, with numerous seed as shown in Figure 2 (Grierson and Long 1984, Sharma et al 2012).

Conservation status: *Podophyllum hexandrum* is one of the Indian Himalaya's most threatened plants as per a reported study of 113 taxa for population dynamics in the Western Himalaya (Samant and Pant 2006). According to new IUCN standards, it has been designated as an endangered species (Chaurasia et al 2012). Approximately, 37.3 tonnes of *P. hexandrum* rhizomes were uprooted in the Himachal Pradesh region of India during 1995-2000. The export of *Podophyllum*, its derivatives, and extracts obtained from the wild is prohibited under Schedule 2-Appendix 2 of Export and Import Policy 1997-2002 (Bhardwaj et al 2019). The State Medicinal Plant Board has been formed in every state to stop the illegal collection of medicinal plants from forests (Sharma et al 2012). In addition, forest departments are responsible for maintaining a record of the harvesting, and shipment of endangered species (Bhardwaj et al 2019).

Some policies regarding the promotion, cultivation, and propagation of medicinal plants from forests have been

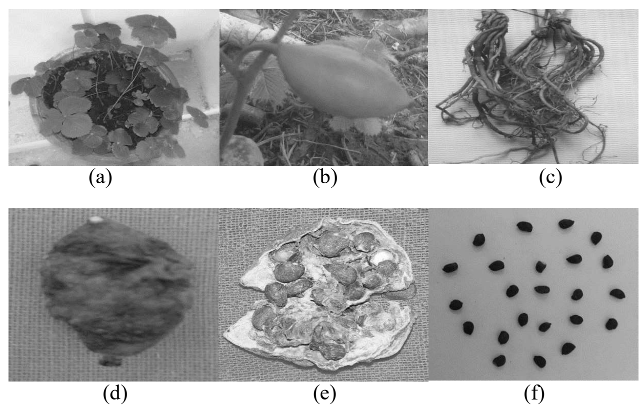


Fig. 2. Salient botanical features of *Podophyllum hexandrum* a) Plant b) Fruit c) Roots d) Dried fruit e) seeds inside fruit f) Separated seeds

Fig. 1. Global distribution of *Podophyllum hexandrum* (Created with mapchart.net)

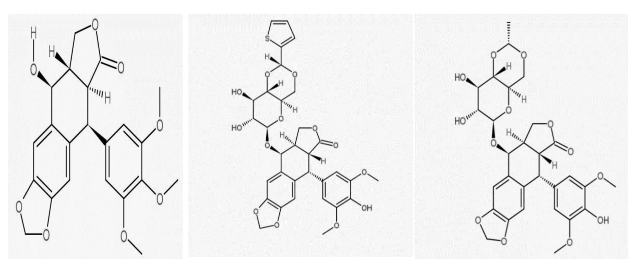
introduced by the government of Himachal Pradesh. These policies are being implemented by government departments/agencies like the department of rural development, Forest department, and Horticulture department by supporting the farmers financially, making them familiar with the market value of medicinal plants, propagation, and transportation of plant materials. The Himachal state government has started herbal gardening in their state, which is also known as 'Vanaspati vanas' with the assistance of the Union Health Ministry. The farmers are trained to cultivate medicinal plants as cash crops through these herbal gardens. Himachal Pradesh has biodiversity conservation biosphere reserves, national parks, and wildlife sanctuaries, and they are spread across all altitudinal zones within the state (HPFD, 2021).The government of Himachal Pradesh has taken steps to conserve "medicinal and aromatic plants" with the desire to become the largest herbal state in the country by 2025 (H.P. Forestry Sector Medicinal Plant Policy 2006). In this regard, so many schemes have been introduced, including Vanaspati Van, Sanjhi Van Yojna, conservation of Green Gold, production of agro techniques, and establishment of medicinal plant nurseries (Ved and Goraya 2008). Several research institutes/universities contribute to the protection and distribution of endangered and threatened species (Samant et al 2007).

In Uttar Pradesh (India) government constituted a committee of experts in 1985 to ban the processing and marketing of all endangered species, *P. hexandrum* was one among them. In addition, it was banned in the Himalayan area of Uttaranchal vide State Govt. Order no. 535/1-9-20 dated January 1986. It was the government's first substantial step toward preserving several valuable plants, including *Podophyllum*, that were under threat of extinction (Shah 1997). In 1994, a major step was taken by the Govt. of India, Public Notice No. 47(PN)/92-97 (www.envfor.nic.in/legis/wildlife/ wildlife9.html) on 30 March 1994. As a result, the export of 56 Himalayan species, including *P. hexandrum*, should be strictly prohibited. The list of these important species has been further amended with notification no. 24(RE-98)/1997-2002 (dgftcom.nic.in/exim/2000/not/not98/not2498.html). A total of 29 species were barred from export, including *P. hexandrum* again (Shah 1997).

In 1997, a market survey was conducted by The Wild Life Trade Monitoring Network India 1997 and found that the endangered medicinal, as well as aromatic plants were being traded at Delhi, Mumbai, Calcutta (Kolkata), and Amritsar (Misra and Jain 1998). *P. hexandrum* is procured only on particular demand from Himachal Pradesh and Jammu and Kashmir in the Delhi and Amritsar markets. In Kolkata trade is quite limited and supplies are made from Sikkim and also illegally from Nepal and Bhutan. According to the 1997-2002 Export and Import Policy, only Kolkata, Cochin, Mumbai, Chennai, Delhi, Tuticorin, and Amritsar ports are allowed to export medicinal plants. Various regulations exist in India to protect endangered plant species, but only a small percentage of the population is aware of them. The important legislation includes the Foreign Trade Act 1992, the export-import policy, the plant fruit and seeds order 1989, and the convention on biological diversity (CBD). There is a separate provision enlisted in schedule VI, in "wildlife protection act 1972" by Govt. of India for endangered and threatened plant species. The Government of India has established a specific provision in Schedule VI of the Wildlife Protection Act, 1972 for endangered and threatened plant species.

Podophyllotoxin and Its Derivatives

Podophyllotoxin, a natural lignan is currently used as an anticancer drug. Podwyssotzki was the first to isolate it from *Podophyllum peltatum* in 1880 (American Podophyllum) (Podwyssotzki 1880). After that, it was isolated from *P. hexandrum* Royle and *P. pleianthum* (Taiwanese *Podophyllum*). The search for natural anticancer drugs stretches back to *Ebers papyrus* in 1550 BC, but the scientific phase of this search was started in the 1950s with the discovery and production of vinca alkaloids, vinblastine, vincristine, and cytotoxic podophyllotoxin isolation (Srivastava et al 2005). Podophyllotoxin from *Podophyllum* sp. is among world's best-known lead anti-neoplastic agents (Wink et al 2005). For the semi-synthesis of etoposide, teniposide, and etopophos (anticancer drugs), podophyllotoxin is the starting material. These compounds have been employed against lung, testicular cancer, as well against some cases of leukemia (Moraes et al 2002). The chemical structures of some of the representative compounds have been depicted in Figure 3. *P. hexandrum* and *P. peltatum* are the plant species that are currently used to extract podophyllotoxin. Indian introduced podophyllin, is a



(a) (b) (c)

Structure source: PubChem https://pubch em.ncbi.nlm.nih.gov; Created using KingDraw http://www.kingdraw.cn/en/index.html

Fig. 3. Chemical structures of representative compounds from *P. hexandrum.* a) Podophyllotoxin; b) Teniposide; c) Etoposide

resin obtained from roots and rhizomes of *Podophyllum* spp. by ethanolic extraction. Podophyllin is comprised of the lignans of podophyllotoxin, α, β-peltatin, and 4'-demethylpodophyllotoxin. In 1820, podophyllin was included in the first Pharmacopoeia of the U.S. as a cathartic and cholagogue. The medicine was excluded from the 12th edition of this Pharmacopoeia that appeared in 1942 because of its extreme toxicity (Horwitz and Lokie 1977). However, in the same year, it was confirmed that the topical application of podophyllin could selectively destroy venereal warts. Further, instead of resin, purified podophyllotoxin is applied against the same (Frega et al 1997, Gross 2001). Pure podophyllotoxin is more effective than podophyllin, quercetin and kaempferol are absent in pure form which is associated with many adverse effects (Von et al 2000, Wiley et al 2002).

Genital warts are very frequent sexually transmitted diseases in the Netherlands that may lead to cervical cancer, and other malignancies (Wiley et al 2002). Podophyllotoxin was found to be an essential component to mitigate sexually transmitted diseases. After that, several glycoside derivatives were developed by Sandoz (Switzerland) to produce more active and less toxic anticancer agents, eventually, etoposide was discovered as a result of this in 1966, which further obtained FDA approval in 1983. To tackle etoposide's poor water solubility, etopophos, or etoposide phosphate, was introduced which gets FDA approval in 1996. Another important podophyllotoxin derivative is teniposide (Imbert 1998). Podophyllotoxin is, therefore, an essential precursor with enormous therapeutic potential.

Mode of Action

The first big move was Kaplan's publication (Kaplan, 1942), explaining the effective use of topically applied podophylline to treat venereal warts (*Condylomata acuminata*). This success resulted in the use of podophyllin against tumor tissues, and the chemical analysis of its components was performed on a broad front at the same time. The next major achievement was the 1946 publication of King and Sullivan (King and Sullivan 1946) revealed the mechanistic basis of podophyllotoxin's action, its cytostatic potential at cell level was close to colchicine, which is a process of suppressing the development of the mitotic spindle that interrupts metaphase during cell division and chromosome clumping (c-mitosis). During the cell cycle (late S or early G2 phases) podophyllotoxin arrested cells and single-strand breaks were observed, which are associated with the interaction of the drug and DNA in HeLa cells. Topoisomerases (Topo) are ubiquitous enzymes that are responsible for solving topological problems that occur during several DNA metabolism activities, such as transcription, recombination, replication, and chromosome division during cell division. The relaxing of supercoiled chromosomal DNA replication is catalyzed by these enzymes, which are classed as Topo I and II. Topo II relaxes DNA by causing transitory double-strand breaks, strand passage, and relegation. Further, this activity necessitates ATP and leads to a two-fold increase in linking number. Topo I's DNA relaxing mechanism requires temporary cleavage of a single strand, unwinding, and relegation. As per existing literature, the primary mechanism of action of the anti-tumor potential of etoposide or teniposide is attributed to their association with Topo II. Etoposide is a semisynthetic derivative of podophyllotoxin, a plant alkaloid. In the late S to G2 phase, this agent blocks cells, and topoisomerase II is the main target. Its attachment with the enzyme-DNA complex

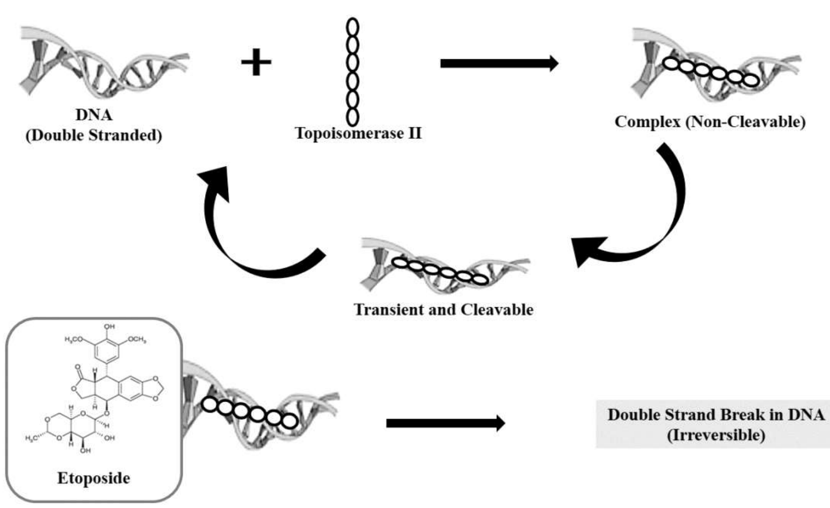


Fig. 4. Mechanism of action of etoposide (Created using biorender.com)

results in the continuity of the complex's transient, cleavable shape and thus makes it vulnerable to irreversible double-strand breaks (Fig. 4). The etoposide is used for the treatment of lung cancer alone and in combination with bleomycin and cisplatin for treating testicular carcinoma (Yousefzadi et al 2010, Nagar et al 2011).

Pharmacological potential of *Podophyllum hexandrum*

Antioxidant activity: The antioxidant activity of ethyl acetate (EAP) and ethanol (EP) extracts of *Podophyllum hexandrum* rhizome and petiole (10 mg mL^{-1}) was investigated using DPPH (2,2-diphenyl-1-picrylhydrazyl) and FRAP (Ferric reducing antioxidant power) assay, with ascorbic acid (88.25% scavenging at 500 µM, and FRAP value 1267.5 µM, respectively) as a positive control. It was observed that DPPH scavenging of EAP and EP of rhizome (90.17 and 94.52%, respectively) was higher than the petiole (68.75 and 77.23%, respectively). Similarly, the FRAP values of EAP and EP rhizome were 1784.09 and 2079.55 µM as compared with the petiole (420.45 and 886.36 µM respectively) (Li et al 2012). The aqueous extract of *P. hexandrum* rhizome was evaluated for antioxidant activity using in vitro assay methods and CCl4 induced toxicity model in mice (in vivo). In the DPPH assay, 90% scavenging was observed at 800 µg/mL, which was comparable to standard vitamin E. Similarly, hydroxyl radical scavenging activity and reducing power of the extract are dose-dependent and are comparable to that of standard catechin and butylated hydroxytoluene, respectively. *In vivo* study revealed that elevated levels of the serum aspartate aminotransferase, alanine aminotransferase, and lactate dehydrogenase were normalized with *P. hexandrum* treatment in rats. *P. hexandrum* aqueous extract decreased the malondialdehyde level to 1.42 from 7.75 nmol/mg protein, and this effect was comparable to vitamin E. Pre-treatment with the extract for 15 days before CCl_4 intoxication enhanced catalase activity significantly. Adding on, the glutathione transferase (GST) activity in the group pre-treated with vitamin E and water extract (50 mg/Kg) was equivalent (Ganie et al 2012). Additionally, methanol and ethyl acetate extracts of *P. hexandrum* along with their isolated active fractionated parts were evaluated for antioxidant activity by using DPPH assay. The results showed that free radical scavenging activity of methanol fraction (40 µg/mL) was 81%, the effect was equivalent to rutoside (85%). However, the activity of the ethyl acetate fraction was lower (45%) (Dar et al 2017).

Similarly, the antioxidant activity of the *P. hexandrum* rhizome water extract was examined using DPPH, superoxide, nitric oxide, and hydroxyl radical scavenging assay. The DPPH scavenging was >75% at 20 µg mL^{-1}, while 57.56% superoxide scavenging was observed at 1 mg mL^{-1}. In addition, >30% inhibition of nitric oxide radicals was observed (0.5 mg mL^{-1}), while in hydroxyl free radical scavenging assay, the extract showed a dose-dependent increase (100-600 µg mL^{-1}) (Arora et al 2010).

Antitumor activity: The water extract of *P. hexandrum* (34.5 mg/Kg body weight, for 15 days) showed anti-tumour effect in Ehrlich ascites tumor (EAT) mouse model evident from tumor doubling time from 1.94-19.1 days (Goel et al 1988).

Anti- mutagenicity: The hexane, methanol, ethyl acetate, chloroform, and water extracts of *P. hexandrum* as well as the fractions of methanol and ethyl acetate extract were evaluated for anti-mutagenicity effect against endosulfan-induced clastogenicity in a piscine model using micronucleus (MN) and chromosomal aberration (CA) test. Endosulfan significantly induced CA frequency and reached 12% at 96 h (Dar et al 2017).

Radioprotective effect: A mouse model was used to evaluate the radioprotective activity of plant extracts. The plant extract was administered (34.5 mg/Kg body weight (b.w.)) to mice before irradiation of 10 Gy. *P. hexandrum* protected mice and its dose-dependent radioprotective properties are comparable to synthetic radioprotective agents such as diltiazem (Goel et al 1998).

The radioprotective effect of semi-purified extract of *P. hexandrum* (intramuscular) in lethally irradiated mice was determined. It was found that extract provided a high survival rate (>90% at 6 mg/Kg b.w.). However, comet assay studies in peripheral blood leukocytes showed that extract administration before irradiation reduced DNA damage score and tail length when compared to the radiation-only group. Furthermore, the spleen cell count after radiation exposure decreased until day 5. In the extract-treated group, the initial count decreased dramatically, but this stage did not prolong. In addition, compared with the control group, after 5 hours of irradiation, >60% decrease was recorded in the thymocytes, and the decline further decreased at a similar rate until day 5. Further, with time thymus was completely degenerated. In the irradiated group pretreated with extract, thymocytes were reduced to day 5, but then they regained their viability within 30 days. These observations indicate that very small doses of extract provide high survival rates, protect DNA, and support rapid immune system replacement (Sankhwar et al 2011).

Similarly, the radioprotective effects of hydroalcoholic materials (HM) extracted from the rhizomes of *P. hexandrum* on gamma radiation (10 Gy) treated mice were evaluated. It was observed that HM normalized the hemoglobin (14.73 g dl^{-1}) and total leukocyte count (TLC) 4166.66 on day 15 as compared to control mice (radiation only). Whereas, the hemoglobin in the radioprotective drug + irradiation group was 21.25% more than control on day 10. In addition, compared with the radiation group, the TLC of the drug + radiation group increased (83.33 times). Further, western blotting studies revealed hemopoietic recovery in irradiated mice evident from overexpression of heme oxygenase 1 and Bcl-2 protein. Therefore, results revealed that the biologically active ingredients of HM play a role in radioprotection by regulating the hematopoietic system (Rajesh et al 2007).

Additionally, aqueous extract (AE) from *P. hexandrum* rhizome was examined for its radioprotective effect by survival analysis, DNA protection ability, anti-hemolytic potential, anti-lipid peroxidation assay. AE application (4-20 mg/Kg b.w., intraperitoneal) before 30 minutes of radiation exposure (10 Gy) showed >80% protection at 8 mg/Kg. Also, it significantly modulated radiation-induced hemopoietic syndrome. Interestingly, 26% supercoiled form (SF) was observed in the irradiated group (250 Gy γ-radiation) as compared to untreated control (pBR322 DNA with 72% SF). The maximum DNA protective effect was noticed at 50 μg mL^{-1} of extract (i.e. 59% of the DNA in the form of SF was retained). Compared with controls, the optimal protection was at 10 μg mL^{-1}. Taking into account that even after radiation exposure extract showed significant anti-hemolytic potential (10-500 μg mL^{-1}). In addition, extract (10-1000 μg mL^{-1}) inhibited almost 90% lipid peroxidation and this effect was comparable to standard gallic acid (Arora et al 2010).

CONCLUSION

For thousands of years, plants have been an important source of medicine. To reduce the burden on the natural population, a vegetative and *in vitro* technique is therefore necessary. Due to application of podophyllotoxin, etoposide, and teniposide against particular types of cancers, the rhizome, and roots of *Podophyllum* species have gained much significance. As a result, there is a noticeable decline in plant populations. Therefore, it is appropriate to provide immediate impetus to generate the reliable traditional mass cultivation protocols of *P. hexandrum* and to urgently maintain its genetic diversity. An alternative strategy for conservation, wherein dependence of plant can be reduced and phytochemicals can be produced *in vitro*. In this regard, plant tissue culture is useful, for the multiplication and survival of species, which are difficult to regenerate and save from extinction. This study will motivate researchers to collect podophyllotoxin from plant tissue culture-derived plants in order to meet the pharmaceutical industry's need.

AUTHOR CONTRIBUTIONS

All authors have made a substantial and direct contribution to the work.

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Received 12 January, 2022; Accepted 22 April, 2022

Indian Journal of Ecology (2022) 49(3) (SI): 1103-1112
DOI: https://doi.org/10.55362/IJE/2022/3638

Manuscript Number: 3638
NAAS Rating: 5.79

Morchella esculenta L.: A Systematic Update on Chemical Components, Biological Activities and Commercial Significance

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Abstract: *Morchella esculenta* L., is a cosmopolitan, edible mushroom, acknowledged as a nutritious species, naturally occurs in the humid and shaded forest habitats. Since ancient times it has been consumed as a dietary and medicinal supplement. In folk medicine, it has got repute for treatment of excessive phlegm, dyspepsia and shortness of breath. Traditionally, it also has promising therapeutic effects on cardiovascular disorders, diabetes, colon cancer and other malignancies. Additionally, in modern times this fungus has immense commercial applications worldwide, and being utilized for the production and formulation of several nutraceutical and other products. In this review, the prior research on *M. esculenta* related to its bioactive components, biological activities, commercial uses, is summarized in a systematic and critical manner. For this purpose, numerous research engine resources, including Pub Med, Google scholar and Science Direct were used. Among numbers of pharmacological activities, the anti-oxidant activity appears to be the most potent activity of *M. esculenta*, followed by anti-microbial, hepatoprotective, enzyme inhibitory and cytotoxic activities. Predominantly, the polysaccharides are responsible for these biological activities. The ethno medicinal and nutritional attributes, commercial significance as well as its emerging potential in nutraceutical and future drug development is also discussed in a comprehensive manner.

Keywords: *Morchella*, Bioactive compounds, Pharmacological profile, Medicinal, Nutraceutical, Commercial applications

Mushrooms have high potential and are widely employed as a source of physiologically beneficial, nutritionally functional food as well as non-toxic medicines due to their distinctive chemical composition. Mushrooms are considered as the main component of gourmet food around the world, mainly for their distinctive flavor, as well as they have been appreciated by mankind as a delicacy, they are prominent for its unique edible and medicinal attributes (Li et al 2018, Shameem et al 2017). Botanically, mushrooms belonging to genus *Morchella* are widely known as 'Morels' or 'True morels'. They are cosmopolitan in distribution and are prevalent in the loamy soil rich in humus, thick coniferous forest, and found naturally in frigid habitats of high altitudes (Raman 2018). True morels (*Morchella* spp.) comprise the most iconic group of wild edible macro fungi with distinctive appearance of honeycomb-like structures (Acay 2021, Wang et al 2019). There are 87 taxonomically accepted species in this genus. Among them, *M. esculenta* L., known as the 'Common morel,' 'Gucchi,' 'Morel,' 'True morel,' 'Yellow morel,' 'Sponge morel,' and 'Morel mushroom,' is the utmost widely recognized *Morchella* species (Li et al 2018). It belongs to the Morchellaceae family of the Ascomycota division. The generic name "*Morchella*" is acquired from the German word "Morel" means "Mushroom," and the specific epithet "*esculenta*" is derived from the Latin word meaning "edible" (Kanwal 2016). This species is a native of North America, Asia, Europe, Australia, China and Japan. It is cherished for its medicinal and nutritional resources owing to the possession of numerous bioactive components including dietary fibers, polysaccharides, vitamins, proteins and other trace elements (Li et al 2019a, Cui et al 2011). Many taxonomists and field mycologists reported numerous chemical compounds from different parts of this mushroom such as fruiting bodies and the mycelia, which have been shown to play a pivotal role in combating varied major gastrointestinal, respiratory illness and so on. Mushroom is highly sought after and cultivated throughout the summer season (March to July) due to its remarkable distinct flavour and nutritional value (Raman 2018). *M. esculenta* is also appreciated economically and socially because of its quite nutritious properties which plays a vital and salutary role for the humankind.

Time to time, many gastronomists as well as science researchers have published valuable studies regarding the diverse aspects of *M. esculenta*. But most of the studies are focused on an individual aspect. Therefore, our main purpose for adopting this approach is to reveal its bio-active components, biological activities, medicinal and therapeutic potential along with its commercial and nutraceutical values in a systematic manner.

MATERIAL AND METHODS

Systematic search strategy: A systematic assessment was undertaken to identify all relevant and published articles which evaluated the aspects of bio-active components, biological activities and medicinal uses by various catalogues such as Google and Science, Direct and PubMed. We gathered the information on the basis of appropriate keywords "*Morchella*", "true morels", "edible mushroom", "bioactive compounds", "pharmacological activities", "medicinal", "nutraceutical" and "commercial applications". To sustain the novelty and authenticity of work, we included only those articles which were in line with our inclusion criteria. A total of 84 articles were retrieved after exclusion of the duplicate manuscripts manually. The systematic assessment was executed in accordance with the preferred reporting items for the systematic review with the help of PRISMA (Fig. 1).

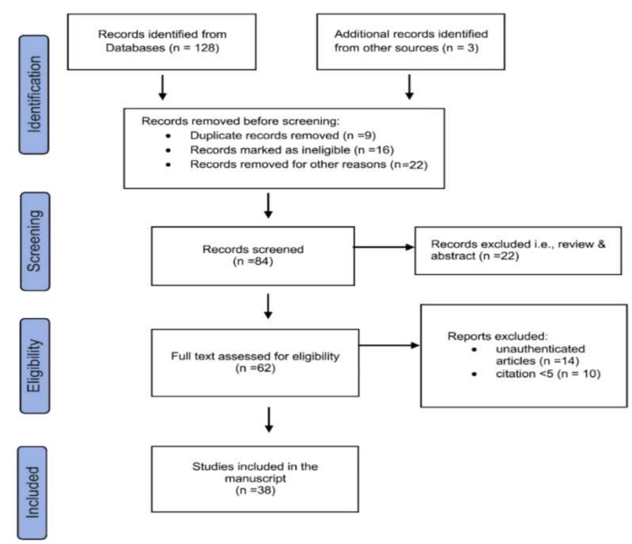
Eligibility criteria, extraction and management of data and quality assessment: On the basis of the following pre-defined eligibility criteria, only full-text, legitimate research-based manuscripts with more than five citations were considered for inclusion. Irrelevant content was eliminated at the very first step of the screening. Abstracts and review articles were also removed through exclusion criteria. Full texts were acquired for all the considered articles (n= 38) to meet the inclusion guidelines Figure 2 represents the quantitative assessment of a total number of articles which consists of pharmacological activities, medicinal uses, photochemistry and economic uses of *M. esculenta*.

Systematic Update

Phytochemistry of *M. esculenta* L.: The characterization of various major classes of secondary metabolites is the basis of pharmacological activities. The classification of major constituents is broadly based on the criteria of content and nature. The present study describes the pharmacological potential of different phytochemicals such as polysaccharides, phenolic compounds, sterols, organic acids, minerals, dietary fibers and trace elements extracted from *M. esculenta*. Moreover, the structural analysis of these phytochemicals with the help of Pub Chem is represented in Table 1 & Figure 3.

Biological activities of *M. esculenta* L.: The multitude of biological studies of *M. esculenta* have been reviewed in this paper and are summarized in Table 2 with the information regarding type of extracts/compounds/fractions, dosage, model and possible outcomes). Out of the total 38 authentic research articles, 26 were selected for pharmacological activities of *M. esculenta* with the help of predetermined inclusion criteria. Through quantitative analysis carried out on the findings published in the selected works, the anti-oxidant activity is found as the dominant activity of this plant, listed in 7 research articles, followed by anti-microbial activity (4 research studies). Moreover, three research articles showed multiple pharmacological properties including anti-oxidant, anti-diabetic and anti-microbial. Further 2 studies each for activities such as anti-inflammatory, anti-tumor, enzyme inhibitory, hepatoprotective, immunomodulatory, protective and 1 study each for other activities such as anti-aging, anti-diabetic, anti-melanogenesis, anti-proliferative, anti-viral, cytotoxic, anti-atherosclerotic, nephrotoxicity and proteolytic activities were examined and reviewed thoroughly.

Therapeutic and medicinal significance: From ancient times, *Morchella* species have been used in traditional Asian medicine for the treatment of various ailments, in China, India, Japan, and Malaysia (Li et al 2018, Kanwal 2016). *M. esculenta* not only has an extensive range of health benefits, but it also



Source: (http://prisma-statement.org/prismastatement/flowdiagram.aspx)

Fig. 1. PRISMA flow diagram for search strategy

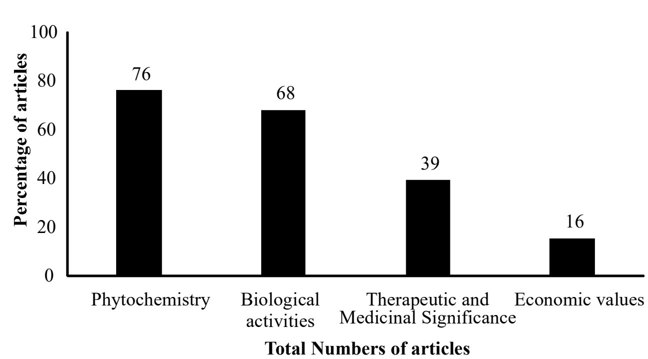


Fig. 2. Quantitative assessment of selected articles

has medical potential, with promising effects on colon cancer, diabetes and cardiovascular disorders. It also manifested several therapeutic applications such as antiseptic, aphrodisiac, emollient, laxative, narcotic and tonic (Li et al 2019a). Furthermore, this true morel helps to boost up the functioning of the immune system (Zhang et al 2018). Despite considerable recent studies to describe various medicinal as well as traditional uses of this mushroom species, the adequate

Table 1. Chemical constituents of *M. esculenta* L.

Major classes	Chemical constituents	References
Amino acid	Alanine, Arginine, Aspartic acid, Cystine, Glutamic acid, Glycine, Histidine, Isoleucine, Leucine, Lysine, Methionine, Phenylalanine, Proline, cis-3-amino-L-Proline, Serine, L-Threonine, Tyrosine, Valine.	Cai et al 2018a, Buscot and Bernillon 1991, (Zhang et al 2019), (Fu et al 2013), (Rossbach et al 2017), (Li et al. 2016), (Lee et al 2018), (Meng et al 2019)
Carbohydrates	Exopolysaccharides, Free sugars, Galactomannan, Heteropolysaccharides, Mannitol, Monosaccharides, Polysaccharide FMP-1, Polysaccharides.	(Raman 2018), (Cai et al 2018b), (Li et al 2018), (Li et al 2019a), (Liu et al 2016), (Ali and Verma 2014), (Cai et al 2018a), (Li et al 2013), (Fu et al 2013), (Cui et al 2011), (Rossbach et al 2017), (Li et al 2016), (Li et al 2017), (Meng et al 2010), (Nitha et al 2013), (Li et al 2019b),(Meng et al 2019), (Lee et al 2018), (Heleno et al 2013), (Wang et al 2021)
Dietary fibers		(Liu et al 2016), (Fu et al 2013), (Cui et al 2011), (Strapáč et al 2019), (Nitha et al 2013), (Meng et al 2010), (Cai et al 2018b), (Meng et al 2019)
Fatty acid	Arachidic acid, Arachidonic acid, Ergosterol (Ergosta153 5,7,22-trien-3-ol), 5-Hydroxymethylfurfural, Docosahexaenoic acid, Docosanoic acid, Eicosadienoic acid, Eicosatrienoic acid, Elaidic acid, Heneicosanoic acid, Heptadecanoic acid, Hexadecanoic acid, α- & γ- Linolenic acid, Myristic acid, Nervonic acid, 1-Octadecanoic acid, (Z,Z)-9,12-Octadecadienoic acid, Oleic acid, Palmitoleic acid, Pentadecanoic acid, Stearic acid, Tetracosanoic acid.	(Bisakowski et al 2000), (Lee et al 2018), (Shameem et al 2017), (Ali and Verma 2014)
Flavonoid	Flavones, Flavonoids, Quercetin.	(Doğan et al 2018), (Zhao et al 2018), (Ali and Verma 2014), (Meng et al 2019)
Minerals	Arsenic, Cadmium, Calcium, Chromium, Copper, Iron, Lead, Manganese, Mercury, Potassium, Selenium, Sodium, Sulphate, Zinc and other trace elements.	(Nitha et al 2013), (Meng et al 2019), (Liu et al 2016), (Fu et al 2013), (Cui et al 2011), (Strapáč et al 2019)
Organic compounds	Citric acid, Citric acid, p-Coumaric acid, Fumaric acid, Lycopene, Malic acid, Organic acid, Oxalic acid, Polyphenol, Quinic acid.	(Ali and Verma 2014), (Li et al 2016), (Raman 2018), (Heleno et al 2013)
Phenolic Compounds	Benzoic acid, Cinnamic acid, Gallic acid, p-Hydroxybenzoic acid, Phydroxybenzoic acids, Protocatechuic acid, Vanillic acid.	(Ali and Verma 2014), (Raman 2018), (Doğan et al 2018), (Zhao et al 2018), (Heleno et al 2013)
Protein	Glycoproteins.	(Li et al 2019a), (Liu et al 2016), (Fu et al 2013), (Cui et al 2011), (Rossbach et al 2017), (Strapáč et al 2019), (Wei et al 2001), (Nitha et al 2013), (Cai et al 2018b), (Meng et al 2019)
Polyol	Quinic acid.	(Ali and Verma 2014)
Sugar acids	Uronic acid, Total sugar.	(Li et al 2019a), (Liu et al 2016)
Steroids	Sterol, Ergosterol derivatives	(Lee et al 2018), (Zhao et al 2018), (Heleno et al 2013)
Terpenoids		(Nitha et al 2013), (Meng et al 2019)
Vitamins	Tocopherols α, γ- & δ	(Liu et al 2016), (Ali and Verma 2014), (Cui et al 2011), (Strapáč et al 2019), (Cai et al 2018b), (Raman 2018), (Heleno et al 2013)
Others	(3β,5α,22E)-Ergosta7,22,24(28)-trien-3-ol, (3β,5α,8α,22E)-5,8-epidioxyergosta-6,22- dien-3-yl β-D-glucopyranoside, (3β,5α,8α,22E,24S)-5,8-epidioxyergosta-6,22-dien-3-ol, (3β,5α,8α,22E,24S)-5,8-epidioxyergosta-6,9(11),22-trien-3-ol, 1-O-octadecanoyl-sn-glycerol, Mycosporin glutamic acid, Mycosporin glutamine,	(Meng et al 2019), (Lee et al 2018)

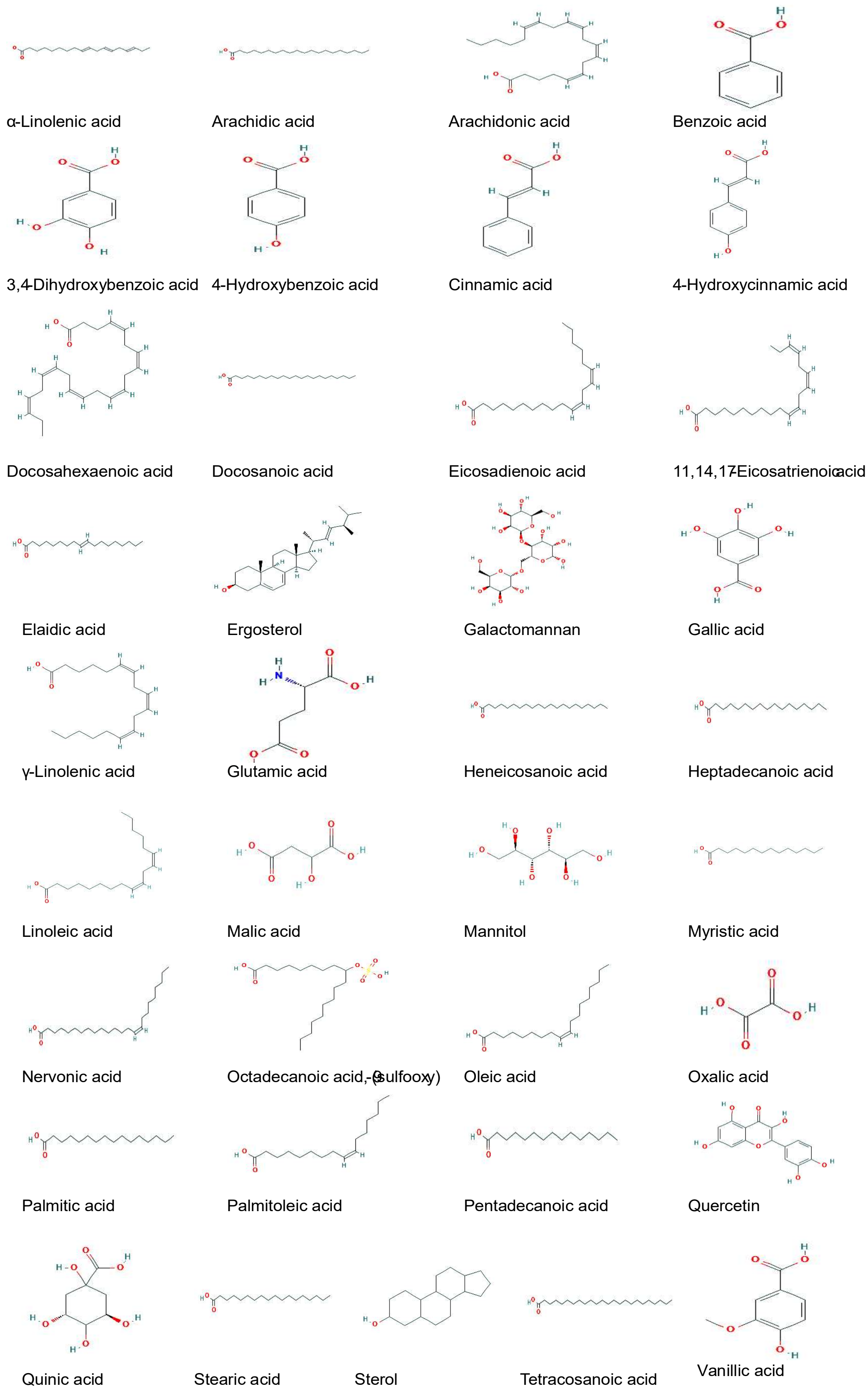


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Fig. 3. Major bioactive components of *M. esculenta* L.

Table 2. Biological activities of *M. esculenta* L.

Biological activities	Extracts/ Fractions/ Compounds	Models/ Cell lines	Assays/Methods	Outcomes	References
Anti-aging activity	Extracellular polysaccharides	Male ICR strain mice	*In vitro* (OH radical, DPPH and reducing power assays); *In vivo* (D-galactose induced mice model)	*In vitro* (EC_{50} = 0.86, 1.09 & 0.481 mg/ml); *In vivo* significantly increased anti-oxidant enzymes activity and function of immune system to reduce oxidative stress.	(Fu et al 2013)
Anti-atherosclerotic activity	Novel polysaccharide (MCP)	LDLR-deficient (LDLR−/−) mice		Decreaseden face and sinus, serum, low-density lipoprotein cholesterol and triglyceride levels and hepatic lipid accumulation.	(Wang et al 2021)
Anti-diabetic activity	*Morchella* protein hydrolysate (MPH), microwave-irradiated (M-MPH) and selenized (Se-MPH) (0.4-2.0 mg/ml)	α-glucosidase and α-amylase enzyme		MPH increased inhibition of enzymes dose dependently.	(Zhang et al 2019)
Anti-inflammatory activity	Total flavones by broth fermentation of co-culture (*M. esculenta* and *Coprinus comatus*)	LPS-stimulated RAW264.7 macrophages		Inhibited nitric oxide (NO) production through the suppression of iNOS expression, TNF-α & IL-1β (pro-inflammatory cytokines) and restrained COX-2 expression.	(Zhao et al 2018)
	Sulfated polysaccharide (SFMP-1) and its derivatives	PM2.5 in rat alveolar macrophage NR8383 cells		Decreased cell death (PM2.5-induced); production (TNF-α & IL-1β); cell apoptosis; iNOS & COX-2 expressions; NF-κB nuclear translation and IκBα phosphorylation.	(Li et al 2019b)
Anti-melanogenesis activity	Polysaccharide FMP-1	B16F10 melanoma cells, Zebrafish larvae.		Decreased melanin contents, tyrosinase activities, expression of MC1R, MITF, TRP-1 and TRP-2, melanogenesis-related proteins.	(Cai et al 2018a)
Anti-microbial activity	Methanol, ethanol and chloroform extracts (30 & 15 mg/ml)	*Escherichia coli, Klebsiella pneumonia* and *Enterobacter aerogenes* etc. and fungal strains	Agar dilution	Maximum ZI 21-28 mm against *K. pneumonia* in methanol and chloroform extracts. And ZI 22.5 & 20 mm for *E. aerogenesand E. coli* in ethanol extract.	(Badshah et al 2012)
	ME-AuNPs	*Escherichia coli, Staphylococcus aureus, Bacillus subtilis* and *Candida albicans*	Micro-dilution	Level of inhibition 0.2210, 0.4421 & 0.1105 mg/ml for *E. coli, S. aureus* and *C. albicans.*	(Acay 2021)
	Ethyl acetate and butanol fractions and morel compounds 1, 2 & 3 (15 & 30 mg/ml)	*Escherichia coli*, *Staphylococcus aureus* &*Pseudomonas aeruginosa*		Butanol fractions showed highest MIC value of 250 μg/ml against *E. coli* & *S. aureus*; MIC values ranged from 250-750 μg/ml for compounds 1 to 3.	(Shameem et al 2017)
	M. esculenta extract	Gram-negative & positive bacterial and fungal strains.	Micro-dilution	MIC ranged between 0.02 to >10 μg/ml. Minimum demelanizing concentration 0.02-0.60 mg/ml against all fungal strains.	(Heleno et al 2013)
Anti- oxidant activity	*M. esculenta* SO-01 exopolysaccharide (25-400 mg /kg b.w.)	Kunming mice (Male)	SOD, GSH-Px and MDA assays for blood, spleen, liver, heart, and kidney	Increased levels of SOD (125, 46.11, 23.33, 12.19 & 41.29%) and GSH-Px (63.24, 63.12, 166.54, 98.01 & 57.68%); ↓ level of MDA (21.80, 67.84, 28.48, 56.15 & 41.62%).	(Meng et al 2010)
	Purified polysaccharides before fermentation (PMPS) and after fermentation (PUPS) (0, 2, 4, 6, 8 & 10 mg/ml)		DPPH, OH radical, Fe metal ions and ABTS radical cation	PMPS exhibited high activity than PUPS among all the assays.	(Li et al 2013)

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Table 2. Biological activities of *M. esculenta* L.

Biological activities	Extracts/ Fractions/ Compounds	Models/ Cell lines	Assays/Methods	Outcomes	References
	Methanol extract from mycelia (0.5-25 mg/ml)		Anti-oxidant activity, reducing power, DPPH radicals and Fe ions chelating effect	EC_{50} values of all the assays were 2.78±0.14, 1.25±0.06, 3.71±0.03 & 3.55±0.01 μg/ml, respectively.	(Mau et al 2004)
	Methanol extract of fruiting body from two location i.e. Serbia and Portugal		Folin–ciocalteu, Prussian blue, DPPH scavenging, β-carotene and Thiobarbituric acid reactive substances (TBARS) assays	Extract (Portugal) increased reducing power in Folin–ciocalteu, Prussian blue (EC_{50} 34.64±1.24, 6.34±0.07 mg GAE/g extract), and DPPH (EC_{50} 6.06±0.05 mg/ml from Portugal had higher); while from Serbia showed higher lipid peroxidation inhibition with EC_{50} 2.39±0.09 & 2.23±0.46 mg/ml in β-carotene and TBARS assays.	(Heleno et al 2013)
	Glycosylated *Morchella* protein hydrolysate (MPH)		ABTS, DPPH, H_2O_2, reducing power, nitrite and superoxide radicals.	MPH increased anti-oxidant activity as comparison to native, heat-treated or xylose mixture of MPH.	(Zhang et al 2018)
	Synthesized *M. esculenta*-based gold nanoparticles (ME-AuNPs) (1, 2, 5 & 10 mg/ml)		DPPH, AA & β-carotene linoleate model system and chelating iron ions.	ME-AuNPs (10 mg/ml) exhibited anti-oxidant capacity of 82, 85 & 77%, respectively for the tested assays.	(Acay 2021)
	Morchella protein hydrolysate (MPH)		ABTS, DPPH, and H_2O_2& reducing power	IC_{50} 71.30, 6030.91, 5276.61 μg/ml & 4.76 μg Vc/mg sample, respectively for the tested assays.	(Zhang et al 2019)
Anti-proliferative activity	MeOH extract, hexane, CH2Cl2, EtOAc & n-BuOH-soluble fractions, and the isolated compounds from fruiting body (100- 600 μM)	A549, H1264, H1299 & Calu-6	WST-1 assay	Cell viability decreased by extract (IC_{50} 0.49-1.35 mg/ml); Hexane-soluble fraction (IC_{50} 205.5-267.9 μg/ml); Compounds 1-O-octadecanoyl-sn-glycerol, (3β,5α,22E)-Ergosta-7,22,24(28)-trien-3-ol and (3β,5α,8α,22E,24S)-5,8-epidioxyergosta-6,9(11),22-trien-3-ol (IC_{50} 171.6-278.0, 169.1-223.8 & 133.1-221.3 μM) in all tested human lung cancer cell lines.	(Lee et al 2018)
Anti-tumor activity	Polysaccharide and its hydrolysate fractions (M1-M4) (200-1000 μg/ml)	HT-29 cells	MTT assay	Fraction M2 significantly increased activity (54.29%) even at 200 μg/ml in 24 h; non-significantlyincreased the inhibitory activity after 48 h up to 800 μg/ml.	(Liu et al 2016)
	Crude Polysaccharides (by *M. esculenta* fermented soybean residue) and its fractions (MP-1, -3 & -4) (50 μg/ml)	HepG2 and HeLa	MTT assay	MP-1 increased growth inhibition effect (68.01%) on HepG-2 cells	(Li et al 2017)
Anti-viral activity	Hexane and ethanol extracts from fruiting body.	efavirenz/FIV reverse transcriptase		Moderate FIV-RT activity with IC_{50} 77.59±8.31 & 211.90±64.25 μg/ml, respectively for both extracts.	(Seetaha et al 2020)
Cytotoxic activity	ME-AuNPs	A549 and HepG2	MTT assay	ME-AuNPs showed activity with IC_{50} 0.548 & 11.672 μg/ml, respectively against both the cell lines.	(Acay 2021)
Enzyme inhibitory activity	Crude extract (FI) and other fractions (a, b, c) isolated from *M. esculenta*	Lipoxygenase activity		12.8% and 2.5-fold increase in purification; Linolenic acid has 29% activity i.e. approx mono-, di- and trilinolein was 11% (enzymic activity has strong specificity); LOX activity has relatively strong affinity 83% (Substrate: Arachidonic acid)	(Bisakowski et al 2000)
	MPH, M-MPH, and Se-MPH (0.6, 1.2, 1.8, 2.4 & 3 mg/ml)			Se-MPH (3 mg/ml) inhibited 41.77% the tyrosinase, that was 1.79- and 1.73-fold high then MPH and M-MPH, respectively.	(Zhang et al 2019)

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Table 2. Biological activities of *M. esculenta* L.

Biological activities	Extracts/ Fractions/ Compounds	Models/ Cell lines	Assays/Methods	Outcomes	References
Hepatoprotective activity	Aqueous-ethanolic extract from mycelia (250 & 500 mg/kg b.w.)	Ethanol and CCl_4 induced elevated GOT, GPT and ALP (liver function enzymes) in male Wistar rats serum		Decreased GOT, GPT & ALP dose dependently; Restored the depleted levels of antioxidants subsequent to ethanol and CCl_4 challenge as compared to 100 mg/kg p.o. Liv 52 with CCl_4 (control).	(Nitha et al 2013)
	ME from fruiting body	Inflammatory factors C57BL/6 mouse		Decreased levels of kappa-B kinase α/β (phosphorylated nuclear factor);Decreased kappa-B α & kappa-B p65 (nuclear factor); alcohol-induced imbalance in prooxidative and anti-oxidative signaling as indicated by upregulation of superoxide dismutase-1 & -2, catalase, hemeoxygenase-1 & -2 and downregulation of kelch-like ECH-associated protein.	(Meng et al 2019)
Immunomodulatory activity	Crude Polysaccharides (by *M. esculenta* fermented soybean residue) and its fractions (MP-1, -3 & -4) (0-100 μg/ml)	LPS		MP-3 & -4 increased proliferation ratio of 313.57 & 190 %, respectively at 25 μg/ml concentration; All polysaccharides increased NO production in macrophages; MP-3 displayed the potent phagocytosis effect on macrophages with absorbance of 0.44 μM at 50 μg/ml.	(Li et al 2017)
	Water-soluble polysaccharide, MEP and its fractions (MEP-I & -II) from mycelium (0-60 mg/kg)	Mice		MEP increased immune-stimulatory activity, with selectively activated T cells, purified lymphocytes; stimulated splenocyte proliferation and improved the level of NO.	(Cui et al 2011)
Nephrotoxicity	Aqueous-ethanolic extract from mycelia (250-500 mg/kg b.w.)	Swiss Albino mice		Decreased serum urea and creatinine;increased SOD levels and restored the MDA and GPx	(Nitha and Janardhanan 2008)
Protective activity	Polysaccharide (FMP-1) from fruiting body *In-vitro* (50 to 400 μg/ml);*In vivo* (50, 100 & 200 μg/ml)	*In-vitro* (Hydroxyl, DPPH and superoxide radicals, reducing power);*In-vivo* (Zebrafish embryos)		*In-vitro*increased scavenging activity with IC_{50} 74.26, 119.32 & 161.49 μg/ml, respectively and reducing power 0.84 at 400 μg/ml; *In-vivo* significantly protect AAPH-induced oxidative damage in zebrafish embryos with rates of 77.33, 83.67 & 90.67%, respectively.	(Cai et al 2018b)
	Polysaccharide (FMP-1) from fruiting body (50, 100, 150, 200, 250 & 300 μg/ml)	A549 cells		Decreased Caspase-3 release and H_2O_2-induced cytochrome C to inhibit cell apoptosis by MDA and ROS level reduction and cellular oxidative stress through PI3K/AKT pathway; increased enzymatic activities of SOD and T-AOC.	(Li et al 2018)
Proteolytic activity	Water, phosphate-buffered saline (PBS) extract and a suspension (200 mg d.w. of spruce in PBS solution)			Increased non-specific proteolytic activity in the PBS fungal suspension of 22.9 mg trypsin/kg d.w., followed by PBS and water extract (13.6 & 10.94 mg trypsin/kg d.w.)	(Strapáč et al 2019)

knowledge of many other remedial uses is still unknown and further investigation on the morels will be required in terms of medicative aspects. The ethno medicinal uses of this species, as published by various authors are summarized in Table 3.

Economic values of *M. esculenta* L.: Since ancient times, the morels have been regarded as having great economic value. Because of their delicious flavor, the consumption of this morel is considerably high throughout the globe. It also forms a well-known mushroom in terms of edibility, medicinal and therapeutic attributes to humankind. Multi-dimensional applications of *M. esculenta* have been demonstrated in Figure 4.

Table 3. Ethno-medicinal uses of *M. esculenta* L.

Major disorders	Indications	References
Respiratory disorders	Shortness of breath, excessive phlegm, excessive sputum, cough and cold.	(Cui et al 2011), (Fu et al 2013), (Lee et al 2018), (Wang et al 2021)
Gastrointestinal disorders	Stomach and gastrointestinal problems, indigestion.	(Raman 2018), (Cui et al 2011), (Fu et al 2013), (Lee et al 2018), (Sulaiman et al 2020)
Immunity and general health	General debility, weak immune system.	(Ali and Verma 2014), (Raman 2018), (Wei et al 2001), (Pfab et al 2008)
Vulnerary	Wounds	(Acay 2021)

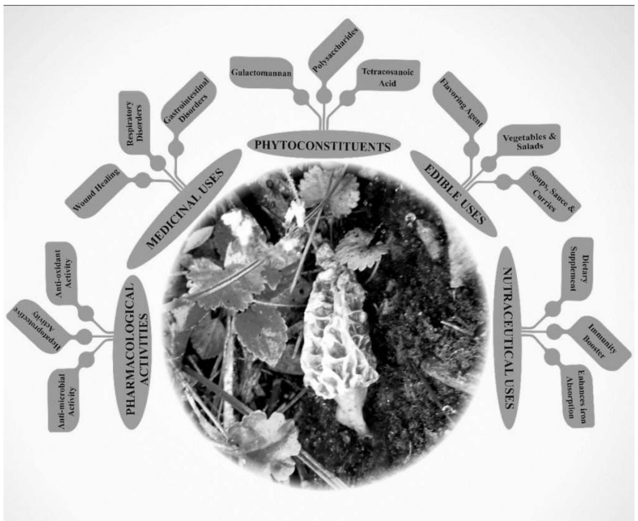

Fig. 4. Applications of *Morchella esculenta* L. (Image is an unpublished image of author)

Edible and nutritional significance: The specific epithet of the name *Morchella esculenta* itself described its edible attributes. Ethno-botanically, at many places in India and Nepal, this mushroom is placed near the traditional cooking stove for slight fermentation. Alternatively, it can be kept in sunlight. Thereafter, fruiting bodies are fully dried in the sun and they can be stored for future consumption in this form. This mushroom is a saprotroph that is used as vegetable due to its flavor and quality and considered equivalent to meat. It is known as *Gucchi* in the Punjab state of India (Kanwal 2016). It is edible as directly in diet, as a soup and also as flavoring agent (Ali and Verma 2014, Nitha and Janardhanan 2008). This morel is regarded for its health-promoting effects, pertinacious edible taste and quality. Additionally, this mushroom includes carbohydrates (4.25 g), some lipids, and proteins (1.62 g), as well as essential amino acids, which make it a good source of proteins (Ali and Verma 2014).

Commercial significance: The mushroom is one of the most nutritious, palatable and tasty foods known throughout the globe. It has lots of commercial uses which are aptly explained by many researchers and gastronomists in their studies. Additionally, fresh as well as dried fruit bodies of this species are consumable. They can be easily stored and packed, to be used for the future consumption. Due to its specific growing requirements, its cultivation is difficult, the labor expenses involved in its cultivation, harvesting and processing are very high; therefore, this morel is one of very expensive mushrooms. It is estimated that about 225 million tons of dried morel is traded internationally every year. Like all forms of morels, *M. esculenta* is one of the extremely culinary important and most valued of all edible mushrooms.

CONCLUSION

Many scientific researchers have described several biological activities of this mushroom. However, none of them described its harmful or toxicological effects. Consequently, a lot of in-depth future investigations on the toxicological aspects of this edible mushroom can be carried out by researchers. Besides, very few studies have been carried out related to its medicinal uses, as became evident during perusal of literature for this review work, and as described in this manuscript. It is thus recommended that further studies should be conducted on its medicinal properties. On the basis of this scientific data available, this species can be considered as edible rather than toxic as no toxic phytochemicals have been reported till date from this mushroom. In light of these findings, further studies to evaluate the toxicological aspects of this mushroom will be a concern. The above data, which was gathered over the last five years, probably sufficiently reveals significant aspects of *M. esculenta* in a comprehensive and methodical manner, yet further studies on many aspects are worth undertaking.

AUTHOR CONTRIBUTIONS

All authors have made a substantial and direct contribution to the work.

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Received 25 December, 2021; Accepted 09 May, 2022

Indian Journal of Ecology (2022) 49(3) (SI): 1113-1121
DOI: https://doi.org/10.55362/IJE/2022/3639

Manuscript Number: 3639
NAAS Rating: 5.79

Effect of Solvents Extraction on Chemical Profile and Biological Potential of *Isodon coetsa* Seeds

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Abstract: *Isodon coetsa* is a perennial medicinal herb of *Lamiaceae* family. Traditionally, root and leaf juices have been reported to treat fever and gastrointestinal disorders. The present study dealt with phytochemical screening and biological potential characterization of *I. coetsa* seeds. The results showed the presence of a higher quantity of secondary metabolites in the methanolic extract of seeds (ME). The antioxidant activity through DPPH analysis was higher in ethyl acetate extract of seeds (94.58% scavenging at 40 µg mL^{-1}) as compared to other extracts. The antimicrobial assays showed the higher antimicrobial potential of ME followed by chloroform extract of seeds (CE) against tested bacteria and fungi with agar disk diffusion method, food poison method, and MIC. The GC-MS analysis of chloroform seed extract revealed octadecanoic acid, 2-(2hydroxyethoxy) ethyl ester (33.75%); dimethylsulfoxonium formylmethylide (21.40%); 9,12,15-octadecatrienoic acid (Z,Z,Z) (12.12 %); 12,15-octadecatrienoic acid, methyl ester, (Z,Z,Z) (7.17%); 9,12-octadecadienoic acid (Z,Z) (6.75%), and hexadecanoic acid, methyl ester (3.69%) as major chemical constituents, whereas methanolic extract of seeds was characterized with bicyclo[2.2.1]heptan-2-one,1,7,7-trimethyl (49.93%); phenol,2-methoxy-3-(2-propenyl) (14.63 %); 9,12,15-octadecatrienoic acid, (Z,Z,Z)- (9.63%); caryophyllene oxide (2.57%), and caryophyllene (2.46%). The present study reported good antioxidant and antimicrobial potential of *I. coetsa* seeds and thus it can be explored further as a source of natural antioxidants and medicinally important phytocompounds for utilization in food as well as pharmaceutical industries.

Keywords: *Isodon coetsa,* Phytoconstituents, Antioxidants, Antimicrobial activity, Gas chromatography/mass spectrometry

Plants with medicinal values have been used for the cure of several diseases since prehistoric times. Their biological potential as well as role in the treatment of various diseases was well documented with the whole plant and sometimes with plant components such as leaves, stems, roots, seeds, and barks, etc. (Petrovska 2012, Kumari et al 2018, Dhatwalia et al 2021, Sharma et al 2021, Balkrishna et al 2021, Sonam et al 2021). Leaves, roots, rhizome, and barks are the most common herbal components in the traditional medicinal system. Seeds are the nutrient powerhouse and are generally utilized for daily food and nature has developed them as a reproductive unit (Rindt 2008). Because of their high nutrient value, they are used to reduce blood pressure, cholesterol, and blood sugar, etc. (Marwat et al 2011) and also carry medicinal properties like anti-inflammatory, diuretic activities, etc. (More et al 2013, Afshari et al 2016). The genus *Isodon* formerly known as *Rabdosia* is one of the major group of Angiosperms. More than 150 species of this genus are distributed worldwide throughout tropical and subtropical Asia and southwestern China (Sun et al 2006). The most common species of the genus *Isodon* are *I. rubescens*, *I. ternifolia*, *I. lophanthoides,* and *I. megathyrsa*. These species have been documented in the Chinese traditional medicine system for the cure of diseases like gastrointestinal and respiratory bacterial infections, enteritis, jaundice, inflammation, and cancer, etc. (Sun et al 2006,Park 2011). Among them, *I. coetsa* (Buch.-Ham. ex D. Don) Kuso (syn. *Plectranthus coesta* Buch.-Ham. ex D. Don) is a medicinal perennial herb mainly distributed in Tropical and Subtropical Asia. The plant is native plant of Bangladesh, Nepal, India, China, Myanmar, Philippines, Jawa, Sri Lanka, Sumatera, and Thailand (KewScience-Plants of the World online 2021). Morphologically, the plant is a perennial herb with opposite ovate or ovate lanceolate leaves and lavender-blue cymes bearing flowers arranged in spreading panicles. This species can be easily differentiated by its thinner leaves, sub-equal lobes, and strongly decurved corolla tube (The Plant List 2013). Traditionally, the roots and leaf juices of *I. coetsa* are used for the cure of fever and gastrointestinal disorders (Sun et al 2006). Additionally, antibacterial and anticancer activities of leaves of *I. coetsa* are also reported in the literature (Sun et al 2006, Zhao et al 2011, Xu et al 2012).

Although none of the literature available on the traditional medicinal property of seeds of *I. coetsa*, therefore, the current investigation was focused to evaluate the phytochemicals and biological properties of the unexplored part (seeds) of the *I. coetsa*. The seeds of *I. coesta* are morphological very much similar to the seeds of *Ocimum* species reported to have medicinal value.

MATERIAL AND METHODS

Seed Source and Seed Extracts Preparation

The seeds of *I. coetsa* were procured from Dr. Y. S. Parmar University of Horticulture and Forestry, Nauni, Solan (H.P.). For the preparation of seeds extracts, 20 g of *I. coetsa* seeds were converted to a coarse powder using an electric grinder and with the cold maceration method, the coarse powder was then extracted using different solvent systems viz., methanol, ethyl acetate, chloroform, pet ether followed by filtration using Whatman filter paper no. 1 (Kumar et al 2018, Kumar et al 2020). All crude seed extracts were dried at room temperature, labeled as methanol seeds extract (ME), ethyl acetate seeds extract (EE), chloroform seed extract (CE), and petroleum ether seed extract (PE), and stored at 4ºC for further use.

Quantitative Determination of Phytochemicals

Estimation of alkaloids: The alkaloids content in the various seeds extracts of *I. coetsa* was checked following the method of Harborne(1973). The crude seed extract (1g) was treated with 100 mL of acetic acid in ethanol (1:9) and covered with aluminum foil. The solution was kept as such for 4 hours, filtered, and kept on a water bath (60ºC) until the volume is reduced by 1 quarter. The ammonium hydroxide (concentrated) was added dropwise to the extract for complete precipitation. After settling down, the solution was filtered and precipitates were collected, washed with ammonium hydroxide (diluted), and filtered again. The obtained alkaloid residues were dried, weighed, and expressed in percentage.

Estimation of flavonoids: The flavonoids content of *I. coetsa* seeds were checked spectrophotometrically using the method of Chang et al (2002)**.** The seed extract (100 mg) was mixed with methanol (4.5 mL) and to the mixture, 0.1 mL of aluminum chloride (10 %) and Sodium acetate (1M) solutions were added. Absorbance was taken after 30 min at 415 nm. The flavonoids content was computed from the rutin (RUT) calibration curve and represented as mg RUT/g of extract.

Estimation of terpenoids: The total terpenoid content of seeds of *I. coetsa* was calculated as per the method of Ghorai et al (2012). To 100 mg of the seed extract, chloroform (3 mL) was added and mixture was thoroughly vortexed and left for 3 min. To the solution concentrated H_2SO_4 (200 µL) was added. The solution was then incubated for $1^{1/2}$-2 hours at room temperature in dark condition and reddish-brown precipitates were formed after incubation. The supernatant was decanted carefully and to the precipitates, 3 mL of methanol (95%) was added and until all the precipitates completely dissolved in methanol the solution was vortexed thoroughly. The absorbance was measured at 538 nm. Terpenoids were calculated from linalool (LIN) calibration curve and expressed as mg LIN/g of extract.

Total tannin content: The total tannin content was estimated using Tambe and Bhambar (2014) method. To 100 mg of the crude extract distilled water (7.5 mL) and Folin-Ciocalteu phenol reagent (0.5 mL) were added. The 1 mL of Na_2CO_3 solution (35%) was added to the mixture and again diluted with distilled water (10 mL). The mixture was dissolved properly and kept for 30 min at room temperature. The standard solutions of Gallic acid (20-100 µg/mL) were prepared and absorbance at 725 nm was measured. The total tannin content was further calculated from the calibration curve of Gallic acid (GAE) and represented as mg GAE/g of extract.

Saponins content: The saponins content of *I. coetsa* seeds was determined following the procedure of Madhu et al (2016). The seed extract (100 mg) was added to 2 mL of vanillin solution (1g of vanillin in 70 mL of ethanol). To this solution, 2 mL of sulfuric acid solution (72 %) was added, properly mixed and the solution was heated at 100ºC using a water bath for 10 min. Absorbance was recorded at 544 nm. The diosgenin (DIO), as a standard material was used and saponins content was measured from the diosgenin calibration curve, and presented in mg DIO/g of extract.

Total phenolic content: Total phenolic content present in the seeds of *I. coesta* was calculated using the Folin Ciocalteu reagent method given by McDonald et al (2001). Briefly, from the stock solution (100 mg extract in 9 mL distilled water), 1 mL was taken, mixed with Folin Ciocalteu reagent (0.5 mL) and 20% Na_2CO_3 solution (1.5 mL). The whole volume of the solution was made up to 8 mL by adding distilled water, followed by forceful shaking. The solution for 2 hours was allowed to stand as such and then absorbance was taken at 765 nm. The total phenolic content was calculated from standard calibration curve of gallic acid and expressed in mg GAE/g of extract.

Total glycosides content: Total glycosides content was observed by following Solich et al (1992) method. The seed extract (100 mg) was mixed with freshly prepared Baljet's reagent (10 mL) and after an hour, the mixture was diluted with distilled water (20 mL) and the absorbance at 495 nm was observed. As a standard, digitoxin (DIG) was used and glycosides content was calculated in mg DIG/g of extract.

Steroids: The steroid content from seeds of *I. coesta* was checked using Madhu et al (2016) methodology. To the seed extract (100 mg), 4 N sulfuric acid (2 mL) and 0.5 % iron (III) chloride solution (2 mL; 0.5 % w/v) were added followed by 0.5 mL of potassium hexacyanoferrate (III) solution (0.5 mL; 0.5 % w/v). On a water bath (70±20ºC) the mixture was heated for 30 minutes and further diluted with distilled water with shaking. The absorbance was taken at 780 nm against the blank solution. As a standard, Cholesterol was used and steroids content was represented in mg/g CHO of extract.

***In vitro* Antioxidant Activity of *I. coesta* Seeds**

***2,* 2-Diphenyl-1-picryl hydrazyl (DPPH) radical scavenging activity:** Different seed extracts of *I. coetsa* were evaluated for their antioxidant activity using DPPH assay (Sharma and Bhat 2009) and ascorbic acid was taken as a control.

$$\text{Scavenging activity \%}= \frac{{}^{A}(\text{control})^{A}\text{-(sample)}}{{}^{A}\ (\text{control})} \times 100$$

where, $A_{(control)}$ was the absorption of the DPPH and $A_{(sample)}$ was the absorption of the plant extracts. The graph was plotted between % radical scavenging activity and different concentrations. From the graph, half-maximal inhibition (IC_{50}) value (µg mL^{-1}) was calculated using the regression method.

Antimicrobial Potential of Different Extracts of *I. coetsa* Seeds

Microbial strains and growth conditions: Pathogenic bacterial (*Bacillus subtilis* MTCC 5521*, Staphylococcus aureus* MTCC73, *Escherichia coli* MTCC739, and *Klebsiella pneumoniae* MTC109] and fungal strain (*Fusarium oxysporum* SR266-9) were used to observe the antimicrobial potential of *I. coetsa* seeds. All pathogens were taken from the School of Microbiology, Shoolini University, Solan. Bacteria were maintained on nutrient agar (NA) plates while fungus was grown on potato dextrose agar (PDA) at 37ºC and 25ºC, respectively.

Agar disc diffusion method for antibacterial and poison food method for antifungal activity*:* For the evaluation of the antimicrobial activity of different seed extracts of *I. coetsa,* the agar disc diffusion method was used *(*Bayer et al 1966). The extracts were taken in different concentrations (2-8 mg mL^{-1} in DMSO, w/v) and antimicrobial activity was expressed in terms of zone of inhibition (ZOI) towards the growth of microorganisms after incubation. As a positive and negative control, Ampicillin and DMSO, respectively were used. A similar procedure was repeated thrice for each bacterial strain. The poison food technique (Ramaiah and Garampalli 2015) was performed to evaluate the antifungal potential of *I. coetsa* against *F. oxysporum* using different concentrations (20-80 mg/mL in DMSO, w/v). As a positive and negative control, Hygromycin B (2 mg mL^{-1}) and DMSO (4 mg mL^{-1}) were used.

$$\text{Inhibition \%} = \frac{(C - T)}{C} \times 100$$

Where, C represents the diameter of the control and T represents the treated colony.

Determination of minimal inhibitory concentrations (MIC): The broth dilution method described by the Clinical and Laboratory Standard Institute (CLSI) was used to investigate the MIC of different *I. coetsa* seeds extracts. Nutrient broth (NB) was used for antibacterial activity, while potato dextrose broth (PDB) was used to observe the antifungal activity. The geometric dilutions of extracts ranged from 50-0.098 µg mL^{-1} was prepared in a microtiter plate (96-welled), including one growth control (only NB/PDB containing DMSO), one with the positive control (NB/PDB inoculated with bacterial and fungal culture) and one with antibiotics (ampicillin/hygromycin B). Inoculums containing 2×10^{6} CFU/mL) were added into each well and the plates were kept at 37°C for 24 h (for bacterial strains) and 25°C for 48 h for fungi (Mohr et al 2017).

Gas chromatography and mass spectrometry (GC-MS) analysis: The GC-MS analysis of the essential oil samples of *M. piperita* and *M. longifolia* leaves was performed as per the standard method of Ladhim et al (2016) in the SERF laboratory of Punjab University, Chandigarh, India. The analysis was done using a GC-MS instrument (Thermo Trace 1300 GC coupled with Thermo TSQ 8000 Triple Quadrupole MS) fitted with a TG 5MS capillary column (30 m x 0.25 mm i.d., 0.25 µm film thickness) for qualitative determination. The essential oil was diluted 1/10 in n-hexane (v/v) before analysis. The Autosampler was built for the injection of extract, injector temperature: 250°C, ion-source temperature: 230°C. Oven temperature: 60°C for 2 min, 60-250°C (10°C/min to 250°C), 250°C for 5 min. Carrier gas: helium gas (99.999%), flow rate: 50 mL/min, injection volume of 3.0 µl, split ratio: 33:3 Mass spectra: 70eV; a scan interval: 0.5 s and fragments rate: 45 to 450 Da. Total GC running time was 5 min. For analysis 1 µl of a sample was used. The components were recognized based on their retention times (R_T). Further, the percentage of constituents was measured based on peak area and phytoconstituents were identified by comparing their mass spectra with those recorded in NIST 2.0 electronic Library and Wiley 275 libraries by considering Match Factor (SI) and Reverse Match Factor (RSI) higher than 600 and also with mass spectrum from the literature.

Data analysis: All the experiments were carried out in triplicate, statistically analyzed with PRISM software, and results were expressed as mean±standard deviation.

RESULTS AND DISCUSSION

Quantitative phytochemical analysis: The quantitative phytochemical estimation revealed a higher amount of phenols (819.39 mg GAE/g), flavonoids (261.98 mg RUT/g), saponins (124.58 mg DIO/g), glycosides (729.23 mg DIG/g), terpenoids (181.69 mg LIN/g) and alkaloid (28.06%) in ME, whereas, total steroid content was higher in CE of *I. coetsa* seeds (444.71 mg CHO/g) (Table 1).

Antioxidant potential of *I. coetsa* seeds: The antioxidant potential of seed extracts of *I. coetsa* increased with an increase in the concentration of seeds extract (5-40 µg mL^{-1}) (Fig. 1). In DPPH assay, the highest free radical scavenging activity (%) was observed with EE followed by ME and CE (with IC_{50} <5 µg mL^{-1}) as compared to PE (IC_{50} ranged between 5-10 µg mL^{-1}). Whereas, Ascorbic acid showed IC_{50} value 29.87 µg mL^{-1} (Fig. 1).

Antimicrobial activity of *I. coetsa* seeds: The antimicrobial activity of extracts depends on concentration and activity was increased with an increase in extract concentration from 2-8 mg mL^{-1} against bacteria and 20-80 mg mL^{-1} against fungi (Fig. 2). Agar disc diffusion assays revealed a higher zone of inhibition with ME and CE against both bacterial and fungal strains. Similarly, the poison food method also showed higher % inhibition with ME and CE (Fig. 3). Broth dilution method showed the maximum antimicrobial activity of ME for *E. coli* (MIC-1.25 mg mL^{-1}), *K. pneumoniae* (MIC-1.25 mg mL^{-1}), *F. oxysporum* (MIC-2.5 mg mL^{-1}), *S. aureus* (MIC-2.5 mg mL^{-1}), and *B. subtilis* (MIC-5 mg mL^{-1}) (Fig. 4).

GC-MS Characterization of chloroform and methanol extracts of *I. coetsa* seeds: The CE and ME showed highest antioxidants and antimicrobial activity among all extracts of *I. coetsa* seeds, therefore, these two extracts were

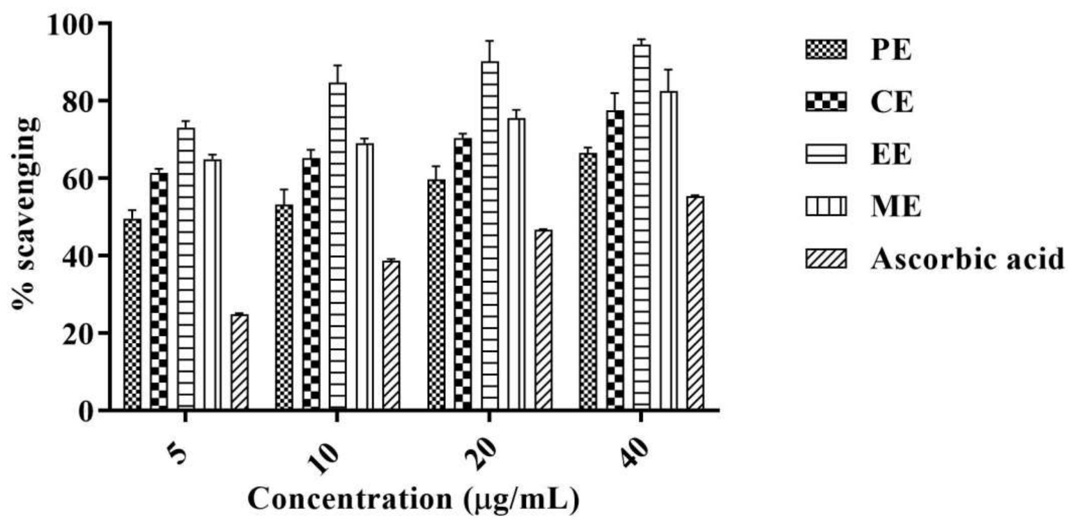

Fig. 1. DPPH radical scavenging activity of *I. coetsa* seed extracts. ME: Methanolic extract; CE: Chloroform extract; EE: Ethyl acetate extract; PE: Petroleum ether extract

Table 1. Quantitative phytochemical analysis of different seed extracts of *I. coetsa*

Phytochemicals	*I. coetsa* seeds (mean±SD)			
	ME	CE	PE	EE
Tannins (mg GAE/g)	198.98±2.71	108.04±0.81	42.67±0.57	77.30±1.47
Phenols (mg GAE/g)	819.39±1.60	346.14±3.16	152.91±2.88	186.26±1.49
Flavonoids (mg RUT/g)	261.98±0.59	127.60±1.01	26.81±0.93	172.55±1.66
Saponins (mg DIO/g)	124.58±0.87	100.72±0.58	67.78±0.44	32.03±0.39
Glycosides (mg DIG/g)	729.23±2.93	473.68±3.34	234±2.30	212.54±3.93
Terpenoids (mg LIN/g)	181.69±0.34	99.14±0.44	43.21±1.11	43.21±1.11
Steroid (mg CHO/g)	403.5±1.63	444.71±0.79	80.55±0.83	262.86±1.58
Alkaloid (%)	28.06±0.05	25.22±0.06	21.26±0.041	19.90±1.20

SD: Standard deviation; ME: Methanol seeds extract; PE: Petroleum ether seeds extract; EE: Ethyl acetate seeds extract; CE: chloroform seeds extract further characterized through GC-MS analysis. GC-MS chromatogram showed the presence of total 19 compounds in CE, and 9 compounds in ME of *I. coetsa* (Fig. 5 a and b). CE was characterized with octadecanoic acid, 2-(2hydroxyethoxy) ethyl ester (33.75%), dimethylsulfoxonium formylmethylide (21.40%); 9,12,15-octadecatrienoic acid (Z,Z,Z) (12.12%); 12,15-octadecatrienoic acid, methyl ester, (Z,Z,Z) (7.17%); 9,12-octadecadienoic acid (Z,Z) (6.75%), and hexadecanoic acid, methyl ester (3.69%) as major chemical constituents (Table 2), whereas ME was characterized by bicyclo[2.2.1]heptan-2-one,1,7,7-trimethyl (49.93%); phenol,2-methoxy-3-(2-propenyl) (14.63%); 9,12,15-octadecatrienoic acid, (Z,Z,Z)- (9.63%); caryophyllene oxide (2.57%) and caryophyllene (2.46%) as major phytocompounds (Table 3).

Plants are the richest source of metabolites, viz., alkaloids, phenols, glycosides, flavonoids, steroids, saponins, and tannins. (Dillard and German 2000). Most of these metabolites have health effects on people in terms of free radical scavengers, substrates for biochemical process, selective inhibition to the hazardous intestinal bacterium, etc. (Webb 2013). The present work is possible the first report on the quantitative estimation of phytocompounds in *I. coesta* seeds. Similar to this study, several studies have reported the presence of alkaloids, glycosides, saponins, flavonoids, tannins, steroids in various plant parts extracts (*Plectranthus hadiensis*, *Coleus aromaticus, Pogestemon patchouli, Ocimum sanctum,* and *Mentha spicata*) of family Lamiaceae (Menon and Sasikumar 2011, Rai et al 2013, Soni and Sosa 2013).

The quantitative phytochemical analysis results showed a higher amount of phytocompounds in ME, indicating the maximum extraction capacity of methanol solvents in comparison to other solvents. Similar to the present study, Swamy et al (2017), Menon and Sasikumar (2011), Rai et al (2013), and Vimala et al (2014) also observed higher phenolic, flavonoids, and tannin content in the methanol extract of *P. amboinicus, P. hadiensis, Leucas linifolia, O. sanctum,* and *O. basilicum,* respectively. The current study also showed higher steroid content in CE followed by ME of *I. coetsa*, similar to the results of Rai et al (2013) on *Pogestemon patchouli* and *Leucas linifolia*. Antioxidants are substances that can protect the cell from free radical's damage and reduce harm (Santos-Sanchez et al 2019). Maximum antioxidant activity was observed in EE and ME of *I. coetsa* with DPPH assay. Onder et al (2020) also observed higher antioxidant potential or lower IC_{50} value in ethyl acetate extracts of leaves of *Thymus sipyleus, Phlomis armeniaca*, and *Sideritis galactica* as compared to the methanol extract. In addition to these, EE of *Mentha officinalis* leaves also

Table 2. GC-MS analysis of chloroform extract of *I. coetsa* seeds

Compound name	Retention time (min)	Peak area (%)	RSI	SI
Butane, 2-ethoxy-2-methyl	3.08	0.21	943	659
1,3,5-Cycloheptatriene	3.62	1.36	926	906
Dimethylsulfoxonium formylmethylide	6.00	21.40	979	979
Dimethyl sulfone	9.69	0.58	841	830
2,4-Heptadien-1-ol, (E,E)-	10.34	0.31	608	586
Dodecane, 2,6,11-trimethyl	13.81	0.35	852	822
Cyclohexasiloxane, dodecamethyl	14.47	0.23	745	631
Caryophyllene	15.75	0.75	878	869
1-Iodo-2-methylundecane	16.60	0.38	865	760
Isoaromadendrene epoxide (Ledene oxide-(II))	16.94	0.75	806	803
Andrographolide	18.39	0.77	785	719
10,12-Tricosadiynoic acid, methyl ester	18.46	0.22	782	778
Hexadecanoic acid, methyl ester	21.28	3.69	903	903
Octadecanoic acid, 2-(2-hydroxyethoxy)ethyl ester	21.95	33.73	747	744
9,12,15-Octadecatrienoic acid, methyl ester, (Z,Z,Z)	22.97	7.17	904	904
Methyl stearate	23.15	0.58	858	858
9,12-Octadecadienoic acid (Z,Z)	23.43	6.75	851	851
Butyl 9,12,15-octadecatrienoate	23.60	1.20	854	806
9,12,15-Octadecatrienoic acid, (Z,Z,Z)	23.95	12.12	864	859

RSI: Reverse match factor; SI: Match factor

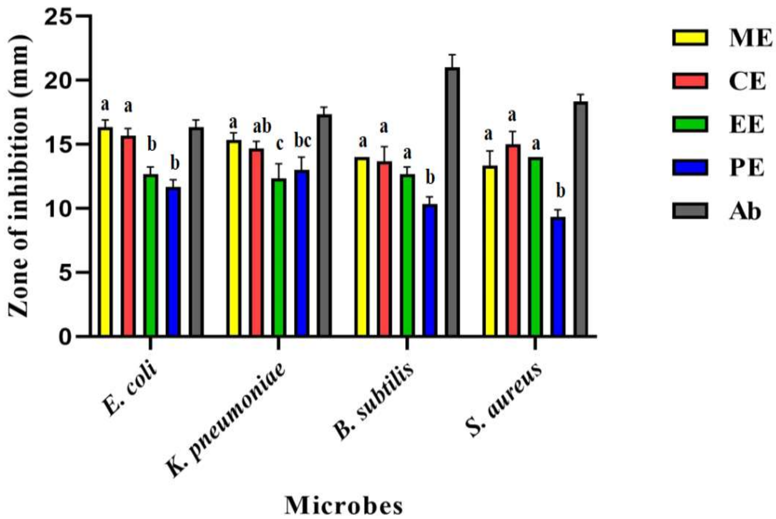

Fig. 2. Antibacterial activity of *I. coetsa* seed extracts (8 μg mL^{-1}) in terms of zone of inhibition against bacterial strains. Ab: Ampicillin (50 μg mL^{-1}); ME: Methanolic extract; CE: Chloroform extract; EE: Ethyl acetate extract; PE: Petroleum ether extract. Different letters in same column indicate statistical significant differences ($p<0.05$) Tukey's test)

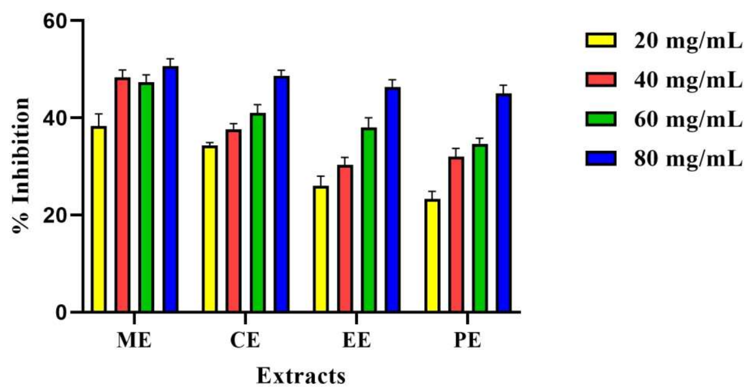

Fig. 3. Anti-fungal activity of *I. coetsa* seed extracts at varying concentrations against *F. oxysporum.* ME: Methanolic extract; CE: Chloroform extract; EE: Ethyl acetate extract; PE: Petroleum ether extract

Table 3. GC-MS analysis of methanolic extract of *I. coesta* seeds

Compound name	Retention time (min)	Peak area (%)	RSI	SI
Ethane, 1,1-diethoxy	3.36	2.81	946	946
Bicyclo[2.2.1]heptan-2-one,1,7,7-trimethyl-, (1S)-	11.84	49.93	960	913
Glycerin	12.13	10.22	940	940
Nonadecan-1-ol trimethylsilyl ether	14.46	2.55	591	534
Phenol, 2-methoxy-3-(2-propenyl)	15.04	14.63	889	889
Caryophyllene	15.75	2.46	790	745
3-Butoxy-1,1,1,7,7,7-hexamethyl-3,5,5-tris(trimeth ylsiloxy) tetrasiloxane	16.64	1.54	714	604
Caryophyllene oxide	17.77	2.57	827	764
9,12,15-Octadecatrienoic acid, (Z,Z,Z)-	22.98	9.63	824	824

showed the highest antioxidant potential followed by butanol, methanol, and petroleum ether extracts (Hassan et al 2019). Swamy et al (2017) observed the highest ferric ion reduction potential in methanolic leaves extract of *Plectranthus amboinicus* [849.63 M of Fe (II)/g dry weight] followed by hexane and acetone extract.

The antimicrobial activity of seeds of *I. coetsa* was higher in ME followed by CE, EE, and PE against *E. coli, K. pneumoniae*, *B. subtilis*, *S. aureus,* and *F. oxysporum*. Similar to our report, methanolic leaves extract of *P. amboinicus* also showed greater antimicrobial activity (*B. subtilis*, *P. aeruginosa*, *S. aureus*, *E. coli*, and *C. albicans*) (Swamy et al 2017). Rauf et al (2012) also revealed the higher antibacterial potential of methanolic extract of *I. rugosus* leaves against *E. coli, K. pneumoniae,* and *S. aureus,* followed chloroform, ethyl acetate, and n-hexane

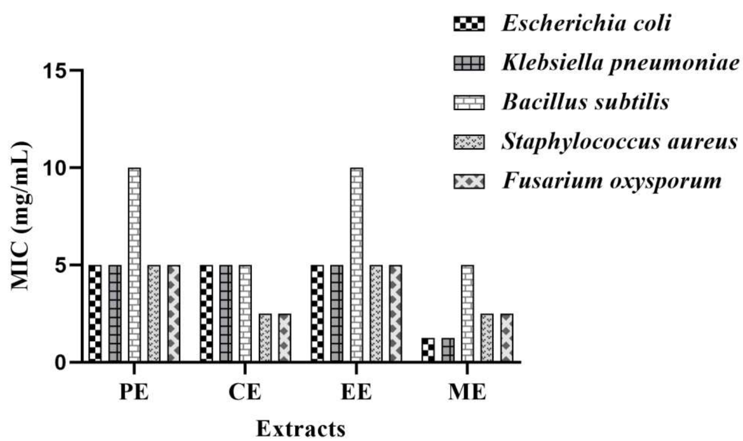

Fig. 4. MIC values of different seed extracts of *I. coetsa* against bacterial and fungal strains. ME: Methanolic extract; CE: Chloroform extract; EE: Ethyl acetate extract; PE: Petroleum ether extract

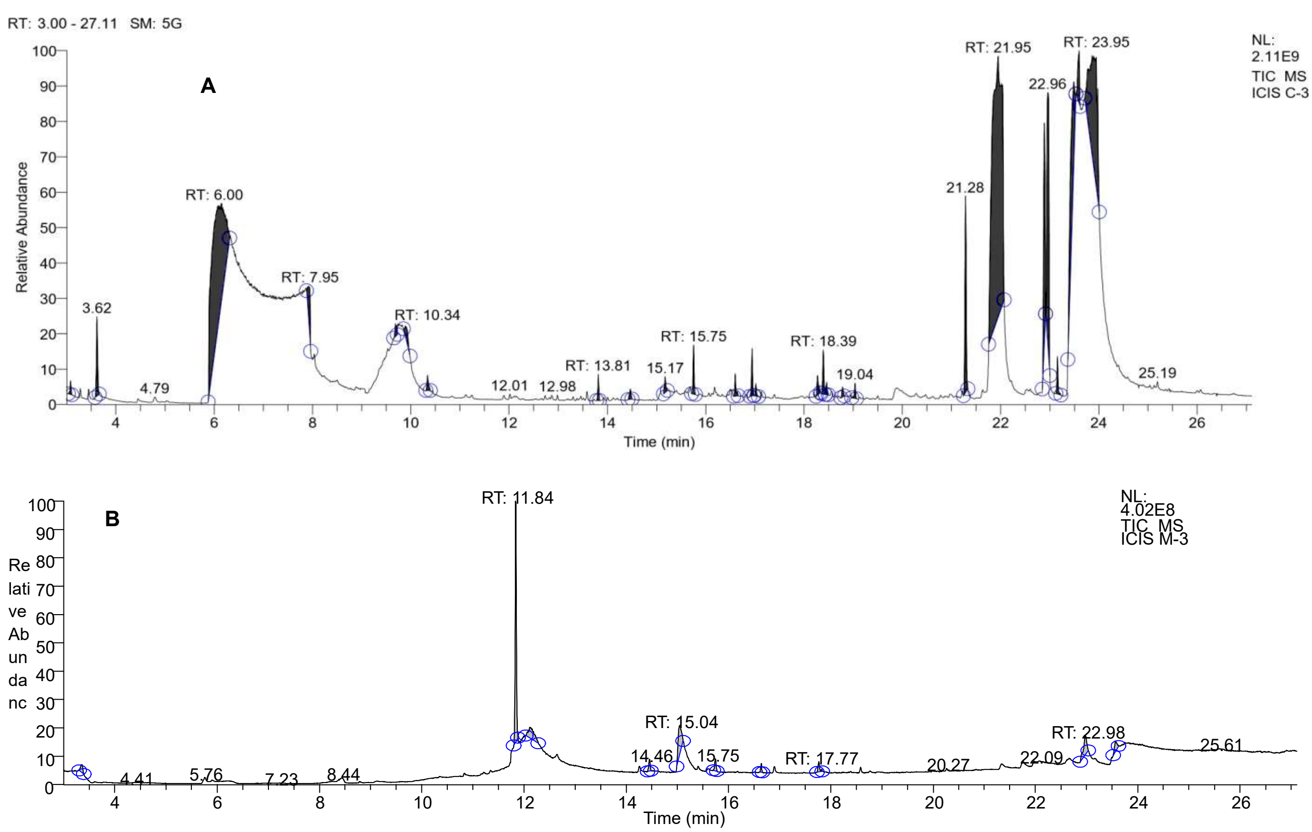

Fig. 5. GC-MS chromatogram of chloroform (a) and methanolic seed extract (b) of *I. coesta*

extract, whereas methanol leaves extract of *I. rugosus* showed higher antimicrobial activity against *Salmonella typhi* and *Klebsiella pneumoniae* than that of ethyl acetate and chloroform extracts (Zeb et al 2017). Further, the chemical characterization of chloroform extract of *I. coetsa* seeds showed the presence of more phytocompounds as compared to that of methanol extract (Tables 3 and 4). Similar to the present study, methanolic extract of *O. sanctum* showed the presence of eugenol (3.31%), caryophyllene (3.61%), germacrene (1.52%), 9,12,15-octadecatrienoic acid methyl ester (1.88%), hexadecanoic acid methyl ester (2.30%), and phenol-2-methoxy-4-(1-propenyl) (3.31%) through GC-MS analysis (Arulraj et al 2014). All the compounds (9,12,15-octadecatrienoic acid, caryophyllene oxide, bicyclo[2.2.1]heptan-2- one,1,7,7-trimethy, dimethylsulfoxonium formylmethylide, octadecanoic acid, and hexadecanoic acid) observed in ME and CE of *I. coetsa* have been reported in the literature as biologically active compounds (Al-Marzoqi et al 2015, Mujeeb et al 2014, Guerrero et al 2017, Paude et al 2019). Therefore, it can be concluded that the biological activities in the CE and ME of *I. coetsa* could be due to the presence of these observed biologically active phytocompounds.

CONCLUSIONS

This study is the first attempt to quantify the phytochemicals of different solvent extracts of *I. coetsa* seeds. The current study concluded the highest extraction capacity of methanol and chloroform solvents for several chemical constituents of *I. coetsa* seeds which are responsible for various biological activities. The results from the present study showed higher antioxidant and antimicrobial potential of *I. coetsa* seeds, therefore, can be utilized in the food industry as a source of natural antioxidants and in pharmaceutical industries for the development of safer drugs. However, further study needs to be done to identify phytocompounds of *I. coetsa* seeds and also their biological potential with *in-vivo* studies.

CONFLICT OF INTEREST

None of the authors have any conflict of interest to declare.

AUTHOR CONTRIBUTIONS

All authors have made a substantial and direct contribution to the work.

ACKNOWLEDGEMENTS

The authors are thankful to Shoolini University, Solan for providing funds for GC-MS analysis.

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Received 12 January, 2022; Accepted 22 April, 2022

Indian Journal of Ecology (2022) 49(3) (SI): 1122-1128
DOI: https://doi.org/10.55362/IJE/2022/3640

Manuscript Number: 3640
NAAS Rating: 5.79

Pharmacological and Therapeutic Properties of *Jasminum officinale* L.: A Review

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Abstract: Nowadays, plant-derived products play an important role to deal with various health problems. The medicinal importance of plants is due to the phytochemicals present in them. Phytochemicals are biologically active secondary metabolites derived from plants that naturally exist. There are several major phytochemicals present in *Jasminum officinale* are in alkaloids, coumarin, emodin, flavonoids, phenol, saponins, sesquiterpenoids, secoiridoids, and tannins and they are known to possess definite pharmacological activities which are responsible for their medicinal properties. Therefore, an acquaintance of phytochemical is essential, to associate their existence along with their synergistic impact on the therapeutic value of a definite medicinal plant related to a specific pharmacological profile. The present review focused on the therapeutic properties of constituents of *J. officinale* along with the proven pharmacological and aromatherapy profile. This study revealed that plants possess several medicinal properties such as gastrointestinal disorders and hypertension which are not explored yet with proven pharmacology and could be further investigated as a potential therapeutic agent by modern biotechnology and clinical studies.

Keywords: *J. officinale*, Phytoconstituents, Pharmacological actions, Therapeutic applications, Aroma therapy

The plants are leading candidates in the development of novel medications because of their extensive range of biological activities, which are influenced by the presence of several phytocompounds (Kumari et al 2018, Balkrishna et al 2021, Dhatwalia et al 2021, Sharma et al 2021, Sonam et al 2021). The genus *Jasminum* comprises over 200 species belonging to the family Oleaceae, which are distributed in Asia, Australia, Africa, and the Southern Pacific Islands area (Lu et al 2019). *Jasminum* officinale is an important herbal plant of this genus and is mainly found in China and widely cultivated in Caucasus, China, Eastern Afghanistan, India, Hindukush, Mediterranean, Northern Persia, and Pakistan. *J. officinale* grows up to 9 m is characterized by twining shrubs, bright, vigorous, deciduous climber and leaves are 6-10 cm long, sharply pointed pinnate, opposite and produces the large flush of clusters of starry, flowers are pure white and responsible for heady scent. Fruits are berry, black, and full of crimson juice (Musaddique et al 2013, Shubhangi et al 2019, Elhawary et al 2020). *J. officinale* showed several pharmacological activities as anti-microbial, anti-viral, and anti-spasmodic, cytotoxic, in addition to wound promoter (Elhawary et al 2020). Leaves are responsible for their therapeutic properties like anti-diabetic, anti-oxidant, antiseptic, anti-spasmodic, and wound healing (Prachee et al 2019). Flowers of *J. officinale* are traditionally used as CNS depressant, a mild anesthetic, astringent, and sedative (Musaddique et al 2013). Prior found chemicals are flavonoid, iridoid, saponins, sesquiterpene, with some biological activities (Zhao et al 2008, Ning et al 2013, Zhao et al, 2013, Guo et al 2014). Whole plants and flowers have several phytoconstituents such as alkaloids, saponins, tannins, resin, flavonoids, and terpenoids. Moreover, the leaves contain ascorbic acid alkaloids, resin, carbohydrates, coumarins, flavonoids salicylic acid, saponins, tannins, and terpenoids (Musaddique et al 2013, Prachee et al 2019). In some places of China, several plants of this genus have been used as therapeutic remedies. Whole parts of the plant such as stem, barks, leaf, root and flowers are being most widely used traditionally. The whole plant is traditionally used for chronic ulcer healing, tumor and skin disease. In the traditional system, leaves are chewed and used in the treatment of ulceration of the mouth (Musaddique et al 2013). In folk medicine, stems have been used to treat many disorders such as chronic inflammatory like angiitis, ulceration, colitis, and enteritis (Lu et al 2019). *J. officinale* contains essential oil which is widely used in aromatherapy. Jasmine oil is very expensive due to the presence of highly active compounds. Most people like it due to its sweet scent fragrance (Shubhangi et al 2019). These oils are very effective in cardiovascular and gastrointestinal diseases (Hafiz Mazid et al 2020). Flowers contain various volatile compounds, including farnesene, linalool, nerolidol, indole, benzyl alcohol, benzyl acetate, benzyl benzoate, hexenyl benzoate, jasmine lactone, and jasmone. Those have medicinal benefits and important ingredients in perfumes, cosmetics, flavorings, and food (Cristian Eugen et al 2018) as well as in cosmetics for hair and skin pomades, lip balms, lipsticks, pastes, powders, soaps, hair perfumes and hair dyes (Jacek et al 2017). Leaves can be used as therapeutic agents to generate clean, inexpensive, eco-friendly silver nanoparticles which have been safely used with no side effects. Nanotechnology used in medicine mainly depends on the natural measure of biological methods to yield accurate ways for management and prevention of disease diagnosis and treatment (Elhawary et al 2020). Jasmine is widely used in aromatherapy for a calming and soothing effect, suppression of stress, pulmonary depression, aphrodisiac and has been prescribed for sexual problems (Shahbaa 2018). Extract of jasmine taken as massage helps to decrease pain severity in the first stage of labor and is more effective in aromatherapy (Mahbubeh 2020).

Medicinal significance: The whole plant is mostly used in traditional medicine (Duke et al 2002, Khare 2007). Jasmine is an ornamental plant that is found throughout Asia and is generally used in aromatherapy. Leaves show pharmacological activities such *as* antiseptic, anti-spasdomic, and wound healing which is reported from ancient Indian literature (Wealth of India, 2003) Whole plant is traditionally used for chronic ulcer healing, tumor and skin disease. *J. officinale* is a remedy for hepatitis and duodenitis. It is also used to treat fever, diabetes, diarrhea, ringworm, ulcers and eruptions in the mouth (Zhao et al 2009). Flowers of *Jasminum officinale* are traditionally used as a CNS depressant, sedative, a mild anesthetic, and astringent (Duke et al 2002, Khare 2007). Syrup formed by the flowers is used for the disorders of the chest, i.e., coughs and hoarseness (Khare 2007). Flowering buds of jasmine are used for the treatment of abscess, dermatological ulcers and ophthalmic disorders (Zhao et al 2009). Leaf juices and flowers have anthelmintic, diuretic and emmenagogue activity.

In the traditional system, leaves are chewed and useful for the treatment of ulceration of the mouth, skin diseases and fever (Barnes 2007, Khare 2007). Jasmine oil is effective in reducing labor pain that helps to enhance the release of endorphins that alleviate pain by applying in the coccyx area (Mukhlis et al 2018). It contains sweet-smelling flowers that contain fragrant oil (Bhattacharya 2010). Jasmine oil has a wide range of applications in traditional medicine including gastric spasms (Arun et al 2016) and cardiovascular diseases (Sandeep 2009). Leaves are also chewed to alleviate several types of pain such as aphthous, stomatitis and toothache. Leaf juice or oil are used as ear drop to alleviate ear pain and help in the treatment of soft corns between the toes, throat, and gums problems. In addition, it is also used in neurological disorders such as depression, nervous exhaustion, and stress-related conditions, skin problems, uterine, musculoskeletal disorders cough as well as help to relax the feeling of optimism, euphoria, confidence (Shukla 2013, Al-Khazraji 2015, Al-Snafi 2018).

Phytoconstituents: *J. officinale* is aneminentindustrial and medicinal plant that contains coumarins, alkaloids, emodin, flavonoids, leucoanthocyanin, phlobatannins, sesquiterpenes, secoiridoids, steroids, tannins and terpenoids (Nikita et al 2019, Elhawary et al 2020). The whole plants and flowers revealed the presence of alkaloids,

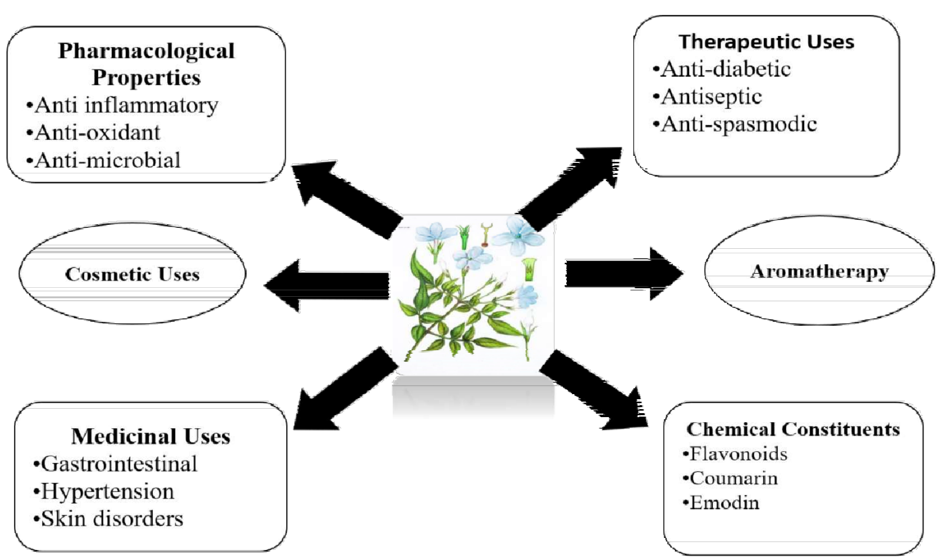


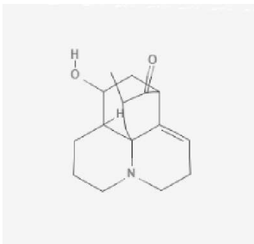
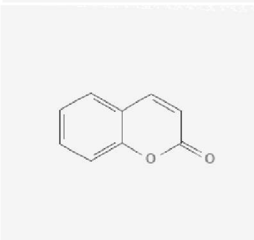
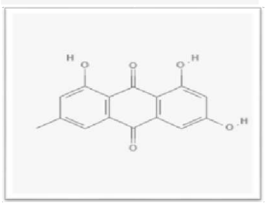
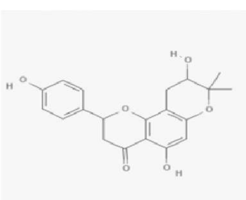
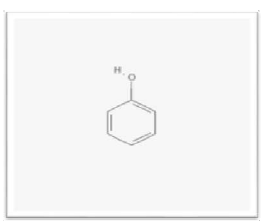
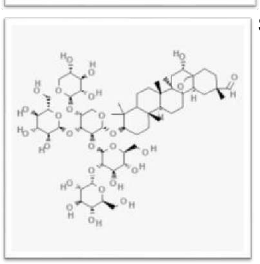
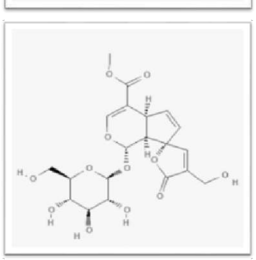
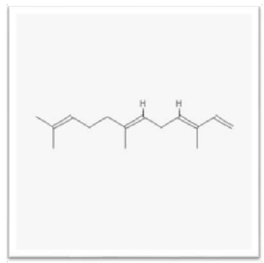
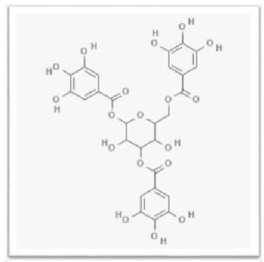
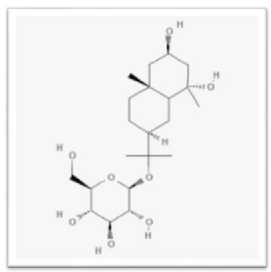
Fig. 1. Properties of *J. officinale* L.

Table 1. Medicinal uses of *Jasminum officinale* L.

Diseases	Part uses	Preparation	References
Amenorrhoea	R; F	ND	Sharma 2001
Bilious	F	ND	Shiddamallayya et al 2010
Blood disease	F; R	Tea	David 2013
Burning sensation	F	ND	Shiddamallayya et al 2010
Cancer	AP; L; F	Extract	Sood 2005
Catarrh	P	ND	Ali Esmail 2018
Chronic inflammatory	S	ND	Ye Lu et al 2019
Cough and hoarseness	F	Syrup	Musaddique et al 2013
Coughs	F	Syrup	David 2013
Dental ailments	L; F	chewed	Ali Esmail 2018
Depression	P	ND	Ali Esmail 2018
Diabetes	F	ND	Shiddamallayya et al 2010
Eye diseases	F; L	Tea	David W2013
Gastrointestinal diseases	R; F	ND	Fleming 2000
Headaches	R	Tea	David 2013
Heart disease	F	ND	Shiddamallayya et al 2010
Hepatic disorders	F	ND	Panda 2013
Insomnia	R	Tea	David 2013
Intestinal worms	F	ND	Panda 2013
Labor pain	P	Massage	Hamid et al 2018
Leprosy	F	ND	Sharma 2001
Mental debility	R	ND	Sharma PC 2001
Musculoskeletal disorders	R	Tea	Ali Esmail 2018
Nerves diseases	F	Tea	David 2013
Nervous exhaustion	P	ND	Ali Esmail 2018
Oral diseases	L; F	Chewed	Ali Esmail 2018
Otorrhoea	L	Juice	Ajay et al 2009
Paralysis	R	ND	Sharma 2001
Respiratory system	P	oil	Panda 2013
Rheumatism	R	Tea	David 2013
Ringworm	L	Chewed	Ajay et al 2009
Sexual problems	P	Oil	Panda H 2013
Skin diseases	WP; L; F	Juice	Ali Esmail A2018
Snakebite	L	Tea	David 2013
Stress	P	ND	Ali Esmail 2018
Thirst	F	ND	Shiddamallayya et al 2010
Tumors	AP; L; F	Extract	Panda H 2013
Ulcer	WP	ND	Musaddique et al 2013
Urinary tract infections	P	ND	Ali Esmail 2018
Uterine disorders	P	ND	Ali Esmail 2018
Wounds	L	Tea	David 2013

Aerial Parts: AP; Flower: F; Flowers: F; Leaf: L; Not defined: ND; Plant: P; Stem: S; Whole plant: WP

Table 2. Active compound present in *Jasminum officinale* L.

Active compound		Part used	References
	Alkaloids	L; F	Dubey et al 2019
	Coumarin	L	Dubey et al, Nikita et al 2019
	Emodin	P	Nikita et al 2019
	Flavonoids	L; F	Dubey et al 2019
	Phenol	L	Dubey et al 2019
	Saponins	L; F	Dubey et al 2019
	Secoiridoids	P; L	Elhawary et al 2020
	Sesquiter-penoids	S	Ye Lu et al 2019
	Tannins	L; F	Dubey et al 2019
	Terpenoids	L; F	Dubey et al 2019

Cont...

Flower: F; Leave: L; Plant: P, Stem: S [Source: https://pubchem.ncbi.nlm.nih.gov/]

saponins, tannins, resin, flavonoids and terpenoids (Table 2). Moreover, the leaves contain ascorbic acid alkaloids, resin, carbohydrates, coumarins, flavonoids salicylic acid, saponins, tannins and terpenoids (Musaddique et al 2013, Prachee et al 2019). This plant is also showing the presence of nor-cinalbicane type sesquiterpenoids and one eremophilene-type sesquiterpenoid (Ye Lu et al2019). Flowers contain many volatile compounds, including farnesene, linalool, nerolidol, indole, benzyl alcohol, benzyl acetate, benzyl benzoate, hexenyl benzoate, jasmine lactone and jasmone (Jacek et al 2017).

Pharmacological activities: The biological studies of *Jasminum officinale* are summarized in Table 3. Through quantitative analysis, the anti-inflammatory, anti-microbial and anti-oxidant activity are s the dominant activity of this plant, followed by the anti-cancer activity, anti-nociceptive activity, anti-ulcer activity, effect on the Central Nervous System (CNS) were also examined and reviewed thoroughly.

Clinical trial based evidence: A clinical trial was conducted to assess the effects of aromatherapy with *J. officinale* in 155 physically healthy nulliparous women aged between 18 and 30 years for 6 months on pain severity and labor outcome

Table 3. Pharmacological profile of *Jasminum officinale* L.

Activity	Extract	Part used	Assays	Outcomes	References
Anti-cancer activity	Aqueous extract of nanoparticles (AgNPs)	L	Bladder (5637) and breast cancer (MCF-7) cell lines	IC_{50} range 9.3 to 40 μg/ml.	Elhawary et al 2020
Anti-inflammatory activity	Jasminol A, B, G and H; Ethanol extract; Essential oil	S; F; WP	Lipopolysaccharide (LPS)-induced NO production	IC_{50} 20.56 to 31.60 μM	Lu et al 2019
			Xylene-induced ear edema	Inhibition 53%	Atta et al 1998
			Cotton pellet granuloma test	Weight reduction in cotton granuloma	Lu et al 2019
			5-lipoxygenase inhibitory activity	47% inhibition of 15-lipoxygenase	WEI et al 2010
Anti-microbial activity	Methanolic extract; Ethanolic extract; Essential oil	L	Disc diffusion method	Maximum inhibition against *K. pneumonia* with inhibition zone (18 mm)	Shekhar et al 2015
			Well diffusion or pour plate methods	Methicillin-resistant *S. aureus* (MRSA) with inhibition zone (4.6 mm)	Gunasekara et al 2017
			Tube dilution assay	Inhibition against *Trichosporon ovoides* with MIC3.1 μl/ml	Saxena et al 2012
Anti-nociceptive activity	Ethanol extract	L	Acetic acid-induced withing	48 and 49% inhibition at 200 and 400 mg/kg.	Atta et al 1998
Anti-oxidant activity	Methanolic extract; Aqueous extract	L	DPPH and free radical scavenging assay	50% scavenging ability at 700 μl.	Shiddamallayya et al 2010
			DPPH and scavenging assay	IC50 value is 76.6 μg/ml.	Seham et al 2019
			DPPH, NO, superoxide, ABTS radical scavenging and reducing power assay	IC_{50} values 41.16, 30.29, 20.19 and 29.48 μg/ml, respectively for DPPH, NO, superoxide and ABTS radical scavenging assays	Dubey et al 2016
Anti-ulcer activity	Petroleum ether; Chloroform extracts	L	Aspirin-induced ulcer	64.03 and 57.47% inhibition of gastric ulcer at 200 mg/kg	Khandal et al 2018
Central Nervous System (CNS)	Alcoholic extract	AP	Pentobarbital induced	Alteration of sleeping and latency time	Elisha et al 1998

Aerial parts: AP; Flowers: F; Leaves: L; Stem: S; Whole Plant: WP; IC_{50}: 50% inhibitory concentration

finding that aromatherapy and control groups displayed a significant difference in labor pain 30 min after the intermediation (Maasumeh et al 2014). In another study, the effect of jasmine oil is applied to reduce labor pain among pregnant ladies for the month, while jasmine oil massage on sacrum for 10 minutes, the average pain score was 4.26 while least at 4 and extreme score at 7 that the average pain notch has lain between 3.75 to 4.57 whereas the average pain score was of 6.64 before test where the lowest score was 6 and the maximum score was 9 that the average pain score was between 6.25 to 6.8 (Mukhlis et al 2018).

CONCLUSION

J. officinale has several medicinal uses and could be explored in advance for the development of novel therapeutic drugs not only for treating diseases such as gastrointestinal and cardiovascular (hypertension) disorders but also in the field of modern biotechnology where its leaves can be used as bioreduction agents to produce inexpensive, eco-friendly and clear silver nanoparticles. The future investigation could be applied to the nanoparticle and therapeutic property of *J. officinale* with the help of modern biotechnology and clinical studies.

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Received 30 January, 2022; Accepted 04 June, 2022

Indian Journal of Ecology (2022) 49(3) (SI): 1129-1151
DOI: https://doi.org/10.55362/IJE/2022/3641

Manuscript Number: 3641
NAAS Rating: 5.79

Organic Farming: Prospects and Constraints: A Review

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Abstract: Exhaustion of the natural resources, destruction of the agrosphere and environmental deterioration resulting from increased man-made environmental modification expressed as climate change, has posed serious threat to existence of humankind. Growing awareness of environmental and health issues associated with the intensive use of chemical inputs has led to interest in alternate forms of agriculture in the world. The best solution to former problem is organic agriculture. Organic farming unites all agricultural systems that maintain ecologically, economically and socially advisable agricultural production. The adverse effects of synthetic chemicals used in agriculture have changed the mindset of some consumers of different countries who are now buying organic with high premium for health. Policy makers are also promoting organic farming for restoration of soil health and generation of rural economy apart from making efforts for creating better environment. Organic farming is being practiced in more than 100 countries of the world. Organic farming through sustainable agriculture meets not only the food requirements of present generation in an eco-friendly way but also the requirements of future generations and maintains our environment. Organic farming, in spite of the reduction in crop productivity provides higher net profit to farmers compared to conventional farming. This was mainly due to the availability of premium price (20–40%) for the certified organic produce and reduction in the cost of cultivation. In view of rising population and demand for food production, conventional farming systems cannot be neglected but organic farming should be certified where it already exists and promoted to the newer areas to the extent possible because it seems safer bet for sustainable agriculture at a time when advanced technologies are still costly and have to be proved safe for long-term development.

Keywords: Organic farming, Sustainable agriculture, Eco-friendly, Conventional farming

Organic agriculture is developing rapidly and today at least 190 countries produces organic food commercially. Organic agriculture is practiced in almost all countries of the world and its share in agricultural land and farms are increasing (FiBL 2022). The market for organic products is increasing at a rapid rate, not only in the major markets like Europe, Japan and North America but also in many other countries including developing countries (Foster and Lampkin 2000, Lin 2003, FAO/ITC/CTA, 2001). The consumer demand for organic products has increased more than three-fold (although from low levels) in the recent past in global sales (Reganold and Wachter 2016). Some countries in Northern Europe are recently observing a rapid increase in the sales of organic foods. Organic food and drink sales reached 97 billion US dollars in 2017 according to Ecovia Intelligence (FiBL2019). In 2022, the countries with the largest organic markets were the United States (49.5 billion euros), Germany (15.0 billion euros), and France (12.7 billion euros). The largest single market was the United States (41 percent of the global market), followed by the European Union (44.8 billion euros, 37 percent), and China (10.2 billion euros, 8.5 percent). The highest per-capita consumption in 2022, with almost 100 euros, was found in Switzerland (418 euros), Denmark (384 euros) and Luxembourg (285 euros). The highest organic market shares were reached in Denmark (13.0 percent), Austria (11.3 percent) and Switzerland (10.8 percent) (FiBL 2022). The world's organic producers are highest in Asia (36%) followed by Africa (29%) and Europe (17%). Organic farming is growing rapidly since last decade on sustainable with annual increase of 20% (Avery 2007 and Lotter 2003).

Generally, man is dependent on plants for basic necessities such as food, fibre, medicine, clothing, shelter etc. The plant growth and yield in all ecosystems depend on the cycling and recycling of nutrients between the plant biomass and the organic and inorganic soil stores. Agriculture, over the years developed as a result of man's quest to feed himself, family and his animals. Through time man discovered that agriculture attracts various input from science, art and also a business of producing plants and animal products for the advantageous use of mankind. Plants are primary producers in agriculture. Plants by the process of photosynthesis, take in carbon dioxide from the air, moisture and nutrients from the soil and traps the energy from sun light thereby converting these simple compounds into complex food materials. Animals are secondary agricultural producers. They eat plants or parts of plants and convert the complex compounds present in plants into animal products such as eggs, meat, milk, hides and wool. Traditional/primitive agriculture relies on the soil, rainfall and the local species of plants and animals. Any plants and organisms which affect the productivity of useful plants and animals were avoided or controlled. The productivity in such system was quite low and capable of feeding the farmers and his family alone. Due to population pressure and increased urbanization, agricultural practices improved with use of high external inputs such as agro-chemicals for pest and weeds, inorganic fertilizers which in return helped to enhance productivity but with serious adverse effect on environment and making the entire system very unsustainable.

Agricultural production and yields during the last decades have been increasing in the industrialized countries along with global fertilizer and pesticide consumption. The rising global trade with agricultural products and the improved access to fertilizers and pesticides have changed agricultural systems. The rapid development in transportation and communication has enabled farmers to buy their inputs and sell their products further away in larger quantities. These developments resulted in increased food security, whereas a greater variety of food has been offered and diets have changed towards a greater share of meat and dairy products. However, such trend has led to a growing discrepancy among populations and agricultural systems, especially developing countries in Africa have seen very few improvements in production and food security. At the same time, the application of unsuitable farming techniques and the rapid increase of farming inputs use have contributed to the rise of environmental problems due to agricultural activities such as radical decline in biodiversity, pollution of surface and groundwater with pesticides and nitrates, soil degradation and to some extent, global warming (Tilman et al 2002). For further repositioning of agriculture for sustainable consumption and income, the knowledge of what is presently going on is needed to shape what will happen in future.

In the more industrialized countries, the increasing concern from the consumer community and from part of the farmers on the negative environmental consequences of intensive agricultural activity, also coupled with the increased demand for healthy food, have both contributed to develop agricultural systems based on sustainable farming practices, primarily focused to preserve the natural resources while ensuring reliable productivity of food. But unfortunately, global warming seems to be the major threat for food security, especially in tropical countries. It is assumed that global warming will worsen the irregularity of rainfall and the drought intensity in many countries. Meanwhile, intensive agriculture which is dependent on agro-chemicals and non-renewable fossil fuels is being responsible for over 20 % of global anthropogenic greenhouse gas emissions (Scialabba 2003). In Asia, this figure could slightly vary chiefly it may be higher as most of the fertilizers used here are nitrogen-based (Stoll 2002) and the industrial process of manufacturing nitrogen fertilizer emits nitrogen dioxide into the atmosphere which is a strong greenhouse gas. Since green revolution technologies is considered as the major food production system in the world but still there is growing evidence that the green revolution has, at its worst, increased inequality, worsened absolute poverty, and resulted in environmental degradation (IFPRI 2002).

In developing countries, agriculture is the vital sector for the socio-economic development of masses. The trend in agricultural production system from traditional/indigenous to modern agriculture has made the agriculture dynamic and improved overtime. Presently, there is another strategy known as organic agriculture, which is a production system that sustains and maintains the soil health, the ecosystem and the people living in that system and beyond. It is completely dependent on natural processes, biodiversity and cycles adapted that are understood by local agricultural farmers in their conditions but without making the use of external inputs having negative effects. Organic agricultural practices is a combination of innovations, art, science as well as business to promote the environmental gains and ensure fair relationships along with the good quality of life for all involved in it (Ibeawuchi et al 2015). Organic agricultural practices enhance productivity by the slow release of essential nutrients to the plants as well as maintains soil biological stand. This brings about increase in productivity without causing any adverse effect on the environment. Therefore, ensuring food security, mitigating poverty and conserving the essential natural resources is significantly important (Rothschild 1998) and is achieved through organic farming and various other means without deteriorating natural resources.

The major challenge for scientists is that it very difficult to feed the ever increasing population with organic food (Moghtader et al 2011). Safe production and secure food supply is one of the major need of low income countries to restore their reservoirs (Arshad and Shafqat 2012). The concept of food security revolves around the components of agriculture, environment, marketing, employment income, health & nutrition and public policy (Johan 1999). Organic farming with limited or no use of synthetic chemicals has huge potential to minimize these negative impacts on ecosystem. Therefore, organic farming has been considered as a major thrust area for achievement of Millennium Development Goals (MDGs) and to ensure sustainable development. Conversion of chemical based farming systems to organic farming contributes to diminish the contribution of agriculture to global warming. It therefore, contributes to the stability of the food supply which is threatened by the climate change (Aubert 2007).

Organic and biodynamic agriculture represent some of the various approaches to sustainable agriculture, and several techniques used in such methods (e.g. rotation of crops, inter-cropping, minimum tillage, integration of crops and livestock, mulching) are in fact practiced under various agricultural systems. However, various facts that makes organic and biodynamic agriculture unique, as regulated under various laws and certification programs is that: (i) almost all chemical and synthetic inputs are forbidden, (ii) genetically modified organisms (GMOs) are prohibited and (iii) soil binding crop rotations are mandatory (Anonymous 1999). Organic agriculture unites all agricultural systems that maintain ecologically, economically and socially advisable agricultural production (IFOAM 2002). These agricultural systems utilize the natural potential of plants, animals and landscapes and are aimed at the agricultural practice's harmonization with the environment.

Organic farming is an integrated production management system which promotes and enhances agro-ecosystem health including biodiversity, biological cycles and soil biological activity. It focus on the usage of management practices such as the use of off –farm inputs, taking into account that regional conditions require locally adapted systems. This is achieved by using agronomic, mechanical and biological methods where possible, without using any synthetic materials, to accomplish any specific function within the system (FAO 2002). Organic farming predominantly restricts the usage of external production factors (resources) by putting a limitation to the use of chemically-obtained fertilizers, pesticides and pharmaceutical preparations. Instead, in order to enhance the yield and protect the crops, organic farming involves other agro-technical methods and several natural factors. Organic farming is a type of agriculture that rely on various techniques such as green manuring, crop rotation, vermicomposting, biofertilizers, animal husbandry and biological pest control. Thus, organic farming involves cultivation of crop/plant by using organic manures that are environment friendly and supports the life of soil and other beneficial organisms in the soil. Organic farming is becoming popular in developing countries, where farmers make use of animals for tilling the land and manures prepared from dung and other waste material of animals. Thereby, organic farming supports the quality of production and crop yield (Auobamiri and Ahmad 2014). Most of the developed countries utilize synthetic chemicals to protect plants/crops from insects, pests attack and other plant diseases. The usage of synthetic chemicals may give high yield for some period of time and protects the plants but the continuous usage of such chemical in farming may result in inactivation of some useful organisms in soil; in addition to this, certain insects or pests and other diseases develop resistance to these chemicals and later the chemical may not show its effect on the insects, pests and other harmful organisms to the crops. Organic farming in some developing countries like India is not new approach and is being followed from ancient days. Bio fertilizers are prepared with beneficial microbes which release essential nutrients to soil and promote the crop growth and product yield without any environmental degradation (Rao et al 2014). Organic agriculture developed as a response to the industrialization of agriculture and its associated environmental and social problems. Since organic agriculture actually delivers overall advantages over conventional agriculture is however controversial. Some claim that organic agriculture are more profitable and eco-friendly (Reganold and Wachter 2016), while others question the role of organic agriculture in future sustainable food systems (Connor and Minguez 2012).

Organic agriculture adheres to the principles that have been developed by the specific local, climatic, economic, social, cultural and historical features. Organic agriculture is mainly based on four basic principles namely health, ecology, fairness and care (Juma 2007) and are key for sustainability in agriculture. Organic production systems can provide major contributions to farmer livelihoods and food supply stability by improving fertility of the soil, providing diversity and therefore, ensuring flexibility to food production systems in accordance to many causalities of climate change. Usually, a local marketing initiative's set up in organic farming and operating strategy should match its scope. The appropriate option thus, chosen will depend on the country, the location, nature and availability of product range, scale of planned operation and existing sector/market conditions (Wai 2000). The impact of organic agriculture in comparison to conventional agriculture has not been extensively studied including various economic and social aspects. Therefore, it is vital that every country should practice organic farming and should minimize the usage of synthetic chemicals, but the green revolution had brought enormous change in food production systems and now it requires organic form of green revolution by meeting the food requirement and to safeguard the soil life and the ecosystem (Sudadi and Sumarno 2014). The fertility of soil is declining with increase use of synthetic chemicals and the harmful organisms are developing resistance towards synthetic chemicals and these chemicals are dangerous to the ecosystem and the animals. Many countries export and import different food products like crops, fruits, seeds etc. but from these, some of the food products are banned to import due to high chemical content which would be detrimental for human health, if consumed (Ul-Haq et al 2014).

In India, the organic movement has its origin in the work of Howard (Howard, 1940) who devised and conceptualized most of the views which were later acknowledged by those people who became active in this movement. The objectives of environmental and socio-economic sustainability are the fundamentals of organic farming (Stockdale et al 2001). The key features comprises of safeguarding the long-term soil fertility by maintaining sufficiency through the use of legumes and biological nitrogen fixation, efficient recycling of organic materials inclusive of livestock wastes and crop residues and weed, diseases and pest control focusing primarily on crop rotations, natural predators, organic manuring and resistant varieties. The immense importance is laid on maintaining the fertility of the soil by returning all the wastes back to the soil primarily through compost to reduce the gap between NPK addition and removal from the soil (Chhonkar 2002). Today, the rapidly increasing population pressure has compelled many countries to use synthetic fertilizers and chemicals to enhance the productivity of farm for meeting their growing food requirements. The continuous and over usage of synthetic chemicals has, however, resulted in deteriorating the soil and human health along with environmental pollution. Therefore, in developed countries farmers are encouraged to convert their existing farms into organic farm.

The key factors influencing consumer demand for organic food is the health awareness and the willingness of the masses to pay for the organic high-priced produce. Generally, consumers of organic products are affluent, health conscious and educated group pushed by strong consumer demand, liberal price premium and concerns about the environment. Because of these unseen advantages, conventional growers are switching to organic farming. Agricultural practices of India date back to more than 4000 years and organic farming is very much native to this country. As mentioned in Arthashastra, farmers in the Vedic period had a fair knowledge regarding seed selection, soil fertility, sowing seasons, plant protection and crop sustainability in different lands (Sofia et al 2006). The farmers of ancient India followed the natural laws and this helped in maintaining the soil fertility over a considerably longer period of time (Chandra and Chauhan 2004). The modern studies concluded that instead of integration of the two forms (organic & inorganic inputs) so as to achieve better crop yields, the application of only organic inputs alone can fulfill the nutritional requirements of the crop. The interaction between organic and inorganic matter may result in either increase or decrease soil nutrients, depending on the planting and nutrient material in question (Frankenberger and Abdelmagid 1985).

Historical background and emergence of organic farming: Although the term 'organic farming' is gaining popularity in current era, but it was initiated in 10000 years back when ancient farmers started cultivation depending on natural sources only. There is short reference of several organic inputs in our ancient literatures like Arthashastra, Kautilya, Mahabharata, Ramayana, Rigveda etc. In fact, organic agriculture has descended from traditional agricultural practices that were being practiced in countless villages and farming communities. The major milestones in the area of organic farming are presented in Tables 1 and 2.

Stage of emergence (1924-1970): The commencement of organic farming could mark out back to 1924 in Germany with Rudolf Steiner's course on Social scientific basis of agricultural development and in his theory he considered the human being as part and parcel of a cosmic equilibrium that she/he must under and in order to live in harmony with the environment. Therefore, a balance must be maintained between the materialistic and spiritual phase of life (Herrmann and Plakolm 1991). These theories were applied to agriculture and laid the foundation of biodynamic agriculture (Kahnt 1986). It was developed at the end of the 1920s in Denmark, England, Germany, the Netherlands and Switzerland (Herrmann and Plakolm 1991, Kahnt 1986, Diercks 1986). In 1930, politician Hans Mueler gave momentum to organic-biological agriculture in Switzerland. His goals were at once economic, political and social as they anticipated on the ability of the farmer and a much more direct and less cluttered association between the production and consumption stages (Herrmann and Plakolm 1991, Niggli and Lockeretz 1996). Maria Mueler applied these theories to orchard production (Niggli and Lockeretz 1996). Hans Peter Rush, the Austrian doctor adapted these ideas and included them in developing a method for the greatest utilization of renewable resources (Gliessman 1990). Hans Peter Rush and Hans Mueler laid the hypothetical foundation for the organic-biological agriculture and its expansion in the Germanic speaking regions and countries (Niggli and Lockeretz 1996, Rigby et al 2001). Sir Albert Howard was the creator of the organic farming movement. His book 'An Agricultural Testament' summarized his research works at Indore in India of 25 years, where he developed the famed Indore composting process, which utilize the primordial art of composting on the scientific basis and explained the relationship between the health of the soil, plants and the animals (Du and Wang 2001). J.I. Rodale started his research and practice on organic farming in the United States of America. His main objective was to build up and revealed the practical methods of rebuilding natural soil fertility. By 1942, he published the magazine 'Organic gardening' (Coleman 1989). Lady Eve Balfour started her first study known as the Haughley experiment in which she compared the natural and conventional farming methods. Her ideas encouraged the development of the soil association that was founded in England in 1946. The main objective of the soil association was to return humus and soil fertility to their basic place in the biological balance. It was set up on the basis of theories given by Sir Albert Howard in his agricultural testament of 1940 (Soil association 2001). During 1950-1960s, organic farming (lemaire-boucher) began to embrace in France due to the awareness of doctors and consumers with regard to food and its effect on health (SOEL 2002). Later, Nature and progress association was founded. Mokichi Okada started natural agriculture in Japan in 1935. His major goals were to respect and focus on the function of soil and nature in the agricultural production, and to harmonize the relationship between nature and humans by enhancing soil humus so to have higher yields without the use of fertilizers and agricultural chemicals. The health and environmental issues became a concern in the 1950s-1960s of the last centuries in Japan and thus, it facilitated the development of natural agriculture. The fundamentals of natural agriculture became the essential contents of Japanese agricultural, standard of organic agricultural products (Sheng et al 1995, Yu and Dai 1995).

Stage of expansion (1970- 1990): The research and development programs for organic agriculture extended worldwide after the 1960s, especially, the expansion and dual polarity of organic agriculture started in 1973 with the oil crisis and the growing environmental issues. So, this was the right time for the new ideas, protest movements, appropriate sociological transformations and the proliferation of alternative life styles. The new thoughts comprises of rational use of natural resources, safeguarding the environment, realizing low input and high efficiency, ensuring food security and sustainable development of agriculture such as organic, organic-biological, bio-dynamic, ecological and natural agriculture were remarkably developed in their concepts, research and practical activities (Herrmann and Plakolin 1991, Rigbyet al 2001, Du and Wang 2001, May 2001, Pacini et al 2002, Conacher and Conacher 1998). In 1970, William Albrecht defines the ecological agriculture as the agriculture

Table 1. Historical perspective of organic farming

Ancient period	
Oldest practice	10000 years old, dating back to Neolithic age, practiced by ancient civilization like Mesopotamia, Hwang Ho basin etc.
Ramayana	All dead things - rotting corpse or stinking garbage returned to earth are transformed into wholesome things that nourish life. Such is the alchemy of mother earth – as interpreted by C. Rajagopalachari.
Mahabharata (5500 BC)	Mention of Kamadhenu, the celestial cow and its role on human life and soil fertility.
Kautilya Arthashastra (300 BC)	Mentioned several manures like oil cake, excreta of animals.
Brihad- Sanhita (by Varahmihir)	Described how to choose manures for different crops and the methods of manuring.
Rig Veda (2500- 1500 BC)	Mention of organic manure in Ria Veda 1, 161, 10,2500-1500 BC, is Green Manure in Atharva Veda II 8.3, (1000 BC). In Sukra (IV, V, 94, 107 112) it is stated that to cause healthy growth the plant should be nourished by dungs of goat, sheep, cow, water as well as meat. A reference of manure is also made in Vrksayurveda by surpala (manuscript, oxford, No 324 B, Six, 107-164).
Holy Quran (590 AD)	At least one third of what you take out from soils must be returned to it implying recycling or post-harvest residue.

Source: Bhattacharya and Chakraborty 2005

Table 2. Key milestones on organic farming

Sir Albert Howard (1900-1947)	Father of modern organic Agriculture, developed organic composting process (mycorrhizal fungi) at Pusa, Samastipur, India and published document"An Agriculture Testament".
Rudolph Steiner (1922)	A German spiritual Philosopher built biodynamic farm in Germany.
J.I. Rodel (1950), USA	Popularized the term sustainable agriculture and method of organic growing.
IFOAM	Establishment of "International Federation of Organic Agriculture Movement", in 1972
One Straw Revolution	Release of the book by Masanobu Fukoka (1975), an eminent microbiologist in Japan.
EU Regulation	EU Regulation on Organic Food, 1991
Codex	Codex guideline on organic standard, 1999.

Source: Bhattacharyya and Chakraborty 2005
The development of the organic farming worldwide had gone through three stages namely emergence, expansion, and growth in chronological sequence

system in which the ecological principles were introduced to the production system of organic agriculture (Coleman 1989). In England, the soil association developed the logo in addition to the legally formulated specifications and quality controls that ensures legal guarantee for the consumers (Yussefi and Willer 2003; Soil Association 2001). The largest non-governmental organization of organic agriculture in the world is IFOAM (International Federation of Organic Agriculture Movements) was founded in1972 (Niggli and Lockeretz 1996). The main organic agriculture associations and research institutions in the world such as FNAB (Federation Nationaled' Agriculteurs Biologiques), FiBL (Forschungsinstitutfuer Biologischen Landbau), which is currently the largest organicresearch institute worldwide, were founded in 1970s-1980s (FA0 2002, Greene 2001). These organizations played the major role in standardization of the produce and market of organic products and support research and consumer's awareness. The governmental action on organic farming gradually began in the different regions and countries as the guidelines for organic farming. In the United States, the regulation on organic farming was implemented in 1974 in Oregon and in California in1979 respectively (Greene 2001). The United States Department of Agriculture (USDA) initiated the research program on organic farming on the large scale on 69 organic farms of 23 states and published the report and recommendations on organic farming explaining the development status and potential remained as issues and the research directions. In this report the guidelines and definition for the organic farming was specified, and an action plan for the development of organic farming was called for. The publication of the report and development of organic farming in the United States was a milestone in legislation (USDA 1980). In France, the organic farming regulation was put into practice in 1985 (Graf and Willer 2001, Dai 1999).

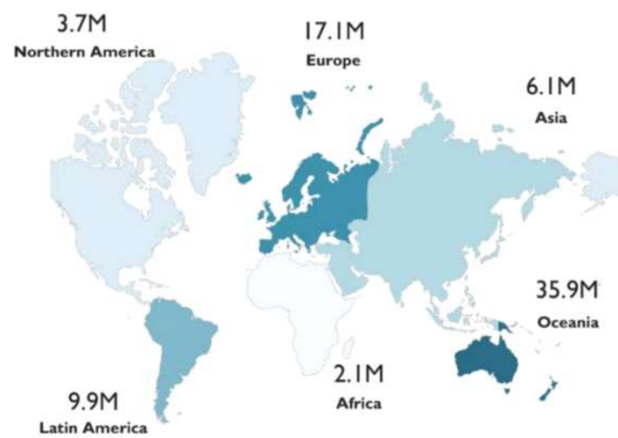
Stage of growth (since 1990): The organic farming altogether goes through a new stage of growth worldwide in the 1990s. The trade organizations for organic products were founded, organic farming regulations were implemented, and organic farming movement was promoted by both the governmental and non-governmental organizations. The first BioFach Fair was emerged in Germany in 1990 which is currently the largest fair for organic products worldwide (ITC 1999). The federal government of the United States published the regulation for organic food products in 1990 (Greene 2001). The European Commission adopted EU regulation 2092/91 on organic agriculture in 1991. Since 1994, this regulation became a law and was granted in almost all European Union countries (IFOAM and FA0 2002). Simultaneously, the North America, Australia and Japan, the major markets for organic products, published and implemented organic regulations in succession (Yussefi and Willer 2003, Niggli and Lockeretz 1996). Both, the International Federation of Organic Agriculture Movements (IFOAM) and the Food and Agriculture Organization of the United Nations (FAO) set out guidelines for the production, processing, labeling and marketing of organic produced foods in 1999. These guidelines were of prime importance for international harmonization of the organic farming standards (FAO and WHO 2001). Organic farming had rapidly developed worldwide during this stage. The main drivers of steady market and production growth were the commitment of many retail chains as well as favorable policy conditions. Together these conditions have provided an opportunity for harmonious increase in supply and demand. The legal framework and state support for organic farming research and development was relatively gaining importance since the end of the 1990s.Therefore, organic agriculture is the holistic production management systems which promotes and enhances agro-ecosystem health including biodiversity, biological cycles and soil biological activity. It laid emphasizes on the use of management practices particularly the usage of off farm inputs, taking into account that regional conditions require locally adapted systems. This is achieved by using, where possible, cultural, biological and mechanical methods, as opposed to using synthetic materials, to fulfill any specific function within the system (FAO and WHO 2001). Terms such as organic, biological, biodynamic and ecological are recognized as organic farming in the EU regulations (Yussefi and Willer 2003, FAO 2002, FAO and WHO 2001).

Organic agriculture worldwide: Approximately, organic farming is being practiced in 190 countries of the world and the area under organic agriculture is continuously growing (FiBL 2022). The total organically managed area is 74.9 million hectares (including conversion areas) in 2022 which is around 1.47 million hectares more than in 2016. About 1.1 percent of the agricultural land is organic. In 11 countries, 10 percent or more of the farmland is organic (FiBL 2019). The major part of the global organic land area is located in Oceania, Europe and Latin America (Yussefi and Willer 2003, FiBL 2022).

Europe: As of the end of 2020, 17.1 million hectares were managed organically by more than 420,000 farms in Europe. In the European Union, 14.9 million hectares were under organic management with almost 350,000 organic farms (FiBL 2022). 3.4 percent of the European agricultural area and 9.2 percent of the agricultural area in the European Union is organic. Organic farmland has increased by over 0.7 million hectares compared to 2019. The countries with the largest organic agricultural areas were France (2.5 million hectares), Spain (2.4 million hectares) and Italy (2.1 million hectares). In 15 countries, at least 10 percent of the farmland was organic: Liechtenstein had the lead (41.6 percent), followed by Austria (26.5 percent) and Estonia (22.4 percent). Retail sales of organic products totalled 52 billion euros in 2020 (European Union: 44.8 billion euros), an increase of 15 percent since 2019. The largest market for organic products in 2020 was Germany, with retail sales of 15.0 billion euros, followed by France (12.7 billion euros) and Italy (3.9 billion euros). In Europe, 46 countries have legislation on organic agriculture (FiBL 2022). The legal protection, grants under rural development programs, and a European as well as several national action plans were the major support for the development of organic farming in the European Union and neighboring countries. One of the chief instruments of the European Action Plan on organic food and farming was an information campaign which was launched during 2008 with the objective of enhancing awareness of organic farming throughout the European Union.

North America: In Northern America, over 3.7 million hectares of farmland were managed organically in 2020. Of these, 2.3 million were in the United States and 1.4 million in Canada, representing 0.8 percent of the total agricultural area in the region. US organic food sales soared to a new high in 2020, jumping to 56.5 billion US dollars (49.5 billion euros). The Canadian organic sector experienced disruptions in 2020 as the growing season's beginning collided with the national lockdown, causing global disruptions. Despite the obstacles, organic acreage increased by 19 percent to more than 3.5 million acres or almost 1.5 million hectares. Organic food and beverage sales in 2020 topped 6.5 billion Canadian dollars (4.3 billion euros), about 33 percent higher than in 2017. Canada continues to be a net importer of organics globally, but exports have stagnated in recent years, with 2020 data showing organic exports at more than 600 million Canadian dollars. Organic equivalency arrangements continue to provide market access for importers and exporters (FiBL 2022).

Latin America and the caribbean: In Latin America, over 270'000 producers managed over 9.9 million hectares of agricultural land organically in 2020. This constituted 13.3 percent of the world's organic land and 1.4 percent of the region's agricultural land. The leading countries were Argentina (4.4 million hectares), Uruguay (2.7 million hectares) and Brazil (1.3 million hectares). The highest organic shares of total agricultural land were in Uruguay (19.6 percent), French Guiana (11.3 percent) and the Dominican Republic (4.8 percent). Many Latin American countries remain important exporters of organic products such as coffee, cocoa and bananas. In Argentina and Uruguay, temperate fruit and meat are key export commodities (FiBL 2022).



Source: (FiBL Survey, 2022)

Fig. 1. Organic agricultural land in hectares (M=millions)

Asia: The total area dedicated to organic agriculture in Asia was more than 6.1 million hectares in 2020. There were nearly two million producers, most of whom were in India. The leading countries by area were India (2.7 million hectares) and China (over 2.4 million hectares). Twenty countries in the region have legislation on organic agriculture, and six countries are drafting legislation (FiBL 2022). Organic wild collection areas play a vital role in China and India, while aquaculture is significant in Bangladesh, China and Thailand. Even though most of the production is for export purposes but still markets continue to provide domestic growth support in the region. Mixtures of regulatory frameworks co-exist in the region. The government standard-setting bodies have set voluntary organic standards in Malaysia, Nepal, Laos, Thailand, the United Arab Emirates and Vietnam. The policy makers have recognized the positive impacts of organic agriculture on economy and local communities, climate change and the carbon footprint of agriculture so they began to integrate organic agriculture into sustainable agriculture development initiatives (FiBL 2019).

Africa: There were more than 2 million hectares of certified organic agricultural land in Africa in 2020. Africa reported 149´000 hectares more than in 2019, a 7.7 percent increase, and nearly 834´000 producers. Tunisia was the country with the largest organic area (more than 290´000 hectares in 2020), and Ethiopia had the largest number of organic producers (almost 220´000). The country with the highest percentage of land devoted to organic farming in the region was the island state of Sao Tome and Principe, with 20.7 percent of its agricultural area dedicated to organic crops.

The majority of certified organic products in Africa are destined for export markets. Key crops are nuts, olives, coffee, cocoa, oilseeds and cotton (FiBL 2022). The majority of certified organic production is in Africa and is mainly meant for export markets. The European Union, as the major recipient of these exports, is Africa's largest market for agricultural produce. In 2011, considerable achievements were reached especially the African Union's (AU) decision to support organic farming and their subsequent leadership in promoting and further developing strategies for organic farming policies such as the African Ecological Organic Agriculture Initiative and the IFOAM-African Union Conference that took place in November 2011 in Nairobi (FiBL 2019).

Oceania: This region includes Australia, New Zealand and the Pacific Islands states. Altogether, there were over 16'000 producers on 35.9 million hectares, constituting 9.7 percent of the region's agricultural land and half the world's organic land. More than 99 percent of the organic land in the region is in Australia (35.7 million hectares, mostly extensive grazing land), followed by New Zealand (over 79'000 hectares) and Papua New Guinea (over 72'000 hectares). The highest organic shares of all national agricultural land were in Samoa (14.5 percent), followed by Australia (9.9 percent), Papua New Guinea (6.1 percent), Fiji (4.5 percent), French Polynesia (3.4 percent) and Tonga (3.2 percent). Four countries in Oceania have legislation on organic agriculture, and twelve countries have a national standard but no organic legislation (FiBL 2022).

Standards, Legislation, Policy Support

According to the FiBL survey on standards and legislation, 93 countries had organic standards in 2018, and 16 countries were in the process of drafting legislation. At least29 countries in Africa, Asia, and Oceania, have adopted national or regional standards for organic agriculture. The European Union (EU) adopted the basic act of its new organic regulation, which will come into force in 2021. In 2019 and 2020, the secondary legislation – the delegated and implementing acts for production, controls, and trade – will be drafted and adopted. In Russia, the law on organic production was signed, which will come into force in 2020. In Ukraine, the Organic Law was adopted in August 2018, and it came into force in August 2019. Although organic farming as a concept has existed for almost 100 years, it has onlygarnered significant attention from consumers, environmentalists, farmers and ultimately policy-makers worldwide since the mid-1980s. Initially set by private scheme owners, mainly organic farmers' organizations, in the 1980s, organic standards started to become part of a legislative process that brought the enforcement of national and regional organic regulations to help facilitate international trading. At the same time, an increasing number of governments began supporting organic agriculture beyond regulation, and there is a growing number of government policies and programs that support organic agriculture development, such as subsidy schemes, market development support, capacity building, and research investment. A recent trend is that municipalities and cities play an increasing role in supporting the development of the organic sector while legislating on broader objectives related to sustainable growth and development of urban areas.

Table 3. Percentage of area under organic farming among different countries in the world

Country	Percentage area under organic farming
USA	0.6
UK	2.7
Germany	10.2
Argentina	3.0
Austria	26.5
Australia	9.9
Japan	0.3
Switzerland	19.6
South Africa	0.04
Italy	16.0
India	1.5
Pakistan	0.08
Sri Lanka	2.6

Source: FiBL 2022

Participatory guarantee systems (PGS): PGS are locally focused quality assurance systems. PGS have proven to be an affordable alternative to third-party certification, an effective tool to develop local markets for organic produce and are particularly appropriate for small-scale farmers. Based on the data collected through the Global PGS Survey 2017 conducted by IFOAM – Organics International, PGS initiatives are established in 66 countries, with at least 311,449 farmers involved in PGS initiatives worldwide. This includes mostly small farmers and small processors. It is estimated that there are currently at least 241 PGS initiatives, of which 127 are fully operational.

Need for organic agriculture: In current scenario, the European Union has banned Indian contingent of mangoes on account of high pesticidal residues. The Indian chillies undergo the same treatment in Saudi Arabia, which happens to be the fifth-largest importer of vegetables from India. Even in India, the most commonly and intensively used pesticide such as endosulphan has been completely banned from its usage in many crops including fruits and vegetables. All these are signals that the concern regarding food safety is getting prominent in both developing and developed economies. Since extensive use of synthetic inputs resulted in various issues such as over-exploitation of the groundwater resources, depletion of fertility of soil and higher susceptibility of crops to various insect-pests attack and diseases, (Sidhu 2002) organic agriculture is being seen as an alternative in some quarters. But it has to be well understood that organic agriculture aims at optimization rather than maximization. It has been estimated that ushering in organic cultivation in about 10 million hectares by 2020 could save Rs. 10,000 crores of government exchequer with the reduction of fertilizer subsidies (Pratap 2006).

Scope and mode to promote organic agriculture: India is one of the leading fruit producing countries in the world, producing about 10% of the world's fruit production (Indian Horticulture Database 2014). Agriculture is the backbone of the Indian economy as nearly 67% of population and 55% of the total work force is dependent on agriculture and other allied activities. Thereby, agriculture sector has the remarkable potential to grow and satisfies the ever increasing demands Indian population. It has been assumed that Indian agricultural should have the growth rate of 4% or more so as to achieve a double digit GDP growth rate (Chandrashekar 2010). The scope and prospects of potential organic agriculture in India is evident by the fact that the farm sector has plentiful organic resources like crop residue, water, livestock, aquatic weeds, forest litter, rural & urban solid wastes and agro- industries, bio-products (Bhattacharya and Chakraborty 2005). The adherence of huge population of the farmer to the natural law in ancient India has played a vital role in maintaining the fertility of soil over a longer period of time (Chandra and Chauhan 2004). The inbuilt advantages such as its diverse agro-climatic regions, local self-sustaining agri-systems, substantial number of progressive farmers and ready availability of inexpensive manpower translate into the potential to cultivate organically a vast basket of products (Munda 2006). More than 65% of the country's cultivated area is rainfed on crop rotation, crop residues, legumes, animal manure and biological pest control. Majority of the farms are of subsistence type in remote and marginal areas. Organic farming is gaining much importance among Indian farmers and entrepreneurs, especially in rain-fed zones, low productivity areas, hilly areas and the north-eastern states where fertilizer consumption is less than 25 kg/ha/year (Mitra and Devi 2016). In fact, North Eastern Region (NER) is considered as home to some niche crops such as Assam lemon, Joha rice, medicinal rice and passion fruits which has high market demands and accounts for 45 per cent of total pineapple production in India (Munda et al 2007). Viewing the benefits of organic agriculture, Uttaranchal and Northeast states have declared themselves as organic-farming states while Mizoram and Sikkim have declared their intentions to shift to total organic farming (Mitra and Devi 2016).Sikkim, by practicing organic farming on approximately 75,000 ha of agricultural land has become India's first fully organic state. Nagaland has 3000 ha area under organic farming whereas Meghalaya has committed to certifying 200,000hectares of land as organic by 2020 (Hill 2016). These regions receive very high rainfall (2000 mm to11000 mm per annum) resulting to the massive production of biomass including weeds, herbs and shrubs (Munda 2006) when a large part of the land falls under forests, pastures, wastelands etc. Lotter et a l(2003) estimated that organic farming performed better in area shaving extreme rainfall because of the less run-off and higher absorption of water in the field. The encouragement for organic agriculture initiated first in the rain-fed areas especially in the hilly areas where there is little or no use of chemical fertilizers and other agro-chemicals due to poor resources with smallholder farmers (nearly 60% of farms in India are less than one ha). Jammu & Kashmir mostly have a hilly topography. Thereby, majority of its area suffers from run-off and soil erosion losses. Besides, more than 70per cent of the arable land is un-irrigated where cultivation of crops alone is very risky (Gupta et al 2005 and Chandra 2014). The varied agro-climatic zones with potential of diversification makes possible to convert at least these areas into organic farming easily (Wani et al 2013). With the success of organic farming, some awakening has initiated in the western and southern states like Karnataka and Maharashtra (Khanna 2012).

Organic farming v/s conventional/modern farming: The organic agriculture differs from conventional agriculture not only gradually but fundamentally. The continuous practice of organic methods thus, seems to provide a new quality in how the agro-ecosystem works. This functioning cannot be explained by summing up single ecological measures. Organic farming tends to improve fertility of the soil in a way and to an extent which cannot be achieved by conventional farming even if the later constantly respects some ecologically principles. Organic agriculture is one of several to sustainable agriculture and many of the methods used (e.g. rotation of crops, inter-cropping, mulching, double digging, integration of crops and livestock) are practiced under various agricultural systems. In organic agriculture almost all synthetic inputs are prohibited and soil building crop rotations are mandated, it is this fact that makes organic agriculture unique. The fundamental rules of organic production are that natural inputs are accepted and synthetic inputs are prohibited, but there are exceptions in both cases. On other hand, today's modern chemical farms have little use for the skilled husbandry which was once the guiding principle of working the land. The main focus today is primarily on productivity -high input in exchange for high returns and productivity (mostly diminishing now however for farmers worldwide). Four important considerations namely what happens to the land, the food it produces, the people who eat it and the communities which lose out are mostly overlooked. The various drawbacks/hazards of modern chemical farming are summarized in Table 4.

Methods of Organic Farming

Soil management/ maintenance of soil fertility: Soil is the foundation of terrestrial life. Specific soil management practices are required to safeguard and conserve the soil resources (Ghorab and Khalil 2016). Improvement and preservation of soil fertility is the major issue during introduction of organic farming technology. Studies reveals that organic farming conserves fertility of the soil and improves system stability better than conventional farming (Stolze et al 2000, Shepherd et al 2003). A study of cotton production under organic conditions in India showed similar

Table 4. Effects of modern farming system

Land exhaustion	The constant use of artificial fertilizer, together with a lack of crop rotation, reduces the soil's fertility year by year.
Fertilizers	High yield levels are produced by applying large quantities of artificial fertilizers, instead of by maintaining the natural fertility of the soil.
Nitrate run-off	About half of the nitrate in the artificial fertilizer used on crops is dissolved by rain. The dissolved nitrate runs off the fields to contaminate water courses.
Soil erosion	Where repeated deep ploughing is used to turn over the ground, heavy rains can carry away the topsoil and leave the ground useless for cultivation.
Soil compaction	Damage to the structure of soil by compression is a serious problem in areas that are intensively farmed. Conventional tillage may involve a tractor passing over the land six or seven times, and the wheelings can cover up to 90 per cent of a field. Even a single tractor pass can compress the surface enough to reduce the porosity of the soil by 70 per cent, increasing surface run-off and, therefore, water erosion. In the worst cases, the surface run-off may approach 100 percent -none of the water penetrates the surface.
Agricultural fuel	As crop yields grow, so does the amount of fuel needed to produce them. European farmers now use an average of 12 tons of fuel to farm a square kilometer of land; American farmers use about 5 tons (1987 figures).
Biocide sprays	The only controls used against weeds and pests are chemical ones. Most crops receive many doses of different chemicals before they are harvested.
Cruelty to animals	On most modernfarms, all animals are crowded together indoors. Complex systems of machinery are needed to feed them, while constant medication is needed to prevent disease. The cruelty involved in managing, breeding, growing and slaughtering farm animals today is unimaginably repulsive and horrifying.
Animal Slurry	With so many animals packed together in indoor pens, their manure accumulates at great speed. It is often poured into lagoons which leak into local watercourses, contaminating them with disease-causing organisms and contributing to algae blooms.
Imported animal feed	Many farms are not self-sufficient in animal feed; instead they rely on feed brought into the farm. This often comes from countries which can ill afford to part with it.
Stubble burning	In countries where stubble is burned, large amounts of potentially useful organic matter disappear into the sky in clouds of polluting smoke.
Loss of cultivated biodiversity	Large and other chemical farms tend to be monocultures growing the same crop and crop variety
Threat to indigenous seeds and animal breeds and species	Native cultivars and animal breeds lose out to exotic species and hybrids. Many native animal breeds are today threatened with extinction. The same holds true for many indigenous plant varieties which have disappeared within the space of one generation.
Habitat destruction	Agribusiness farming demands that anything which stands in the way of crop production is uprooted and destroyed. The wild animals and plants which were once a common sight around farms are deprived of their natural habitat and die out.
Contaminated food	Food, both plant and animal products, leaves the farm contaminated with the chemicals that were used to produce it.
Destruction of traditional knowledge systems and traditions	Rural indigenous knowledge and traditions, both agricultural and non-agricultural, is invariably connected to agriculture and agricultural systems.
Control of agricultural inputs and food distribution channel	The supply and trading in agricultural inputs and produce is in the hands of a few large corporations. This threatens food security, reducing the leverage and importance of the first and the last part of the supply chain - the farmer and the consumer.
Threat to individual farmers	Chemical agriculture is a threat to their livelihoods and changes their lifestyles, unfortunately not for the better.

Source: www.localfoodworks.org

yield levels as in modern cultivation techniques, but the quality of the soil showed advantages for the organic system as indicated by soil organic matter, water stable aggregates and mean weight diameter (Blaise 2006). The fertility of the soil is maintained by several ways under organic farming (Partap 2010) such as optimization of agricultural crop within each farm; optimum and efficient use of available organic fertilizing resources (humus, turf, turf-and-humus composts, putrid mud, organic wastes of agricultural production and others); taking the advantages of diversification by increasing areas under perennial grasses, application of bacterial substances and expanding the areas under green fodder; recommencement of planned chemical land reclamation, which would make use of local deposits of limestone and chalk; use of local raw material resources for enhancement of soil fertility (defecate, glauconites, phosphorites, phosphate slag, sapropels, zeolites and others); limiting the expansion of areas under harmful crops, which can further worsen the phytosanitary state of the soil; introduction of minimum tillage & widecut tillage methods and direct sowing technology; application of contour structural arrangement of the territory in land use, which presumes optimization of the state of natural environment within the territory of watersheds or ravine and gully systems; developing field-protecting and water-protecting measures.

Ecological benefits: The ever rising concern about environmental degradation, declining natural resources and urgency to meet the food requirements of the increasing population are forcing farm scientist and policy makers to critically examine and provide an alternative to chemical agriculture. Nemecek et al (2005) found greenhouse warming potential in organic systems 29 to 32 percent lower on per ha basis than in a mineral fertilizer system and 35 to 37 percent lower than in the conventional manure-based system. The economic returns from the ecological farming system are really significant, if one gets a premium price for the organically grown rice. The declines in productivity or no effect on yields is over looked by the higher prices that farmers get for their organic produce (Rao et al 2006). Various studies have confirmed that organic agriculture is productive and sustainable (Mader et al 2002).

Efficient energy utilization: The requirement of energy for organic farms in the production process as measured per rupees of produce is only one third of what it is required for their conventional counterparts. This is because N fertilizer and pesticides are not used by organic farmers and the comparison of total energy input/ha with total energy output favors organic farming systems. In one study it was revealed that the soil organic matter was relatively higher inorganically managed soil in comparison to conventional soil despite of similar contents of organic carbon (Marinari et al 2007). The nitrate leaching can only be reduced by carefully managing crop rotations including catch and cover crops (Thorup-Kristensen et al 2003). Meanwhile, a study conducted by Hoeppner et al (2006) on the impact of organic versus conventional management on energy use, energy output and energy-use efficiency revealed that a) the energy consumption was 50% lower with organic as compared to conventional management b) energy output was 30% lower with organic in comparison to conventional management c) the efficiency of energy (output energy/input energy) was highest in the organic management.

Superior food quality: Nowadays, food quality is one of the main concerns of scientists as well as consumers. Nitrates in water and farm produce, pesticides residues, desirable components, keeping quality and physiological imbalances are some of the important characteristics of food quality. It is most often ignored fact that by applying integrated methods, differences resulting from cultivation methods are mostly in favor of the organic variants (Velimirov 2006). The synthetic toxicants are considerably reduced in organic foods, if not completely avoided (Baker et al 2002, Mahnke-Plesker et al 2005). Population belonging to higher and middle economic status are more concerned about the food quality and therefore are willing to pay higher prices for organic food products.

Waste utilization: The ever growing prices of chemical fertilizers have facilitated the usage of organic wastes in the fertilizer practices on the farm. Good manure management implies improved fertilizers value of manure and slurry and fewer nutrient losses. Composting of all organic wastes in general and of Farm Yard Manure (FYM) or feedlot manure in particular is important in organic farming. The self-sufficiency of nitrogen in organic systems is a major advantage in times of shortage of fossil energy (Cormack 2000). Sewage and sludge use for crop production can form an important component of organic farming, if treatment and application methods are improved further. Lotter et al (2003) found that water holding capacity in organic plots was approximately 100 percent higher than in conventional plots during torrential rains.

Use of traditional knowledge: Most countries have utilized different kinds of traditional organic materials to improve or enhance the productivity and fertility of their agricultural soils. However, several years ago, organic recycling practices in some countries were mainly replaced with chemical fertilizer which were applied to high yielding cereal crops that responded to a high level of fertility and adequate moisture including irrigation. Consequently, the importance of organic matter to crop production and its proper use in soil management is often overlooked or sometimes forgotten. Due to these changes and the failure to implement effective soil conservation practices, the agricultural soils in a number of developing and developed countries have suffered from serious degradation and decrease in productivity because of nutrient run-off, excessive soil erosion and decreased soil organic matter levels. Therefore, in order to achieve self-sufficiency in utilization of organic materials such as usage of agricultural residues and urban wastes to protect agricultural soils from water and wind erosion and to prevent nutrient losses through run-off and leaching, organic farming has been looked as the most reliable method of agricultural production.

Integrated Intensive Farming System (IIFS) or Intensive use of resources: IIFS comprises the intensive utilization of farm resources. In order to ensure environment sustainability, such intensification should be based on techniques which are knowledge intensive and which replaces market purchased chemical inputs with farm grown organic/biological inputs. It is concluded that organic agriculture encourage more species and have more abundance of organism groups than conventional farming that ensures better utilization of wide variety of resources (Bengtsson et al 2005). Pretty et al (2006) suggested several ways to improve water use efficiency in organic agriculture such as reducing evaporation through minimum tillage, using more water-efficient varieties and inducing microclimatic changes to reduce crop water requirements.

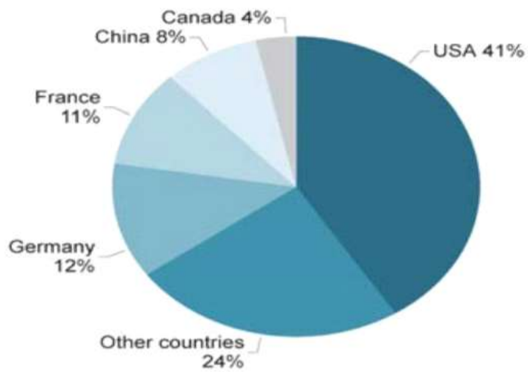
Economic Benefits: Partap (2006) in his recent study of Indian market observed that nowadays there are adequate numbers of people who are willing to pay more for safe food supplies from organic market. Some main findings from research on yields suggested that yield equivalent to or better than conventional agriculture can be achieved under organic systems, although often they are not and yields decrease during conversion period but then improve afterwards (Wynen 1994, Stonehouse et al 2001, Mendoza 2002). The estimates made by the International Fund for Agricultural Development (IFAD) reported that the income of associated small farmers in organic farming can increase substantially (Giovannucci 2005) and Partap and Vaidya (2009).

Biodiversity conservation: The number of species is more in organic grasslands as compared to conventional grasslands, as a result of which the plant communities are richer in species and structure (Frieben 1997). In European organic farming systems, many researchers have found greater diversity and abundance of soil and surface-living arthropods such as beetles, parasitic flies, spiders and wasps as well as non-pest butterflies and many other invertebrate species in comparison to conventional farming systems (Feber et al 1997, Stolze et al 2000, Tybrik et al 2004). Organic farming systems are the most convenient tool used by the planners to balance production and conservation (Hole et al 2005). Therefore, many projects and schemes worldwide working to conserve indigenous varieties and seed banks are linked to organic agriculture projects (Stolton 2002).

Role of organic farming in sustainable agriculture: In India, about 1.5 million hectare area is under organic farming (this includes certified and area under organic conversion) with 835,000 number of certified organic producers. This accounts for about 2.59% of total agricultural land (Ramesh et al 2010). The majority of small farmers utilize locally available resources in India. As such in many marginal areas of India, organic farming is present not by choice but by default. In organic animal husbandry, integration of livestock with cropping or integrating more than one livestock species can be the basis of a sustainable and balanced farming system, allowing effective resource use and nutrient recycling (Subrahmanyeswari and Chander 2008). The future of organic livestock farming appears to be bright as compared to intensive livestock production especially in dry land areas of India (Chander et al 2007). In rainfed areas, livestock is the major source of occupation for the millions of Indian small scale farmers because crops may fail but livestock sustain the life of poor farmers. The maintenance cost of these livestock is very low in comparison to the crossbreds. This type of mixed farming system is common in India. The farmers have little knowledge about the systematic and scientific approach of organic agriculture management of farm (Tewari and Tewari 2007). However, it is mandatory to provide resources/inputs to the organic farmers in the form of technical knowledge so as to enable their livestock systems to be modified and certified which is essential in organic production systems (Subrahmanyeswari and Chander 2008).

Global market for organic food: The organic food market continues its positive trajectory, with global sales reaching 97 billion US dollars in 2017. Organic crops are now grown in almost every country, however demand remains concentrated. The Figure below shows that North America and Europe comprise almost 90 percent of global revenues. These two regions account for just one quarter of the organic land area. Although internal markets are now developing, much of the organic crops grown in Asia, Africa and Latin America are destined for export markets.

North America: North America remains in the pole position, with the region's organic food market valued at 48.7 billion US dollars in 2017. The US has the largest market for organic foods in the world, worth 45.2 billion US dollars. The North



Source: FiBL-AMI survey, 2022, based on retail sales with organic food

Fig. 2. Global market for organic foods: Distribution of retail sales by country 2020

American organic food market is characterized by mergers, acquisitions and investments. Such activity has led to large operators, which operate at every level of the supply chain. White wave Foods, a leading organic food enterprise, was set up by the purchase and merger of several organic food entities. The French multinational Danone acquired White wave Foods for 12.5 billion US dollars in July 2016. General Mills, a large American food company, bought Annie's in 2014. It also owns a brace of other organic food brands. UNFI, a leading wholesaler and distributor of organic foods, acquired Supervalu in July 2018. Supervalu is a conventional supermarket chain, with about 3000 American stores. At the retail side, Whole Foods Market became the world's largest natural and organic food retailer by buying rivals in USA, Canada and the UK. It was bought by Amazon for 13.7 billion US dollars in June 2017. Amazon is now actively promoting the Whole Foods Market 365 and related private labels on its online platform.

Europe: Valued at 39.6 billion US dollars, the European market for organic foods is the second largest in the world. Healthy growth continued in most country markets in 2017, with some countries (such as France and Denmark) reporting exceptional growth. Europe has the largest concentration of organic food retailers in the world. Most are located in Germany, France, and Italy. Much of the growth however is coming from mass market retailers, such as supermarkets, hypermarkets, and discounters. Almost all leading food retailers are marketing organic foods under their private labels. In countries like Switzerland and Denmark, retailer private labels generate the most sales for many organic product categories. Central & Eastern European (CEE) countries, such as Poland, Hungary, and Romania, have traditionally been important growers and exporters of organic crops. However, internal markets are slowly developing in these countries.

Other regions: The combined value of the organic food market in other regions (Asia, Australia, Latin America, and Africa) totaled 8.7 billion US dollars in 2017. Asia has the third largest market for organic products. Historically, the most important consumer markets were in Japan and South Korea; most developments are now occurring in the Chinese and Indian market. A number of organic food enterprises are being set up to cater for the local market. For instance, over ten organic dairy companies have been set up in China in the last decade to cater for the domestic market. In Asia, a transition is taking place whereby countries are moving from an export to domestic focus. Organic foods are in demand as a growing middle class seeks food products that are better for their health and avoid contentious agricultural chemicals.

China has a large market for organic products partly because the country has experienced a number of food scandals; these include selling rotten meat, sewage oil in food products, contaminated pork and beef, as well as numerous incidents of adulteration and counterfeiting. Brazil has the largest market for organic products in Latin America. Similar to Asia, demand is coming from a growing middle class that is seeking healthy nutritious foods. Conventional food retailers comprise most organic food sales. Farmer markets are also important in Brazil, with many producers selling direct to consumers. Other Latin American countries, such as Argentina, Peru, Chile, and Colombia, have export oriented organic food markets. Australia and New Zealand also have important markets for organic products. Both countries are established as leading exporters; organic products include beef, lamb, kiwi fruit, apples, pears, onions, wine, and dairy products.

Current scenario of organic farming in India: The 'Sevagram Declaration' played a vital role for promotion of organic agriculture in India since January 1994. Organic farming has grown many folds with the passage of time due to number of initiatives at government and non-government level. The National Programme on Organic Production (NPOP) defined its regulatory framework while the National Project on Organic Farming (NPOF) has represented the promotion strategy and provided necessary support for area expansion under certified organic farming. Before the implementation of NPOP during 2001 and introduction of accreditation process for certification agencies, there was no institutional arrangement for estimation of organically certified area. Initial estimates during 2003-04 suggested that approximately 42,000 ha of cultivated land were certified organic. By 2009 India had brought more than 9.2 million ha of land under certification and it has been increased further. According to the International Fund for Agriculture and Development (IFAD) about 2.5 million hectares of land was under organic farming in India in 2004. Further, there are over 15,000 certified organic farms in India. India therefore is one of the chief suppliers of organic food to the developed countries. No doubt, the organic movement has again started in India. Organic food and farming systems are a promising and innovative means of handling the challenges faced by the world in the area of agriculture and food production. Organic production has encouraged dynamic market growth, contributed to farm incomes and created employment for more than three decades now. At the same time, it delivers public goods in terms of animal welfare, rural development and environmental protection. In addition to this, the development generated by the organic sector have played a vital role in pushing agriculture and food productions generally towards sustainability, quality and low risk technologies. The various advantages of organic farming for small farmers all over the world include low capital investment, high income, ability to achieve higher premium in the market and the ability to use traditional knowledge. According to a research conducted by the Office of Evaluation and Studies (OE), International Fund for Agriculture Development (IFAD), small farmers in China, Latin America and India can benefit significantly from organic farming and will help in mitigating poverty in these countries. Organic farming tends to minimize modern farmers struggles which involves various debts and farmland mortgages. Organic farming refers to means of farming that does not involve usage synthetic inputs such as chemical fertilizers and chemical pesticides. Numerous small farmers have been practicing organic farming, since they are unaware of the market opportunities they are notable to reap the benefits of organic farming.

Table 5. Indian states and agricultural products involved in organic farming

Indian states involved in organic farming	Main organic agricultural products of India
Gujarat	Bajra-mustard-wheat
Kerala	Chilly
Karnataka	Cereals-cereals
Uttaranchal	Cereals-pulses
Sikkim	Kholar
Rajasthan	Maize Ginger
Maharashtra	Soybean
Tamil Nadu	Large cardamom
Madhya Pradesh	Passion fruit
Himachal Pradesh	Bhilwara Urd
	Bharatpur Bajra and wheat
	Alwar Wheat and bajra
	Cotton grass
	Dungarpur pulses-cereals
	Bajra
	Mustard
	Til
	Wheat
	Nagour Guar-cumin
	Moong
	Ganganagar cotton
	Jaisalmer bajra
	Jhunjhunu pulses and wheat
	Banswara maize
	Jaipur Guar

Source: Chandrashekar 2010

Strategies to increase yields in organic farming: Recent meta-analyses revealed that globally the yield of organic crops are on average 80% (de Ponti et al 2012), 66–95% (Seufert et al 2012) or 81% (Ponisio et al 2015) of conventional yields. Yield differences vary considerably with crop types (with legumes showing a considerably smaller yield gap than cereals or tubers) growing conditions and management practices. The two most important yield limiting factors in organic crop production are supply of nitrogen (N) and control of perennial (Askegaard et al 2011). These two factors are closely linked as sufficient N is available for rapid early establishment and growth of crops which play a strong role on reducing weed infestation by inducing greater weed suppression ability of the crop (Olesen et al 2007). The most commonly used organic fertilizers such as compost, manure, green manure and organic wastes are quite low in plant available N and this in combination with slow N mineralization in the spring due to low temperatures limits yield in organic crops, especially in the Nordic countries (Dahlin et al 2005). Yield losses due to the insect-pest attack and diseases also affect the organic-conventional yield gap. The number of crop protection products permitted for organic farming is very limited (EU 2014) although they constitute an important input for decreasing crop losses, especially in some horticultural crops (Letourneau and van Bruggen 2006). The limitation of crop protection products or other effective crop protection measures restricts organic yields. It should be here noticed that copper-based products are most commonly used in European organic farming for crop protection products especially for controlling fungus attacks in vines, fruit crops and potatoes (Niggli et al 2016) but copper fungicides are banned in Scandinavian countries by national legislation. Therefore, organic farmers often has to rely on plant varieties bred for high-input conventional systems i.e. high-yielding varieties with poor weed competitive abilities and shallower rooting depth (Lammerts van Bueren et al 2011) whereas in conventional production systems, these deficits are corrected by the use of herbicides and inorganic nutrients. To overcome these limiting factors, a wide range of strategies are available. Niggli et al (2016) describe such strategies as summarized in Table 7 for arable crops that are applicable to Northern Europe. Some of the strategies comprise of execution of well-known best practices. The use of appropriate crop rotation design to control weed infestation, disease and pest outbreaks particularly for horticultural crops, which are susceptible to many pests and pathogens (Letourneau and van Brugge 2006). The new crop protection strategies in combination with the development and increased use of a variety of biological control agents (e.g. bacteria, fungi and predatory arthropods) (van Lenteren2012) will be chiefly important to minimize the yield gap. Increased use of resistant varieties is also critical, but these varieties are however not fully resistant, implying that direct crop protection measures will be especially important to secure high yields and product quality in high value crops (Speiser et al 2006).

Quality of produce in organic farming: Nowadays, the chief concern for the agricultural scientists and policy makers is environmental hazards and to develop farming methods which are useful to produce quality food. In order to accomplish this goal, the first step is to search for alternate fertilizers which can replace the inorganic source of fertilizers. Several organic materials have been used as fertilizers in organic crop production. But, use of these materials (animal waste and urban sewage waste) in modern agriculture invites pollutions such as heavy metals, chemical residues and parasites (McCalla et al 1986). To overcome this problem, farmers have adopted a kind of biological fertilizer called Bokashi in Japanese, an aerobically fermented using oil seed sludge, rice bran and fish processing byproduct as materials. A microbial inoculate, including lactic acid bacteria, yeast and actinomycetes, is usually inoculated to materials before fermented. This kind of organic fertilizer is easily stored for long time without bite smell. However, the major problem observed is the low nutrient availability at the early stage of crop growth even if the nutrient availability is hold longer than chemical fertilizers (Xu 2000). However, the researchers counter the same problem that it is difficult to obtain same yield in organic farming as in conventional farming. Two leafy vegetables were grown under greenhouse conditions and the dynamics

Table 6. Strategies to increase yields in organic arable crops

Area of intervention	Important for	Strategies to increase yields
Soil fertility	All crops, but especially on stockless farms	• Crop rotation design and management including optimal management of legume pre-crop effects and green manure crops • Increased crop diversity • Intercropping • New technologies for reduced tillage • Increased cooperation between livestock farms and stockless farms • Adding/promoting supportive microorganisms and fungi in soil
Plant nutrients	All crops (except nitrogen for legumes)	• Optimal use of legumes in rotations • Effective use of manures • Increased recycling and use of nutrients from society • Novel treatments of organic food wastes to produce high quality composts • Technological solutions for safe sewage sludge treatments and recycling
Crop-weed competition	All crops, but especially in stockless systems without perennial leys	• Crop rotation design and management • New physical weed control strategies and techniques including cover crop management • Use of the false seedbed technique • Precision farming and robots
Control of diseases	All crops, but especially potatoes and legumes	• Use of tolerant or resistant crop varieties • Crop rotation design and management • Preventative strategies like intercropping, deep ploughing, optimal planting date etc. • New techniques and products for preventing fungal infections, physical methods and bio-control organisms • Replace copper that is currently used • Use of certified and dressed seeds
Control of pests	All crops, several pests in oilseed rape and potatoes	• Crop rotation design • Habitat manipulation (hedgerows, wild flower strips etc.) to strengthen functional biodiversity (e.g. natural enemies) • Physical/biological methods like nets, traps and repellents • Selective pest control products with low negative side-effects

Source: Niggli et al 2016

of both the plant growth and the organic fertilizer were examined to enlighten the plant limiting factors and benefits of this organic fertilizer. Leaf-picking or leaf-peeling harvest method was adopted to prolong the growth and harvestable period. It has been proved that quality of crop particularly the vegetables and fruits is improved by the application of organic fertilizers (Larson et al 2000). The nutritional profile of leafy vegetables was studied including sugar contents, vitamin C and the ionic-nitrate and for the analysis, the organic and inorganic grown vegetables were compared. From results, it was observed that the concentration of sugars and vitamin C were significantly higher but nitrate was lower in organically grown vegetables than chemically fertilized vegetables (Maynard and Barker 1979). In case of chilies, it was noticed that the chilies grown on vermin composted vegetable waste showed higher carbohydrate and protein concentration (Yadav and Vijayakumari 2004). Organic potato tubers farming may be expected to have significantly higher dry matter contents (19%) that are considered good for processing into French fries without deteriorating the texture of the fries when concentrations exceed 23 per cent (Haase et al 2007). Similarly, application of FYM at 10 t /ha alone increased the economic yield and quality parameters like protein and amylose content, hulling percentage and milling percentage of rice (Dixit and Gupta 2000). It is observed that organically grown potato showed 66% higher yield than the conventional crop (Mourao et al 2008). The quality analysis given in Table 11 clearly revealed that acidity, ascorbic acid and total soluble sugars were maximum in organic farming was closely followed by integrated nutrition with a slight edge over the chemical farming. The amount of total solids in all the organic farming treatments was in the range of 22.41 to 25.43 per cent as compared to chemical farming treatment (20.50 %). Similarly, in onion the total solids, ascorbic acid and reducing sugars were more in organic onion as compared to chemical farmed onion (Table 12). The quality of produce can be improved through organic farming (Kaur et al 2006 and Walia and Kler 2007a).

Export Pattern of Organic Products from India

The export of organic food from India is increasing as more farmers are shifting to organic farming. Since the domestic consumption of organic food is quite low in India, so the main market for Indian organic food industry lies in the Europe and US. India has now become a principal supplier of organic basmati rice, organic herbs, organic spices etc. About 53% of the organic food produced is exported from India. This is significantly higher in comparison to the percentage of agricultural products exported. In 2003, only 6-7% of the total agricultural produce was exported from India (Food Processing Market in India 2005).

The upliftment in the demand for organic food products in the developed countries and extensive support provided by the Indian government so as to enhance the agri-exports, are the major reasons for growth of the Indian organic food industry. The prices of organic food products in India are relatively 20 -30% higher than non-organic food products. This is a very high premium for most of the Indian population where the per capita income is merely USD 800. Though the per capita income in India is rising swiftly but the domestic market is not adequate to consume the entire organic food produced in the country. As a result, exports of organic food are the principal aim of organic farmers as well as the government. The Indian government is dedicated towards promoting organic food production in the country. During the Tenth Five Year Plan, the Indian government has allocated Rs.100 crore or USD 22.2 million for promoting sustainable agriculture. APEDA (Agricultural and Processed Food Export Development Authority) manages the export of organic food (and other food products) in India. The National Programme

Table 7. Quality characters of potato in maize-potato-onion cropping system

Treatments	TSS (%)	Acidity (%)	Ascorbic acid mg/100 g	Moisture (%)	Total solids (%)
50 % rec. NPK + 50 % N as FYM	5.75	0.209	3.2	74.99	25.01
1/3 N FYM + 1/3 N Vermi-compost + 1/3 N non-edible cake(T2)	6.00	0.212	3.4	74.57	25.43
100 % NPK + sec. & micro nutrient	4.50	0.218	2.8	79.50	20.50

Table 8. Quality characters of onion in maize-potato-onion cropping system

Treatments	TSS (%)	Ascorbic acid mg/100 g	Reducing sugars (%)	Total solids (%)	Moisture (%)
50 % rec. NPK + 50 % N as FYM	10.80	7.07	3.50	12.50	87.50
1/3 N FYM + 1/3 N Vermi-compost + 1/3 N non-edible cake	11.20	7.11	3.64	12.80	87.20
100 % NPK + sec. & micro nutrient	9.80	3.56	2.43	10.80	89.20

for Organic Production in India was initiated by the ministry of commerce. The programme provides standard for the organic food industry in the country. Since these standards have been developed taking into consideration international organic production standards such as IFOAM and CODEX, as a result, Indian organic food products are being accepted in the US and European markets. APEDA also provides a list of organic food exporters in India and is presented in Table 8. The country wise export pattern for organic products from India is given in Table 9.

Since organic farming is labour intensive and labour is quite expensive in developed countries so organic food production costs are higher in these countries. However, in a country like India, where availability of labour is quite high and relatively cheap, organic agriculture is view as a good cost effective solution to the increasing costs involved in chemical farming. Currently most of the organic farmers in India are still in the evolution phase and hence their costs are still high. As these farmers are expected to adopt the organic farming, the production costs are likely to reduce, thus, making India as one of the significant producers of organic food.

Risks Involved in Organic Farming

However, there are both risks and opportunities associated with strategies to increase yields in organic production. The final outcome largely depends on management, i.e. how strategies are managed and worked out to increase the yield of crop. The various risks involved in organic farming are presented in Table 10.

Environmental deterioration and human health: At

Table 9. Organic food products exported from India

Category	Organic products
Organic cereals	Wheat, rice, maize or corn
Organic pulses	Red gram, black gram
Organic fruits	Banana, mango, orange, pineapple, passion fruit, cashew nut, walnut
Organic oil seeds and oils	Soybean, sunflower, mustard, cotton seed, groundnut, castor
Organic vegetables	Brinjal, garlic, potato, tomato, onion
Organic herbs and species	Chilly, peppermint, cardamom, turmeric, black pepper, white pepper, amla, tamarind, ginger, vanilla, clove, cinnamon, nutmeg, mace
Others	Jaggery, sugar, tea, coffee, cotton, textiles

Source: Chandrashekar 2010

Table 10. Country wise export of organic food products from India (2013-14)

Country	Export volume (Metric tons)	Percentage share	Export value (Rs. crore)	Percentage share
Australia	749.95	0.42	14.58	1.10
Canada	38545.57	21.68	182.41	13.73
China	76.35	0.04	1.57	0.12
European Union	56946.72	32.03	553.85	41.69
Iran	38.00	0.02	1.21	0.09
Israel	312.93	0.18	3.72	0.28
Japan	309.07	0.17	16.12	1.21
Korea Republic	143.48	0.08	2.33	0.18
Malaysia	43.44	0.02	0.91	0.07
New Zealand	599.79	0.34	4.23	0.32
Philippines	110.11	0.06	1.88	0.14
Singapore	73.02	0.04	0.97	0.07
Sri Lanka	78.51	0.04	2.45	0.18
Switzerland	4306.56	2.45	33.89	2.55
USA	74942.72	42.16	498.83	37.55
Others	489.04	0.28	9.65	0.73
Total	177765.26	100.00	1328.60	100.00

Source: Deshmukh and Babar 2015

present, concerns are voiced both in respect of environment and health quality. Eutrophication of water bodies due to high nitrate and phosphate concentration, increasing levels of nitrates in drinking water sources, accumulation of heavy metals such as lead, chromium and cadmium in soil and water resources are the principal causes of environmental deterioration due to agriculture. Dhaliwal et al (2000) reported high concentration of NO_3 (mg/litre) at different locations in Punjab, Haryana and UP which was much higher than the safe limit of 45 mg NO_3/litre. Nitrate in drinking water is the main reason of blue baby syndrome. Likewise, pesticide contamination of food and feed in Punjab were studied by Dhaliwal et al (2000) and sizeable amount of contamination was found in grains, vegetables, feed and milk (Table 2). The average dietary intake of pesticide residues (Table 3) by vegetarian Indian is 362.5 mg/day and non-vegetarian Indian is 356.3 mg/day as against developed countries varying from 7.6 to 149.0mg/day (Ghosh 2000). The heavy metals and other potentially toxic elements are the most serious soil pollutants. Amines produced from the nitrogenous fertilizers cause cancer in human beings. Herbicide residues affect the central nervous system, respiratory system and gastro-intestinal system of human beings. These chemical residues also cause depression, insomnia, oral automatism, myoclous and hyper-reflexia of man (Ghosh 2000). Such harmful effects are now being focused at various forums on account of alarming health hazard situations. To negate such harmful effects organic farming is one of the important options for adoption (Walia and Kler 2007a).

Table 11. Risks associated in organic farming

Business risks						
	Agricultural/ Technological		Communication risks	Non- agricultural		
	Production risks			Managerial risks	Social risks	Profit risks
Yield risks	Specific primary production risks			Institutional and regulatory risks	Informational risks- information shortage, misinformation etc.	
	Climatic risks	Environmental risks and disasters -weather conditions -temperature, rain, sun etc. and climate change -extreme weather events such as frost, droughts, floods, storms etc.		Management and organization risks- including human resources risks	Seasonality risks	
					Research, development and knowledge transfer risks	
	Sanitary risks	Ecological risks -pests, diseases and weeds risks -epidemic diseases -GMO risks -pollution risks (land, water etc.)		Market and marketing risks including price risks- inputs and outputs	Society risks	
		Input risks including supply risks		Administrative risks	Local development risks	
	Post- harvest production risks	Processing risks		Financial and investments (land, facilities, equipment, technology and other) risks	Life standards and purchasing power risks	
		Storage risks				
		Sorting and packaging risks		Unfair competition risks	Intentional or non-intentional violations risks- including theft, warfare, terrorism etc.	
		Transport and distribution risks				
Price risks						

Source: Terziev et al 2015

Table 12. Pesticide contamination of food and feed in Punjab

Commodity	Number of samples	
	Analysed	Contaminated
Cereals	30	30
Rice grain	99	99
Vegetable	96	64
Animal feed	15	15
Animal feed + fodder	105	105
Milk	24	23

Source: Dhaliwal et al (2000)

Table 13. Average dietary intake of pesticide residues (mg/day/person)

Country	Average dietary intake
Australia	20.0
Canada	13.3
Germany	149.0
United kingdom	12.0
United States of America	7.6
India	
-Vegetarians	362.5
-Non vegetarians	356.3

Source: Ghosh (2000)

Controversies and constraints: Export of organic produce to western markets has lucrative appearance as it is widely publicized advantage of high income. Market of indigenous organic food market is infancy and may remain as such in future. There is remote possibility of a poor farmer of remote area to get premium price for his organic produce after successfully overcoming all the steps and formalities beginning from farm certification to final export. The demands of families of such farmers might force them to dispose off their organic produce in local market without any premium. In a section of pro-change farmers of agriculturally important areas currently engaged in food grain production began to convert their farms to organic with the intention of getting premium price, there will be no option left for country other than importing food grains as it has practiced a few decades back was warned by Chhonkar and Dwivedi (2004). The main end product of organic decomposition is nitrate. Nitrate, from organic matter under decomposition is continuously released. Release of nitrate is not synchronized with either crop demand or its uptake, it tends to accumulate in excess in soil and pose environmental risk. Irrespective of the origin of ions weather organic or inorganic, they will behave similarly. The nitrate ions from organic sources are less mobile and have lower denitrification potential than from inorganic fertilizers is without evidence. The trace elements and heavy metals vary widely in animal manures and sometimes their concentration exceeds than inorganic fertilizers. Application of these organic manures in large quantities in the agricultural fields may pollute the soil and there will be every chance to enter into the food chain and create health hazard. The biggest myth about organic farming as indicated by Chhonkar and Dwivedi (2004) is that our country has enough organics available to replace chemical fertilizers to sustain the present level of crop production. All tappable nutrients from organic sources will be barely able to meet the deficit nutrients in soil after crop removal at present level of production. To maintain the present level of food grain production in India without use of inorganic fertilizers, the net additional area to be brought under cultivation will be more than the total geographical area of the country. There are contentions that organic farming is unsustainable. The comparatively lower yields and dependence of manure from low yield cattle has prompted criticism that organic farming is environmentally unsound and incapable of feeding the world's population. Norman Borlaug, father of the “Green revolution” asserts that organic farming practices can at most feed 4 billion people, after expanding cropland dramatically and destroying ecosystems in the process (Mahapatra et al 2009). Some Other constraints of organic farming are practicability of green manuring crop is limited due to high cropping intensity; incorporation cost is involved; non-availability of seeds of green manuring crops; use of undecomposed FYM; organic manures are bulky and transportation cost is involved; limited availability of FYM; most of cow dung is used for making cow dung cakes used for fuel purposes; fewer recommendations on bio-pesticides; labour cost are high for controlling weeds manually; yields are low in organic farming during the initial 2-3 years, marketing problems; cumbersome certification process; regulation problems; risky method especially in insect and disease prone crop.

CONCLUSION

The farmers of India had been practicing environment friendly agriculture for centuries till the introduction of the so-called 'green revolution' which was based on the conventional farming methods came into existence in the western countries. Still many resource-poor, marginal and small farmers, have not fully adopted the conventional farming and they follow more or less the traditional eco-friendly agriculture systems. They use local or own farm derived renewable resources and manage self-regulated ecological and biological processes. This has become vital to cultivate the acceptable levels of crop, livestock and human nutrition products and above all to safeguard both the crops and humans from pests and diseases through the use of locally available low-cost inputs. Such a situation is suitable for making the farming community aware of the organic farming methods to make the switch over less troublesome. A country like India can enjoy a number of benefits from the adoption of organic farming. The price premiums for the products, conservation of the natural resources in terms of improved soil fertility and water quality, prevention of soil erosion, preservation of natural and agro-biodiversity are major benefits of organic farming. Economic and social benefits like generation of rural employment, lower urban migration, improved household nutrition, local food security and reduced dependence on external inputs will be large gains in the Indian conditions. The control of environment pollution and the consequent increase in the quality of human life will be other contributions of organic farming. There is a good demand for organic products in the domestic and export market. The main rules and regulations for accreditation and certification of organic products are in place in India. Considering the above, it may be concluded that organic farming will progress tremendously in India.

The organic production is coming farmer's movement and consumer choice which cannot be ignored. All facilities should be necessarily provided to organic farmersin the form of appropriate package of practice, voluminous amounts of organic inputs and good domestic as well as export market. Organic farming should not be discouraged under any circumstances. The immediate task is to arrange availability of organic inputs and low-cost certification process.

Therefore, it is recommended that Governments should develop appropriate policies for extensive adoption of organic agriculture by millions of individual farmer households. Specifically, Governments should encourage farmers to establish effective organizations to promote organic agriculture. In addition to this, they should support the development of alternatives to chemical pest control and chemical fertilizers. Meanwhile, local NGOs and all other related sectors should assist farmers to minimize the use of synthetic chemicals in farming. Actions should be taken to increase consumers' awareness of organic consumption. For this massive extension works and support from state government for capacity building of local NGO's are needed. More research need to be conducted on markets for organic products and operational mechanism for risk insurance should be secured through financial support during the conversion period and provision of incentives or subsidies for organic agricultural production.

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Received 12 May, 2022; Accepted 13 June, 2022

Indian Journal of Ecology (2022) 49(3) (SI): 1152-1170
DOI: https://doi.org/10.55362/IJE/2022/3642

Manuscript Number: 3642
NAAS Rating: 5.79

Bioactive Potential of Essential Oils: A Review

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Abstract**:** Essential oils (EOs) are one of the main phytoproducts, extracted from different plant parts like flower, bark, stem, leaves, roots and fruits by different methods. These are also known as ethereal oils or volatile oils with low molecular weight, highly aromatic, pale yellow or colourless, with low density generally, complex mixture of different compounds and are multifunctional which harbor an immense wealth of biological properties such as antibacterial, antifungal, anti-cancerous, anti-mutagenic, anti-diabetic, antiviral, anti-inflammatory and anti-helminthic, being explored extensively in diverse fields. Essential oils are often used for aromatherapy; a form of alternative medicine useful to induce relaxation is attributed to aromatic compounds. They are usually stored as secondary metabolites in oil ducts, resin ducts, glands or trichomes (glandular hairs) of the plants. EOs also has a significant role in plant defence against the external agencies and signal sending mechanism.

Keywords**:** Anti-cancerous, Anti-inflammatory, Bio-active potential, Essential oils, Hydro-distillation

The plant kingdom, since times immemorial has been a treasure of various phytoproducts, which due to their chemical composition attribute immensely toward the health care (Sabo and Knezevic 2019). The commercial exploitation of natural products for their relevant medicinal value and complementing it with the mainstream synthetic medicinal compounds has led to a recent upsurge in their demand and use (Blowman et al 2018). One of the main phytoproducts, are the Essential oils (EOs). These are extracted from different plant parts like flower, bark, stem, leaves, roots and fruits by different methods (Ali et al 2015). Various methods such as using microwave, pressure distillation with boiling water or steam, liquid carbon dioxide, solvent extraction, cold pressing, resin pressing and absolute oil extraction are employed to extract different EOs (Ishfaq et al 2018). Mostly the essential oils (EOs), present in the different plant parts are obtained through the process of steam or hydro distillation (Dhakad et al 2018). They are usually stored as secondary metabolites in oil ducts, resin ducts, glands or trichomes (glandular hairs) of the plants. EOs also has a significant role in plant defence against the external agencies and signal sending mechanism (Soujanya et al 2016). Around 2000 different plant species have been identified that produce about 3000 essential oils and out of these about 300 different types of essential oils are commercially exploited in pharmaceutical, food, cosmetic, sanitary and agro industries (Raveau et al 2020). These oils harbor an immense wealth of biological properties such as antibacterial, antifungal, anti-cancerous, anti-mutagenic, anti-diabetic, antiviral, anti-inflammatory and anti-helminthic which are being explored extensively in diverse fields.

Chemical Composition: The EOs also known as ethereal oils are volatile oils with low molecular weight, highly aromatic, pale yellow or colourless, with low density generally; complex mixture of different compounds and are multifunctional (Ishfaq et al 2018). Their vapour pressure at room temperature is quite high so that they are found partly in the vapour state (Dhifi et al 2016). Chemically these oils are composed of hydrocarbons which could be monoterpenes or sesquiterpenes, alcohols, ketones and aldehydes (Nieto 2017). The rich and complex composition of the EOs, on the basis of chemical constituents and their structure determine their biological properties (Gautam et al 2014). The compounds identified belong to four major categories of which terpenes and terpenoids constitute the major group with phenolic and aliphatic compounds the other two groups (Bayala et al 2018).

Major plant families producing essential Oils- About 10% of the 17,000 known plethora of plants species are aromatic (Aziz et al 2018). The genera of about 60 plant families are considered to be Essential oil producing, of these the selected plant families like Apiaceae, Asteraceae, Lamiaceae, Myrataceae, Rutaceae, Lauraceae, Cuppressaceae, Poaceae and Piperaceae produce the essential oils of medicinal and industrial importance (Raut and Karuppayil 2014). They are rich in mainly terpenoids as a main chemical component while phenylpropanoids rich plant families are Apiaceae, Lamiaceae, Myrataceae, Piperaceae and Rutaceae (Chami et al 2004). Among the 17 species of family Asteraceae evaluated, 13 species yielded essential oil from both fresh and dried samples. *Erechities valerianifolius* (wolf) DC yielded highest oil content both in fresh and dried samples (do-Amaral et al 2018). Essential oils of family verbenaceae are mainly recognized for their antimicrobial properties (Pérez et al 2018). Members of family apiaceae account for antibacterial, antifungal, anti-cancerous and antiviral properties (Raut and Karuppayil 2014) while, members of family Lamiaceae are known for antiviral, antimicrobial and anti-mutagenic activities besides being useful in treating intestinal and respiratory disorders (Nilufar et al 2017). Citrus oils of the family Rutaceae are medicinally active essential oils with major components as citral, geraniol and geranyl acetate which mainly exhibit antimicrobial and anti-cancerous properties (Raut and Karuppayil 2014). Family Rutaceae show antimicrobial potential attributed to limonene and linalool which are the main components of their essential oils. Other essential oil yielding families include Fabaceae, Pinaceae, Cupressaceae and Zygophyllaceae (Carson and Hammer 2011).

Techniques of essential oil extraction: Different plant parts (Bakkali et al 2008) like buds, flowers, leaves, stem, twigs, seeds, fruits, root and bark produce essential oils which is usually stored in glands, oil ducts, resin ducts or trichomes of the plant (Başer and Demirci 2007). Different techniques of oil extraction are steam distillation, hydro distillation microwave hydro diffusion, high pressure solvent extraction, supercritical CO_2 extraction, ultrasonic extraction and solvent free microwave extraction (Farhat et al 2010) but on commercial scale steam distillation is preferred (Masango 2005). It requires prolonged heating and stirring consuming lots of energy and time for the completion of the process with high consumption of solvent (Chemat et al 2009). Moreover, some volatile components are lost through steam distillation. In solvent free extraction method, it is not possible to obtain a solvent free product (Khajeh et al 2010). The method of oil extraction is based on its application (Rassem et al 2016). The product extracted could differ in quality, quantity and in composition depending on plant age, organ from which it is extracted, climate and soil composition (Angioni et al 2006). In order to obtain a constant composition of the oil the plant needs to be growing on the same soil and under the same environmental conditions (Bakkali et al 2008). To ensure good quality of essential oil commercially they are analyzed by GC-MS technique.

Chemical composition- Essential oils are natural, low molecular weight, highly volatile, secondary plant metabolites having 20-60 components at different concentrations (Bakkali et al 2008). These are grouped into mainly two categories of biosynthetic origin (Pichersky et al 2006). The major group includes terpenes and terpenoids and the other group is of aromatic and aliphatic compounds but, terpenes and terpenoids are found in abundance in essential to the oil (Zuzarte and Salgueiro 2015).

Terpenes: Terpenes and terpenoids are made as a result of condensation of 5 carbon base units called isoprene having two unsaturated bonds. These units are joined in one direction. Mostly essential oils are complex mixtures of monoterpenes ($C_{10}H_{16}$) and sesquiterpenes ($C_{15}H_{24}$) along with phenols, alcohols, ether, aldehydes and ketones which are responsible for their characteristic odour.

Phenylpropanoids: These are aromatic compounds derived from phenylpropane (Bakkali et al 2008) and contain one or more C_6-C_3 units with C_6 Being a benzene ring. Many phenylpropanoids are phenols which may include oxygenated hydrocarbons like eugenole, anthole and safrole (Rassem et al 2016).

Pharmacological actions of essential oils: The essential oils have been screened mainly for their various biological activities like antibacterial, antifungal, antioxidant and many more activities commercially (Ali et al 2015). Some of the pharmacological properties are discussed below.

Antibacterial property of essential oils: The essential oils exhibit antibacterial potential. These have been used since ancient Egyptian times in embalming to curb the bacterial growth. Still the serious bacterial infections are the leading cause of deaths even after the discovery of antibiotics due to several antibiotic resistant strains emerging up (Raut and Karuppayil 2014). The prolonged use of antibiotics in high doses leads to toxicity. Therefore, the plant secondary metabolites are being explored as an alternative source against the pathogenic bacteria (Galvão et al 2012). The plant essential oils are known to cover the broad spectrum

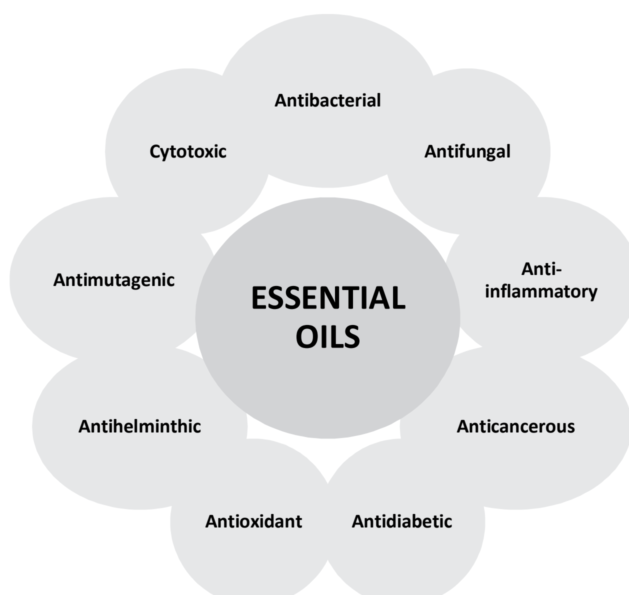

Fig. 1. Bioactive potential of essential oils

inhibitory activities of gram positive and gram negative bacteria (Teixeira et al 2013). In vitro evidences indicate that the essential oils act as antibacterial agents of different bacterial strains including *Liestera, Monocytogenes, Salmonella typhimurium, E. coli, Shigella dysenteria* and *Bacillus aureus* (Schmidt et al 2005). Among the major constituents of essential oils, the oxygenated terpenoids manifest the highest antibacterial activity (Pérez et al 2018). The antibacterial effect of essential oils of different plants vary on different bacteria like sandalwood oil (*Santalum album*), manuka oil (*Leptospermum scoparium*) and veitver (*Chrysopogon zizanoides*) oils are effective against gram positive bacteria (Hammer et al 2006). However, the essential oil of *Achillea clavennae* is effective against gram negative bacteria. The essential oils of Oregano and Thyme are known to inhibit the growth of certain bacterial strains such as *E coli, S. enteridis, S. choleraesuis and S. typhimurium* (Penalver et al 2005) due to their phenolic components carvacrol and thymol. The high phenolic content was the cause of inhibition (Chouhan et al 2017). Three species of thymus *i.e T. capitata, T. munbyanus and T. glandulosus* showed high concentration of oxygenated monoterpenes and both the phenols carvacrol and thymol showing the highest antibacterial effect of all essential oils against all bacterial strains (Moukhles et al 2018). Due to the emergence of drug resistant bacterial strains the essential oils have to target at the cellular level to alter the bacterial gene expression. Essential oils of the aromatic plants like *Carum copticum* and *Syzgium aromaticum* have been used to modify the expression of *E. coli* and *P. aeruginosa* respectively. Oxygenated terpenoids manifest the highest antimicrobial activity (Pérez et al 2018). The primary mode of action of essential oil is the membrane destabilization of the pathogen as they are lipophilic in nature and hence are permeable through the cell wall and cell membrane making the bacterial cell wall more permeable due to their components like polysaccharides, fatty acids and phospholipids resulting in the loss of ions and cellular contents leading to cell death (Saad et al 2013).

Antifungal activity: The human beings and plants both are susceptible to fungal infections. The antifungal property of essential oils has been regarded as the potential substitute for conventional synthetic fungicides (Elshafie and Camele 2017). With the emergence of fungus resistant strains, the use of synthetic fungicides has been limited as they increase toxicity levels (Lopez-Reyes et al 2013). The fungal infections being caused by eukaryotic pathogens show similarities with the host at the molecular and cellular level and hence hard to treat. Hence these infections are associated with high mortality rates (Sardi et al 2013). The antifungal activity is generally linked to high lipophilic nature and low molecular weight of terpenes and terpenoids which are capable of disrupting the cell membrane causing cell death (Nazzaro et al 2017). The various plant and human pathogenic fungi are susceptible to plant essential oils (Raut and Karuppayil 2014). The higher amount of E-cinnamaldehyde explains higher antifungal activity in *Cinnamomum aromaticum* (Szweda et al 2015). The spore development of fungi is inhibited due to essential oils rich in phenylpropanoids like eugenol and monocyclic sesquiterpenoids like alpha-bisabolol (Pragadheesh et al 2013). The Lemon grass oil with the concentration ranging from 0.006 to 0.03% is most effective against filamentous fungi (Raut and Karuppayil 2014). Essential oils of certain plants like *Eucalyptus, Meleluca* have components like citral, citronellol, gerniol and geranyl acetate which show cell cycle inhibitory activities against *Candida albicans* (Zore et al 2011). The essential oil components like eugenol, thymol and carvacrol affect Ca^{2+} and H^{+} ions leading to their loss and inhibiting growth of *S cerevisiae* (Rao et al 2010). The essential oils of many aromatic plants like *Mentha piperata, Brassica nigra, Angelica archangelica, Cymbopogon nardus, Skimmia laureola, Artemisia seiberi and Cuminium cyminum* show positive antifungal activity (Samber et al 2015). Analysing the fungal contamination of indoor air quality clove oil was found to have the maximum potential to exhibit antifungal activity (Schroder et al 2017). Membrane fluidity abnormalities result in leakage of cytoplasmic contents and hence loss of fungal viability.

Anti-inflammatory activity: Many animal and human diseases usually result in inflammations which are normally treated with non-steroidal anti-inflammatory drugs (NSAIDs) and corticosteroids which have enormous side effects. To address this problem, the anti-inflammatory potential of natural plant essential oils has been explored. Their main components like eugenol and carvacrol when evaluated showed major anti-inflammatory activity (Pérez et al 2011). Essential oils are traditionally used as anti-inflammatory, analgesic and antipyretic remedies for various infections. The monoterpenoid constituent of aromatic oils is useful in treating common cold and other respiratory infections. Free radical scavenging is one of the mechanisms of inflammation preventive activity (Miguel 2010). The plants like Aloe, Anise, Bergmot, Lavender, Juniperus, Cinnamon leaf and Thyme yield essential oils having anti-inflammatory potential. Their action is based on inhibition of Cox-2-enzyme. The anti-inflammatory activity was analysed in plants of families Capparidaceae, Euphorbiaceae and Liliaceae on stem barks of *Drypetes gossweileri*, roots of *Pentadiplandea brazzeana* and red bulbs of *Allium cepa* and *Allium sativum* showed that

Table 1. Plants from different families exhibiting anti-inflammatory potential

Plant	Family	Parts used	Major constituents	References
Afromomum melegueta	Zingiberaceae	Grains	(6)-paradol, (6)-shogoal, (6)-gingerol	Akpanabiatu et al (2013)
Afromomum denielli	Zingiberaceae	Leaf, stem, rhizome	α-pinene, β-pinene, 1,8-cineole, α-terpeniol, β-ocimene	Pérez et al (2011)
Ageratum fastigiatum	Asteraceae	Leaves	GermacreneD, α-humulene, β-cedrene	Del-Vechio-Vieira et al (2009)
Allium sativum	Liliaceae	Bulb	diallyl trisulfide, diallyl disulfide, allyl methyl trisulfide, diallyl sulfide and diallyl tetrasulfide	Foe et al (2016)
Allium cepa	Liliaceae	Bulb	diallyl trisulfide, dipropyl trisulfide, 2-methyl-3,4-dithiaheptane, methyl propyl trisulfide, dipropyl tetrasulfide and 2-propenyl propyl disulfide.	Foe et al (2016)
Aucoumea klaineana	Burseraceae	Resins from tree bark	α-pinene, α-phelandrene, p-cymene, 1,8-cineole	Dongmo et al (2010)
Bursera morelensis	Burseraceae	Young stems and pieces of bark	α-pinene, α-phelandrene, p-cymene, caryophyllene	Alina et al (2014)
Canarium scheinfurthii	Burseraceae	Resin from tree bark	γ-terpinene, α-phellandrene, α-thujene, β-phellandrene, *p*-cymene, α-pinene, sabinene, β-pinene, limonene, octyl acetate, nerolidol, *n*-octanol, and α-terpineol	Pérez et al (2011)
Calycorectes sellowianus	Myrtaceae	Leaf	Guaiol, α-caryophyllene	Apel et al (2010)
Cinnamomum insularimontanum	Lauraceae	Fruit	αpinene, αpinene, camphene, limonene, citronellal, citronellol, citral	Lin et al (2008)
Cinnamomum osmophloeum	Lauraceae	Leaf	1,8-cineole and santolina triene and the sesquiterpenes spathulenol and caryophyllene oxide	Tung et al (2008)
Chaerophyllum aromaticum	Apiaceae	Leaf	Sabinene, terpinolene, α-terpinene	Kurkcuoglu et al (2018)
Citrus aurantium	Rutaceae	Fruit peel	linolool, α-terpineol, (R)-limonene and linalyl acetate	Karaca et al (2007)
Citrus sinensis	Rutaceae	Fruit peels	limonene, β-pinene and γ-terpinene	Pérez et al (2011)
Citrus sunki	Rutaceae	Fruit peel	limonene, β-pinene and γ-terpinene,	Yang et al (2010)
Cleistocalyx operculatus	Myrtaceae	Buds	Myracene, (E)-α-ocimene, (Z)-α-ocimene, linalool	Dung et al (2009)
Cordia verbenacea	Boraginaceae	Leaf	Artemetin a flavon α-humulene, trans-caryophyllene	de-Freitas et al (2008)
Cyperus esculentus	Cyperaceae	Rhizome	Cyperene, humulene, silinene, zierone, limonene	Udefa et al (2020)
Chenopodium album	Chenopodiaceae	Leaf	p-cymene, ascaridole, pinnae-2-ol, α-pinene, α-pinene, α-terpineol	Biradar et al (2010)
Dennettia tripetala	Annonaceae	Leaf	Z-Phenylnitroethane, linalol, methyl eugenol	Oyemitan et al (2008)
Driyms brasiliensis	Winteraceae	Leaf and stem bark	GermacreneD, bicyclogermacrene cyclolorenone	Lago et al (2010)
Drypetes gossweileri	Eurphobiaceae	Stem barks	diallyl trisulfide , dipropyl trisulfide, 2-methyl-3,4-dithiaheptane, methyl propyl trisulfide, dipropyl tetrasulfide and 2-propenyl propyl disulfide	Foe et al (2016)
Fortunella japonica	Rutaceae	Fruit	dl-limonene, carvone	Pérez et al (2011)
Garcinia brasiliensis	Guttiferae	Fruit peel	γ-muurolene, spathulenol, δ-cardinene, torreyol, α-cardinol, cadalene, γ -cardinene	Martins et al (2008)
Hedychium coronarium	Zingiberaceae	Rhizome	Linalool, 1,8-cineole, α-terpineol, β-trans-ocimenone, sabinene, terpinen-4-ol, 10-epi-γ-eudesmol	Lu et al (2009)
Helichrysum italicum	Asteraceae	Flowers and leaves	β-caryophyllene, α-pinene, 1,8-cineole, p-cymene, spathulenol, germacreneD-4-ol	Bouzid and Zerroug (2018)
Illicium anisatum	*Illiciaceae*	Leaves	Eucalyptol, sabinene, a-terpinenyl acetate, kaurene, isopimaradiene, safrol, b-linalool, d-cadinene, a-cadinol and terpene-4-ol	Kim et al (2009)

Cont...

Table 1. Plants from different families exhibiting anti-inflammatory potential

Plant	Family	Parts used	Major constituents	References
Lippia sidaoides	Verbenaceae	Leaves	Thymol, p-cymene	Monteiro et al (2007)
Melaleuca alternifolia	Myrtaceae	Leaves	Terpen-4-ol, α-terpinene, γ-terpinone, α-terpineol	Vila and Cañigueral (2006)
Melissa officinalis	Lamiaceae	Leaves	Nerol, citral, isopulegol, caryophyllene, citronella	Bounihi et al (2013)
Mezoneuron benthamianim	Caesalpinoideae	Leaves and stem	3-carene, pinene, trans-nerolidol, farnesene, thujone	Olufunke et al (2009)
Myrciaria tenella	Myrtaceae	Leaves	β-caryophyllene, spathulenol	Apel et al (2010)
Nepta cataria	Lamiaceae	Leaves	Trans-nepetalactone, cis-neptalactone neptalactol	Ricci et al (2010)
Ocotea quixos	Lauraceae	Flowers	Trans-cinnamaldehyde, methyl-cinnamate	Radice et al (2017)
Olea europea	Oleaceae	Fruits	Oleuropein a phenol, α-pinene, 2,6-dimethyloctane, 2-methoxy, intraperitoneal, 3-isopropylpyrazine	Eidi et al (2012)
Origanum ehrenberghii	Lamiaceae	Leaves	Thymol, p-cymene	Loizzo et al (2009)
Origanum vulgare	Labiatae	Leaves	Trans-sabinene hydrate, thymol, carvacrol	Pezzani et al (2017)
Pelargonium graveolens	Geraniaceae	Leaves	Citronellol, citronellyl formate, linalool, geraniol, isomenthone, menthone	Asgarpanah and Ramezanloo (2015)
Pentiplandra brazzaena	Capparidaceae	Roots	diallyl trisulfide, dipropyl trisulfide, 2-methyl-3,4-dithiaheptane, methyl propyl trisulfide, dipropyl tetrasulfide and 2-propenyl propyl disulfide	Foe et al (2016)
Pogostemonis herba	Lamiaceae	Leaves	Patchoulol, delta-guaiene, alpha-guaiene, seychellene, alpha-patchoulene, aciphyllene, trans-caryophyllene	Xian et al (2011)
Pimpinella corymbosa	Apiaceae	Roots	(4-2-propenyl) phenylangelate, [4-(3-methyloxiranyl) phenyltiglate], [4-methoxy-2-(3-methyloxiranyl) phenyl isobutyrate], [4-methoxy-2-(3-methyloxiranyl)phenylangelate] and (epoxy pseudoisoeugenol-2-methylbutyrate)	Pérez et al (2011)
Plumbago zeylanica	Plumbaginaceae	Roots	Plumbagin, 1-octen-3-acetate, limonene	Vanitha et al (2020)
Psidium guajava	Myrtaceae	Leaves	β-caryophyllene, limonene, selin-7-(11)-en-4□-ol	El-Ahmady et al (2013)
Rosamarinus officinalis	Lamiaceae	Leaves	1,8-cineole, α-pinene, camphene, β-myracene	Borges et al (2019)
Sabina virginiana	Cupressaceae	Leaves	Limonene, safrole, asarone, α-pinene	Aboaba et al (2010)
Thymus vulgaris	Labiatae	Leaves	Thymol, carvacrol, α-pinene, p-cymene, limonene	Boukhatem et al (2020)
Terminalia chebula	Combretaceae	Fruits	Chebulanin, gallic acid	Zaidi et al (2012)
Zanthoxylum piperitum	Rutaceae	Fruits	Limonene, geranyl acetate	Lee et al (2017)
Zanthoxylum sclnifolum	Rutaceae	Fruit pericarp	□-phellandrene, citronellal, gernyl acetate	Kim (2014)
Zingiber officinale	Zingiberaceae	Rhizome	[6]-gingerol, [8]-paradol and [8]-shogaol	Munda et al (2018)
Zingiber zerumbet	Zingiberaceae	Rhizome	zerumbone, alpha-humulene, humulene epoxide II, caryophyllene oxide and camphene	Singh et al (2014)
Zizyphus jujube	Rhamanaceae	Seeds	13-Heptadecyn-1-ol, 7-Ethyl-4-decen-6-one, Lineoleoyl chloride, Linoleic acid, 2,5-Octadecadiynoic acid, methyl ester and Palatinol	Al-Reza et al (2010)

it was higher in in *P brazzaena* and *A cepa* as their essential oil is rich in organosulphur compounds and hence attributes to this property (Foe et al 2016). Fruits of *Piper nigrum* contain caryophyllene and Limonene as its major constituents that help in reducing carrageenan and dextran induced inflammation (Jeena et al 2014). Essential oils from the fruits *Pycnocycia bashargardiana* (Myrtaceae) had myristicin which exhibited anti inflammatory property (Fatemeh and Khosro 2012). The lipogenase activity measurement using essential oils of *Cymbopogon giganteus* and *C citratus* can give the information about its potential use as an anti-inflammatory (Bayala et al 2018). The essential oils of these two species of *Cymbopogan* have shown the cytotoxic effect on tumour cell cultures leading to identification of citral one of the major components of their essential oil showing anti-inflammatory property. Hence, treating several inflammatory disorders using herbal therapy and the bioactive constituents of essential oils is an attractive approach.

Cancer preventive property: Cancer is a complex genetic disorder posing a serious life threat and a leading cause of death claiming about 8 million lives world over annually. Supressing the malignant cell growth is one of the major challenges in the treatment of cancer. Certain essential oils tested positive for cancer suppressive activity when tested on a number of human cancer cell lines (Edris 2007). Various types of cancers like glioma, colon cancer, gastric cancer, human liver tumour, pulmonary tumour, breast cancer and leukaemia could be supressed after the treatment with plant essential oils (Hamid et al 2011). The potential of essential oils as anti cancerous agents is still in juvenile stage but about 25% of chemotherapy agents are plant based and 25% are chemically modified phytoproducts (Amin et al 2009). Paclitaxel molecule used in chemotherapy was originally derived from a bark of a tree *Toxus brevifolia* (Weaver 2014). It works at the cellular level which induces arrest of mitosis and targeting tubulin a component of cytoskeleton ultimately leading to apoptosis. A sesquiterpene hydrocarbon found in majority of essential oils used in treating Glioma increased the survival time of the patients suffering from it (Tan et al 2018). D-bisabolol a sesquiterpene in *Matricaria chamomilla* induces apoptosis in glioma cells (Edris 2007). Geraniol a natural component of essential oil of *Cymbopogon martini* reduces the amount of enzymes thymidylate synthetase and thymidine kinase (Carnesecchia et al 2004) in colon cancer cells which enhances 5-fluorouracil cytotoxicity. D-limonene is one of the major components of essential oils especially in citrus fruit peels constituting 90-95% of the total oil. About 26-34% of d-limonene is found in spearmint oil (Edris 2007). It has shown a widespread application in chemo preventive and chemotherapeutic activities in preclinical studies of breast cancer. Also d-limonene has shown anti proliferative and proapoptotic effect of cancer cells (Yu et al 2018) in lung cancer. It can induce the formation of apoptotic bodies on BCG-823 gastric cancer cells which are formed in time and dose dependent manner. The essential oils in garlic along with its organosulphur components have exhibited anticancerous potential (Thomson and Ali2003). They reduce the expression and activation of various cell growth stimulatory proteins and target the cancer cells (Petrovic et al 2018). Diallyl trisulphide (DATS) one of the major components of garlic essential oil arrests the division of human live tumour cells at G2/M phase of cell cycle (Wu et al 2004). The terpenoids and polyphenols present mostly in essential oils induce apoptosis or necrosis and hence preventing the proliferation of tumour cells (Bakkali et al 2008). Myristicin an active component of *Myristica fragrans* oil show hepato protective activity by inducing apoptosis (Lee et al 2005).

Mechanism of essential oil: The essential oils mainly operate by inducing programmed cell death better known as apoptosis, necrosis, arrest of cell cycle and dysfunctioning of main cell organelles is attributed mainly to the lipophilic nature and low molecular weight of their major components which allows them to enter the affected cell causing the increase of membrane fluidity. Due to this alteration in cell membrane, ATP production is reduced, pH gradient is altered and finally loss of mitochondrial potential leads to cell death (Sharifi-Rad et al 2017).

The mechanism operating to exhibit the anti cancerous effect of plant EOs is mainly constituent dependent which chiefly are phenols, aldehydes, and alcohols. The toxicity of EOs towards mammalians decreases with the increase of average lipophilicity of its components, while in prokaryotes the toxicity increases with increasing lipophilicity. This indicates the extraordinary role of EOs among natural compounds. The cancerous cells are sensitive to plant isoprenoids which reduce tumour cell-size in patients (Elshafie and Camele 2017).

Antidiabetic potential: There are major health issues cropping up worldwide due to the modern lifestyle changes leading to obesity which is the base line of several diseases including impaired glucose tolerance causing type2 diabetes which has affected the major portion of the population. The glucose levels have been maintained by several synthetic drugs including metformin. The alternative therapy used is plant based products like essential oils which are reported to exhibit potential anti diabetic potential. The essential oils extracted from *S aromaticum* and *C cyminium* show potent anti diabetic activity (Sahu et al 2021). Non-polar *Toona sinesis* extract also exhibit anti diabetic potential (Hsieh et al 2012). In an in vitro anti diabetic screening model based glucose consumption it is shown that using *Melissa officinalis* essential oil the glucose consumption was remarkably increased (Yen et al 2015). The anti diabetic potential of essential oil of *Hedichyium spicatum*, a member of family Zingiberaceae was explored on diabetic rats. The rhizome oil had 1,8 cineole as its key ingredient limonene was able to lower the glucose levels indicating to the potential to cure type 1 diabetes (Berbudi et al 2020). The essential oils of *Artemessia sieberi* exhibited that the blood glucose level reduction was comparable to metformin a common hypoglycemic in alloxan induced diabetic rats (Hussain et al 2017). The essential oil extracted from leaf sheath of *Cymbopogan citratus* (Graminae) supported that by molecular docking its anti diabetic nature and could be supplemented with diabetic drugs (Bharti et al 2013). The essential oil of *Pelargonium graveolans* TL when administered together with glibenclamide a known

Table 2. EOs effective in treating different types of cancers

Type of cancer	Plant essential oil	Family	Activity	Oil constituents	Refrences
Glioblastoma	*Hypericum hiricum*	Hypericaceae	Anti proliferative	cis-β-guaiene, δ-selinene and (E)-caryophyllene cis-guaiene	Quassinti et al (2013)
	Zanthoxylum tingusssuiba	Rutaceae	Apopototic	α-bisabolol	Detoni et al (2012)
	Ocimum basilicum	Lamiaceae	Cytotoxic	methyl cinnamate, linalool, β-elemene and camphor.	Kathirvel and Ravi (2012)
	Lippia multiflora	Verbenaceae	Anti-proliferative	thymyle acetate	Bayala et al (2018)
	Ageratum conyzoides	Asteraceae	Cytotoxic	precocene	Bayala et al (2018)
	Melissa officinalis	Lamiaceae	Apopototic	caryophyllene oxide, caryophyllene and β-copaene	Queiroz et al (2014)
	Salvia officinalis	Lamiaceae	Anti-proliferative	a-thujone, c-muurolene camphor, borneol, and sclareol	Russo et al (2013)
	Drimys brasiliensis	Winteraceae	Cytotoxic	cyclocolorenone	Gomes et al (2013)
	Malus domestica	Rosaceae	Cytotoxic	eucalyptol, phytol, α-farnesene and pentacosane	Walia et al (2012)
Melonoma	*Afrostyrax lepidophyllua*	Huaceae	Chemopreventive	2,4,5,7-tetrathiaoctane	Fogang et al (2014)
	Scorodopholeus zenkeri	Fabaceae	Chemopreventive	2,4,5,7-tetrathiaoctane	Fogang et al (2014)
	Athanasia brownii	Asteraceae	Chemopreventive	oxygenated sesquiterpenes with selin-11-en-4α-ol, caryophyllene oxide, humulene epoxide II and (E)-nerolidol	Rasoanaivo et al (2013)
	Neolista variabillima	Lauraceae	Cytotoxic	trans-beta-ocimene, alpha-cadinol, terpinen-4-ol, tau-cadinol, beta-caryophyllene and sabinene	Su et al (2013)
	Casearia sylvestris	Salicaceae	Cytotoxic	sesquiterpene a-zingiberene	Bou et al (2013)
	Salvia bracteata	Lamiaceae	Anti-proliferative	β-caryopyllene, γ-muurolene, bicyclogermacrene, caryophyllene oxide and ot-humulene	Cardile et al (2009)
	Melaleuca alternifolia	Myrtaceae	Necrosis	Terpinene-4-ol, γ-terpinene, α-terpineole, 1-8cineole and p-cymene	Russo et al (2013)
	Salvia rubifolia	Labiatae	Apoptotic		Russo et al (2013)
	Platycladus orientalis	Cupressaceae	Antiproliferative	linalool, β-caryophyllene and α-cedrol	Loizzo et al (2008)
Breast cancer	*Satureja khuzistanica*	Lamiaceae	Cytotoxic	Carvacrol and limonene	Yousefzadi et al (2014)
	Cadrelopsis grevei	Rutaceae	Cytotoxic	β-farnesene, δ-cadinene, α-copaene and β-elemene	Afoulous et al (2013)
	Solanum spirale	Solanaceae	Cytotoxic	(E)-Phytol, n-hexadecanoic acid, beta-selinene, alpha-selinene, octadecanoic acid and hexahydrofarnesyl acetone	Keawsa-Ard et al (2012)
	Boswellia sacra	Burseraceae	Apoptosis	E-beta-ocimene, limonene, E-caryophyllene	Suhail et al (2011)
	Laurus nobilis	Lauraceae	Antiproliferative	1,8-Cineol	Al-Kalaldeh et al (2010)
	Origanum vulgare	Lamiaceae	Antiproliferative	trans-sabinene hydrate	Al-Kalaldeh et al (2010)
	Salvia triloba	Lamiaceae	Antiproliferative	1,8-Cineol	Al-Kalaldeh et al (2010)

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Table 2. EOs effective in treating different types of cancers

Type of cancer	Plant essential oil	Family	Activity	Oil constituents	Refrences
	Garcinia atroviridis	Clusiaceae	Cytotoxic	palmitoleic acid, palmitic acid, while the leaf oil (E)-β-farnesene and β-caryophyllene	Tan et al (2018)
	Origanum syriacum	Lamiceae	Antiproliferative	Carvacrol	Tan et al (2018)
	Casearia sylvestris	Flacourtiaceae	Cytotoxic	β-caryophyllene and α-humulene	Silva et al (2008)
	Melissa officinalis	Lamiaceae	Apoptosis	Citral	Dudai et al (2005)
	Salvia officinalis	Labiatae	Antiproliferative	1,8-cineole	Russo et al (2013)
	Thymus broussonetti	Lamiaceae	Cytotoxic	borneol, thymol, camphene, ρ-cymene, *α*-pinene and linalool. Camphor, *α*-terpineol, eucalyptol, germacrene D and borneol	Russo et al (2013)
	Citrus bergamia	Rutaceae	Cell death	Limonene, Linalyl acetate	Navarra et al (2015)
	Garcinia celebica	Clusiaceae	Antiproliferative	α-copaene, germacrene D and β-caryophyllene	Tan et al (2018)
	Salvia officinalis	Lamiaceae	Antiproliferative	α-thujone, 1,8-cineole and camphor	Privitera et al (2019)
	Cyperus articulatus	Cyperaceae	Cytotoxic	sesquiterpenes, anozol, monoterpenes, furanone, nootkatone, 6-methyl-3,5-heptadien-2-one, retinene, nopinone, cycloeucalenol, toosendanin, ethanone and vitamin A.	Kavaz et al (2019)
	Glandora rosmarinifolia	Boraginaceae	Cell growth inhibition	*m*-camphorene, heptacosane, nonacosane, hydroxy-methyl-naphthoquinone, 2,6-dimethyl-10-(*p*-tolyl)-2,6-(*E*)-undecadiene, cembrene C and phytol	Poma et al (2018)
	Semenovia suffruticosa	Apiaceae	Antiproliferative	Z-β-ocimen, linalool and β-bisabolol	Soltanian (2019)
	Cymbopogon flexuosus	Poaceae	Cytotoxic	Citral, Gerniol	Russo et al (2013)
	Tagetes minuta	Asteraceae	Cytotoxic	β-Ocimene, (E)-caryophyllene and germacrane D	Ali et al (2015)
Colon cancer	*Afrostyrax lepidophyius*	Huaceae	Chemopreventive	2,4,5,7-tetrathiaoctane	Fogang et al (2014)
	Sacrodopholeus zenkeri	Fabaceae	Chemopreventive	2,4,5,7-tetrathiaoctane	Fogang et al (2014)
	Athanesia brownii	Asteraceae	Chemopreventive	oxygenated sesquiterpenes with selin-11-en-4α-ol, caryophyllene oxide, humulene epoxide II and (E)-nerolidol	Rasoanaivo et al (2013)
	Neolistea variabillina	Lauraceae	Cytotoxic	trans-beta-ocimene, alpha-cadinol, terpinen-4-ol, tau-cadinol, beta-caryophyllene and sabinene	Su et al (2013)
	Satureja khuzistanica	Lamiaceae	Cytotoxic	Carvacrol and limonene	Yousefzadi et al (2014)
	Artemissia campestris	Asteraceae	Cytotoxic	β-myrcene, α-pinene, trans-β- ocimene, β-cymene and camphor	Al-Snafi (2015)
	Rosa damascena	Rosaceae	Apoptosis and necrosis	β-citronellol, nona- decane, geraniol, heni-cosane eicosane, linalool, methyl eugenol	Shokrzadeh et al (2017)

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Table 2. EOs effective in treating different types of cancers

Type of cancer	Plant essential oil	Family	Activity	Oil constituents	Refrences
	Melissa officinalis	Lamiaceae	Apopotosis	Citral	Dudai et al (2005)
	Salvia libanotica	Labiatae	Cell cycle arrest, apoptosis	Linalyl acetate, α-terpeniol, camphor	Russo et al (2015)
	Semenovia suffruticosa	Apiaceae	Antiproliferative	Z-β-ocimene, linalool and β-bisabolol	Soltanian (2019)
	Cymbopogon flexuosus	Poaceae	Cytotoxic	Citral, Gernial	Russo et al (2015)
	Citrus aurantium L. subspamara	Rutaceae	Cytotoxic	Limonene, α-pinene, β-myrcene	Odeh et al (2020)
Ovarian cancer	*Cymbopogon citratus*	Poaceae	Antiproliferative	Citral, geranial	Bayala et al (2018)
	Guatteria pogonopus	Annonaceae	Anti tumour	γ‐patchoulene, (E)‐caryophyllene, β‐pinene, germacrene D, bicyclogermacrene, α‐pinene, and germacrene B	do N Fontes et al (2013)
	Malus domestica	Rosaceae	Cytotoxic	eucalyptol, phytol, α-farnesene and pentacosane	Walia et al (2012)
	Patrinia scabra	Caprifoliaceae			
	Thymus broussonetti	Lamiaceae	Cytotoxic	borneol, thymol, camphene, ρ-cymene, *α*-pinene and linalool. Camphor, *α*-terpineol, eucalyptol, germacrene D	Russo et al (2015)
Liver cancer	*Thymus citriodorus*	Lamiaceae	Apoptosis	borneol, thymol, 3,7-dimethyl-1, 6-octadiene-3-ol, 1-methyl-4-[alpha-hydroxy-isopropyl] cyclohexene and terpenes camphor	Wu et al (2004)
	Artemissia indica	Asteraceae	Cytotoxic	ketone, germacrene B, borneol and *cis*-chrysanthenyl acetate	Rashid et al (2013)
	Pituranthos tortuosus	Apiaceae	Cytotoxic	terpinen-4-ol, sabinene, γ-terpinene and β-myrcene	Bayala et al (2018)
	Neolistea variabillina	Lauraceae	Cytotoxic	trans-beta-ocimene, alpha-cadinol, terpinen-4-ol, tau-cadinol, beta-caryophyllene and sabinene	Su et al (2013)
	Zanthoxylum schinifolium	Rutaceae	Apoptotic	geranyl acetate, citronella, sabinene	Paik et al (2005)
	Glandora rosmarinifolia	Boraginaceae	Cell growth inhibition	*m*-camphorene, heptacosane, nonacosane, hydroxy-methyl-naphthoquinone, 2,6-dimethyl-10-(*p*-tolyl)-2,6-(*E*)-undecadiene, cembrene C and phytol	Poma et al (2018)
	Cymbopogon flexuosus	Poaceae	Cytotoxic	Citral, Gerniol	Russo et al (2015)
Uterus and cervix cancer	*Casearia sylvestris*	Salicaceae	Cytotoxic	β-caryophyllene and α-humulene	Silva et al (2008)
	Liquidambar styraciflua	Altingiaceae	Cytotoxic	d-monene, α-pinene and β-pinene, and of the stem oil were germacrine D, α-cadinol, d-limonene, α-pinene, and β-pinene	El-Readi et al (2013)
	Schinus terebinthifolius	Anacardiaceae	Cytotoxic	germacreneD, bicyclogermacrene, β-pinene and β-longipinene	Santana et al (2012)
	Curcuma wenyujin	Zingiberaceae	Apoptotic	Furanodiene	Sun et al (2009)
	Aristolochia mollissima	Aristolochiaceae	Cytotoxic	(*E*)-β-santalol acetate and camphene	Bayala et al (2018)
	Melaleuca alternifolia	Myrtaceae	Necrosis	Terpinene-4-ol, γ-terpinene, α-terpineole, 1-8cineole and p-cymene	Russo et al (2015)

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Table 2. EOs effective in treating different types of cancers

Type of cancer	Plant essential oil	Family	Activity	Oil constituents	Refrences
	Salvia officinalis	Lamiaceae	Antiproliferative	α-thujone, 1,8-cineole and camphor	Privitera et al (2019)
	Lavandula angustofolia	Lamiaceae	Reduce cell viability	Linalool	Pereira et al (2018)
	Cymbopogon flexuosus	Poaceae	Cytotoxic	Citral, Gerniol	Russo et al (2015)
Lung cancer	*Xylopia futrescense*	Annonaceae	Cytotoxic	(E)-caryophyllene, bicyclogermacrene, germacrene D, δ-cadinene, viridiflorene and α-copaene	Bayala et al (2018)
	Guatteria progonopsis	Annonaceae	Anti tumour	γ - patchoulene, (E) - caryophyllene, β - pinene, germacreneD, bicyclogermacrene, α - pinene, and germacrene B	do N Fontes et al (2013)
	Neolistea variabillima	Lauraceae	Cytotoxic	trans-beta-ocimene, alpha-cadinol, terpinen-4-ol, tau-cadinol, beta-caryophyllene and sabinene	Su et al (2013)
	Tridax procumbens	Asteraceae	Apoptosis	Pinene pinene ß phellandrene and Sabinene	Manjamalai et al (2012)
	Artemissia indica	Asteraceae	Cytotoxic	ketone, germacrene B, borneol and *cis*-chrysanthenyl acetate	Rashid et al (2013)
	Listea cubeba	Lauraceae	Apoptosis	1,8-cineol, sabinene, α-terpinyl acetate α-pinene and β-pinene	Ho et al (2010)
	Solanum spirale	Solanaceae	Cytotoxic	(E)-Phytol, n-hexadecanoic acid, beta-selinene, alpha-selinene, octadecanoic acid and hexahydrofarnesyl acetone	Keawsa-Ard et al (2012)
	Melissa offcinalis	Lamiaceae	Apopotosis	Citral	Dudai et al (2005)
	Thymus broussonetti	Lamiaceae	Cytotoxic	borneol, germacrene D cymene, ρ-*α*-pinene, thymol, camphene, linalool, camphor, *α*-terpineol, eucalyptol and borneol	Russo et al (2015)
	Zingiber striolatum	Zingiberaceae	Cytotoxic	β-phellandrene, sabinene, β-pinene, geranyl linalool, terpinen-4-ol, α-pinene and crypton	Tian et al (2020)
	Lavandula angustofolia	Lamiaceae	Reduce cell viability	Linalool	Pereira et al (2018)
	Malus domestica	Rosaceae	Cytotoxic	eucalyptol, phytol, α-farnesene and pentacosane	Walia et al (2012)
Oral cancer	*Neolistea variabillima*	Lauraceae	Cytotoxic	trans-beta-ocimene, alpha-cadinol, terpinen-4-ol, tau-cadinol, beta-caryophyllene and sabinene	Su et al (2013)
	Solanum spirale	Solanaceae	Cytotoxic	(E)-Phytol, beta-selinene, n-hexadecanoic acid, alpha-selinene, octadecanoic acid and hexahydrofarnesyl acetone	Keawsa-Ard et al (2012)
	Pinus densiflora	Pinaceae	Apoptotic	beta-phellandrene and alpha-pinene	Jo et al (2012)
	Salvia officinalis	Labiateae	Antiproliferative	α-thujone, 1,8-cineole and camphor	Privitera et al (2019)

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Table 2. EOs effective in treating different types of cancers

Type of cancer	Plant essential oil	Family	Activity	Oil constituents	Refrences
Leukemia	*Neolistea variabillima*	Lauraceae	Cytotoxic	trans-beta-ocimene, alpha-cadinol, terpinen-4-ol, tau-cadinol, beta-caryophyllene and sabinene	Su et al (2013)
	Casearia sylvestris	Salicaceae	Cytotoxic	β-caryophyllene and α-humulene	Silva et al (2008)
	Artemesia indica	Asteraceae	Cytotoxic	ketone, germacrene B, borneol and *cis*-chrysanthenyl acetate	Rashid et al (2013)
	Juniperus excelsa	Cupressaceae	Cytotoxic	α-pinene and cedrol	Saab et al (2012)
	Juniperus oxycedrus	Cupressaceae	Cytotoxic	calamenene, cuparene, and cis-thujopsenal	Saab et al (2012)
	Cedrus libani	Pinaceae	Cytotoxic	germacrene D and β-caryophyllene	Saab et al (2018)
	Pinus pinea	Pinaceae	Cytotoxic	β-caryophyllene, α-terpineol, β-longipinene	Saab et al (2018)
	Malus domestica	Rosaceae	Cytotoxic	eucalyptol, phytol, α-farnesene and pentacosane	Walia et al (2012)
	Melissa officinalis	Lamiaceae	Apopotosis	Citral	Dudai et al (2005)
	Melaluca alternifolia	Myrtaceae	Necrosis	Terpinene-4-ol, γ-terpinene, α-terpineole, 1-8cineole and p-cymene	Russo et al (2015)
	Zingiber striolatum	Zingiberaceae	Cytotoxic	β-phellandrene, sabinene , β-pinene, geranyl linalool, terpinen-4-ol, α-pinene and crypton	Tian et al (2020)
	Lindera umbellata	Lauraceae	Apoptosis	Linalool	Pereira et al (2018)
Kidney cancer	*Satureja khuzistanica*	Labiatae	Cytotoxic	Carvacrol and limonene	Yousefzadi et al (2014)
	Platycladus orientalis	Cupressaceae	Antiproliferative	linalool, β - caryophyllene and α - cedrol	Loizzo et al (2008)
	Prangos asperula	Apiaceae	Antiproliferative	Sabinene, β-phellandrene, γ-terpinene and α-pinene	Loizzo et al (2008)
	Sideritis perfoliata	Labiatae	Cytotoxic	β-Phellandrene	Mesquita et al (2019)
	Aristolochia mollissima	Aristocholiaceae	Cytotoxic	(*E*)-β-santalol acetate and camphene	Bayala et al (2018)
Bone cancer	*Pyrolae herba*	Ericaceae	Antiproliferative	n-Hexadecanoic acid cedrol, 6,10,14-trimethyl-2-pentadecanone and cis-9-octadecadienoic acid	Cai et al (2013)
Pancreas cancer	*Boswellia sp*	Bursaeraceae	Apoptosis	E-beta-ocimene, limonene, E-caryophyllene	Suhail et al (2011)
	Kadsura longipedunculata	Schisandraceae	Apoptosis	Cadinene, camphene, borneol, cubenol and δ - cadinol	Bayala et al (2018)
	Angelica archangelica	Apiaceae	Antiproliferative	α-pinene, δ-3-carene, limonene and α-phellandrene	Maurya et al (2017)
Skin cancer	*Schefflera heptaphylla*	Araliaceae	Antiproliferative	pinene, phellandrene, myrcene, limonene, germacrene, caryophyllene	Li et al (2009)
Prostrate cancer	*Zingiber striolatum*	Zingiberaceae	Cytotoxic	β-phellandrene, sabinene, β-pinene, geranyl linalool, terpinen-4-ol, α-pinene and crypton	Tian et al (2020)
	Salvia officinalis	Lamiaceae	Antiproliferative	α-thujone, 1,8-cineole and camphor	Privitera et al (2019)

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Table 2. EOs effective in treating different types of cancers

Type of cancer	Plant essential oil	Family	Activity	Oil constituents	Refrences
	Lavender angustifolia	Lamiaceae	Antiproliferative	Linalool, linalyl acetate	Zhao et al (2018)
	Curcuma aromatica	Zingiberaceae	Apopotosis	xanthorrhizol, *ar*-curcumene di-epialpha-cedrene, Zingiberene, β-sesquiphellandrene and turmerone	Xiang et al (2017)
	Bursera glabrifolia	Burseraceae	Antiproliferative	α-terpineol, α-terpinene, limonene and β-pinene	Villa‑Ruano et al (2018)
	Cymbopogon citratus (DC.) and Cymbopogon giganteus Chiov.	Poaceae	Antiproliferative	C. giganteus: Limonene, Mentha-1(7), 8-dien-2-ol cis, Mentha-1(7), 8-dien-2-ol trans, trans-Mentha-2,8-diene-para-ol and Mentha-2,8-diene-1-ol, cis-para C. citratus: geranial/citral A and neral/citral B.	Bayala et al (2018)
	Iryanthera polyneura ducke	Myristicaceae	Cytotoxic	Spathulenol, α-cadinol and τ-muurolol	Martins et al (2019)

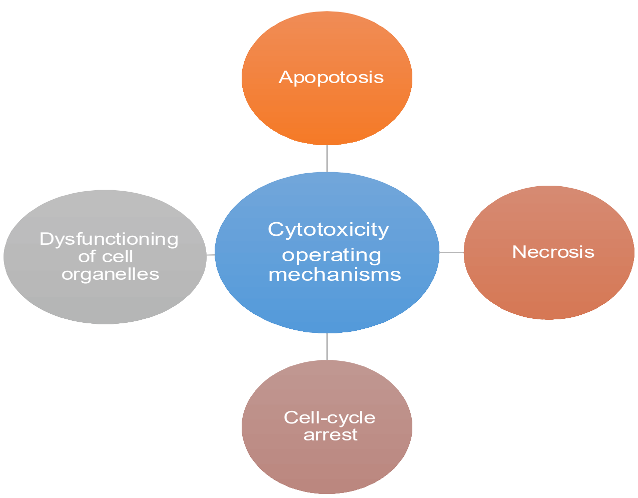

Fig. 2. Cellular mechanisms for carcinogenic prevention by EO

antidiabetic drug significantly decreased the serum glucose levels and a dose of 150mg/kg body weight was more effective than glibenclamide hence preventing diabetic complications associated with oxidative stress in alloxan induced diabetic rats. *Satureja khuzestanica* essential oil resulted in decrease of fasting blood glucose levels in diabetic rats (Abdollahi et al 2003). The combination of different essential oils of Cinnamon, Cumin, Fennel, Oregano and Myretle are known to enhance insulin sensitivity in type-2 diabetes (Talpur et al 2005). Still more research is needed to authenticate the hypoglycemic activity of essential oils.

Anti-oxidant property: The anti-oxidant property is among one of the pivotal biological properties of essential oils which manage the oxidative stress in pathology (Valgimigli 2012) when used in small quantities as compared to the amount of the material which they have to protect (Amorati et al 2013). The antioxidant potential of essential is basically explored as they are natural and non-toxic as compared to the synthetic oxidant such as butylated hydroxyl anisole or butyl hydroxyl toluene which is harmful to human health (Lanigan and Yamarik 2002). This activity depends on the rate constant of a reaction between antioxidant and the chain of free radicals. The antioxidant property is mainly attributed to particularly the phenolic component of essential oils which stop or delay the aerobic oxidation which is composed of terpenoids and phenylpropanoids (Sanchez-Vioque et al 2013). Free radicles generate oxidative stress and hence reactive oxygen species cause oxidation of biomolecules like amino acids, proteins, unsaturated lipids leading to various health issues such as ageing, arteriosclerosis, cancer, alzheimers disease, diabetes and asthma (Edris 2007). The antioxidant activity of *Thymus* and *Origanum* essential oil is attributed to thymol and carvacrol (20.5% and 58.1%) in Thymus and (35% and 32%) in *Origanum* and in essential oils of *Cympogon giganteus* and *Cymbopogon citratus* is mainly attributed to oxygenated monoterpenes. In *C giganteum*, beta caryophyllene shows antioxidant activity while limonene and citral shows anti stress activity in *C citratus* (Bayala et al 2018). The flowers of *Origanum vulgare* a flowering herb exhibited highest anti-oxidant activity among the other parts (Morshedloo et al 2018). The anti-oxidant activity from essential oil of *Lawsonia immerimis* was attributed to eucalyptol, a- pinene and linalool as its major constituents. Hence it shows the good potential of being a good natural antioxidant (Zafar et al 2018).

Antihelminthic bioactivity:Helminthesis is one of the major diseases resulting in the death of grazing animals especially in the underdeveloped countries. The essential oil of *Thymus boveri* was tested for antihelminthic property using adult earthworm and revealed that the major component of its essential oils trans geraniol, alpha-citral, beta-citral showed antihelminthic properties even higher than piperazine citrate (Jaradat et al 2016). Schistosomiasis caused by a flat worm Schistosoma was controlled with essential oil of *Tanacetum vulgare* (Asteraceae) having beta-thujone as its major constituent. *T vulgare* is a potential source of schistosomicidal compounds (Godinho et al 2014). The volatile essential oil derived from leaves of *Eucalyptus globulus* (Myrataceae) having 1,8-cineole as its major component showed antihelminthic property as compared standard drug albendazole at concentration of 10mg/ml. *Artemisia* species possess anti helminthic properties especially against the infections caused by gastrointestinal nematodes in ruminants. The effect of *Artemisia sieversiana* and *Artemisia parviflora* on *Haemonchus contortus,* a parasitic nematode that the mentholic plant extracts inihibited egg hatching, larval and adult motility thus reducing worm burden in animals (Irum et al 2017).The essential oils of three plant species *Citrus aurantifolia, Anthemis nobile and Lavendula officinalis* were evaluated for their in vitro egg hatching, larval development and adult worm motility using different concentration against *Haemonchus controtus* showed a significant antihelminthic activity (Ferreira et al 2018). The essential oil of *Albizia adiantifolia* isolated from leaves, stem, bark and roots have oxygenated mono terpenes. The anti helminthic activity of this essential oil was confirmed by using it against *E eugeniae* worm which showed a relatively higher activity as compared to albendazole an antihelminthic drug in concentration dependent manner (Akande et al 2018).

Antiviral property: Aromatic medicinal plants yield natural essential oils which exhibit exceptionally good antiviral properties (Reichling et al 2009). These antiviral activities are basically inhibition of viral replication attributed to the presence of monoterpenes, sesquiterpenes and phenylpropanoids. Herpes virus was inactivated by Eucalyptus and Thyme oils (Schnitzler et al 2001). The reoccurrence of herpes viral infections was significantly treated with *Meleluca alternifolia* (Carson et al 2001). It acts on the viral envelope structures so that adsorption into the host cell is prevented. Oregano oil exerts antiviral activity against yellow fever (Meneses et al 2009). The essential oils basically inhibit gene expression and thus prevent viral infections. *Artemissia arborescence* shows its activity against Herpes simplex virus type-1 (HSV-1) (Sinico et al 2005). The essential oil of *Melissa officinalis* L is composed of mainly of citral and citronellal (Allahverdiyev et al 2004) which inhibit the replication of HSV-2. The Lemon grass essential oil has potent anti-HSV-1 activity which inhibits viral replication. *Mentha piperata* shows virucidal activity against HSV-1, HSV-2 and acyclovir resistant strain of HSV-1 (Schuhmacher et al 2003). The essential oil of *Eryngium* species exhibits the antiviral activity on cucumber mosaic virus which affected *Chenopodium* (Dunkić et al 2013). In South East Asia Japanese encephalitis is a viral disease caused by Japanese encephalitis virus (JEV) and transmitted through *Culex* sp. of mosquito. The essential oil of *Trachyspermum ammi* (Ajwain) in vitro showed the antiviral effect on JEV (Roy et al 2015). A blend of *Eucalyptus globatus* and *Cinnamon zeylanicum* essential oil shows antiviral activity (Astani et al 2011; Vimalanathan and Hudson 2014) which was H1N1 and HSV-1. The essential oil of *Zataria multiflora* (Lamiaceae) exhibits antiviral effect on Newcastle disease virus (NDV) which causes Newcastle disease of poultry by cytotoxicity (Mohammadian et al 2015). The essential oil of Eucalyptus contains 1, 8 cineole and beta- caryophyllene interfere with virion envelope and hence limiting its entry in host cell (Amandine et al 2017). The antiviral property of essential oils is still to be evaluated.

CONCLUSION

This review summarizes the therapeautic and immunomodulatory properties of major bioactive compounds found in the essential oils. The various bioactivities attributed to different plant essential oils discussed above make them important natural products to be researched on. These essential oils are found to be safe as food preservatives as they domot posses any side effects on human health. The therapeautic properties encourage to utalize them as medications and in beauty care products.

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Received 27 February, 2022; Accepted 20 May, 2022

Indian Journal of Ecology (2022) 49(3) (SI): 1171-1196
DOI: https://doi.org/10.55362/IJE/2022/3643

Manuscript Number: 3643
NAAS Rating: 5.79

Integration of Ethnobotany and Diversity of Medicinal Plants in Manar Beat, Karamadai Range of the Western Ghats, India

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Abstract: The present study was carried out among the inhabitants of "Irulas", a tribe settled in the Manar beat of Karamadai Range, the Western Ghats, to make a documentary on the medicinal plants with quantitative scrutiny for the treatment of various human ailments. Systematic and exhaustive field survey was carried out over two years. Acquired data were analyzed by using Use Value (UV), Informant Consensus Factor (ICF) and Fidelity Level (FL). In total, 252 plant species representing 191 genera belonging to 76 families were identified and addressed by the tribe under 13 major disease categories. Euphorbiaceae was one of the wide-spread family, including 7.5% (19 species). Leaves were the most frequently used plant parts and most of the medicines were prepared in the form of decoction (62%). Among all, *Capparis grandiflora* was reported with UV of 0.96 and skeleto-muscular system disorders have the highest ICF of 0.76. The high FL (100%) was for 12 species. This study documents eight plant species recorded for therapeutic use in the Karamadai range for the first time. The present study is the first quantitative survey with the traditional use of medicinal plants in this region, also will help in the conservation of this invaluable inheritance. Plants with the highest use values in the study are suggested to take-up pharmacological activities in the future that result in the development of potential drugs to treat various ailments.

Keywords: Western ghats, Medicinal plants, Irula tribe, Use value, Fidelity level, Informant consensus factor

Plant resources are considered an integral part of human societies used by diverse cultural groups for thousands of years to foster well-being and are the natural remedies in antiquity by people worldwide, and the use of herbal medicines remains the predominant form of healthcare services (Bussmann et al 2018, Kigen et al 2019). The vegetation in the Indian sub-continent is distributed chiefly in the Himalayas, Western and Eastern Ghats (Revathi et al 2013). Approximately 3,500 species of medicinal plants from India have their therapeutic importance and many of them are still used by several tribal communities, especially for their first aid (Venkatachalapathi et al 2018). Besides, other factors such as deforestation, over-exploitation of natural resources, overgrazing, habitat destruction, fragmentation, and agricultural land expansion, heavily threatened the traditional medicinal plant resource and the associated indigenous knowledge (Assen et al 2021). As such, this is a timely effort to document, promote and conserve the tradition of the country's medicinal plant lore. Such documents are essential to define and maintain the cultural identity of the people. Ethnobotanists responsible for documenting complete information on plants and their medicinal uses.

According to WHO 70 to 90 percent of the world's population, particularly in developing countries, use medicinal plants for their health care. Irulas, one of India's 615 tribal communities, inhabit different topographic habitats in Tamil Nadu (plains, mountains, valleys, etc.). They are the second-largest tribal community in Tamil Nadu. The Irulas are not living on the hills but depend on the forest for their traditional activities (Senthilkumar et al 2018). The primary aim of this research was to evaluate the richness of the ethnomedicinal plant species used by the Irulas in Manar beat through quantitative analysis and to undertake an ethnobiological assessment of the socio-cultural background and medical understanding of diseases treated by traditional healers of the Irulas through quantitative ethnobotanical methods.

MATERIAL AND METHODS

Study area and the tribal people: Karamadai range is a reserve forest that comprises five beats: Velliangadu East beat, Velliangadu West beat, Nellimarathur beat, Pillur beat, and Manar beat. The present study was undertaken in the Manar beat in the Coimbatore District of Tamil Nadu, South India. It has a surface area of 22.7971 km^2 between the elevations about 442m above mean sea level. The geographical location of the study area is 11°18' N and 76° 53" E. The natural vegetation in this study area represents biomes, ranging from moist deciduous forest, dry deciduous forest, scrub jungle and riparian vegetation. The temperature of the study area is scarcely fluctuating from year to year. The maximum mean daily temperature is 37°C during summer and the minimum mean daily temperature is 15°C during winter. The annual average rainfall is 651.6 mm while the maximum rainfall was recorded from October to November during the northeast monsoon. Karamadai reserve forest is a part of the Western Ghats which is highly valued by botanists and ornithologists who have been overviewed by a wide variety of endemic flora and fauna. Irulas, a forest-dwelling tribal community, dispersed in and around the Manar beat of Coimbatore District. An exhaustive ethnobotanical survey was carried out from May 2018 to April 2020. Field visits were made fortnightly in all seasons. A total of 74 informants (43 males and 31 females) comprise different strata of participants. Selected informants ranged between 20-80 years were questioned by the community for further inquiry. Among them, 9% were above 70-80 years old, whereas 30% were between 40-50 and 14% were younger than 30. A questionnaire was designed to deal with the following ethnomedicinal uses for the plant such as parts of the plant used, medicinal uses, and preparation methods. The social biodata for each participant, such as gender, age, class, educational background, and occupation. During the investigation, two interview methods were also conducted. The 'Specimen display' method is initially used (Upadhyay et al 2010). Plant species were shown to traditional healers to elicit medicinal information. The same plant was shown to individual healers to verify the accuracy of the results. The field data sheet was prepared and used for documentation. The second method was a stroll through the forest with the healers to identify plants and gather detailed information. The plants were first identified by their local names in consultation with the tribal people. Hence, they gained knowledge from their ancestral treatment procedures. Further, the scientific identification of plants was confirmed by a taxonomist.

Plant identification and preservation: The collected plant species were thoroughly checked on authentic websites for correct nomenclature (www.plantlist.org) and compared with IUCN Red List to identify their status. The conservation status of the listed medicinal plants was measured using the following IUCN Red List 2020-1 category and criteria (www.iucnredlist.org). They were arranged alphabetically by Bentham and Hooker's (1862-1883) classification system, including binomial name, family name, vernacular name, forest type, etc. Flowers of India, 2020 verified the local names and the forest types were identified with the help of the India biodiversity portal, 2020. The listed plants were confirmed with the help of published regional floras such as the Flora of Presidency of Madras (Gamble 1984) and the Flora of Tamil Nadu Carnatic (Matthew 1983). Later the unknown specimens were identified by comparing voucher specimens of herbarium collections deposited in the Botanical Survey of India, Southern Circle, TNAU Campus, Coimbatore, India. All the preserved specimens were stored for future reference at the Department of Botany, Vellalar College for Women (Autonomous), Erode, Tamil Nadu, India with valid accession numbers (VCW/BH/Acc. No.1-74).

Ailment categories: Based on the information obtained from Irulas, the survey was grouped into 13 different ailment categories. Many diseases have been classified as ailment category according to the body systems treated. There are 58 different types of illnesses reported in these 13 categories. It includes circulatory system/cardiovascular diseases (CS / CD), dental and oral care (DOC), dermatological infections/diseases (DID), ear, nose, throat problems (ENT), endocrinal disorders (ED), fever (Fvr), gastro-intestinal ailments (GIA), genito-urinary ailments (GUA), hair problems (HP), liver problems (LP), animal/poisonous bites (PB), respiratory problems (RP) and skeleto muscular system disorders (SMSD).

Data Analysis Tools

Use value: The use-value (UV) was calculated for each plant to objectively provide a quantitative measure of its relative importance to the informant. This was calculated with the formula below.

$$UV = \sum U/n$$

Where UV is the use-value of a species, 'U' is the number of use reports cited by each informant for a particular plant species and 'n' refers to the total number of interviewees for a precise plant. Generally, UV is calculated to determine the plants with the highest use (most frequently indicated) in treating an ailment. 'UVs' is high when the use for a plant has many reports and low when there are few reports of its use (Barnert and Messmann, 2008).

Informant consensus factor: The informant consensus factor (Fic) was used to use plants in disease categories amongst plant users in the study area.

$$Fic = (N_{ur} - N_t) / (N_{ur} - 1)$$

Where, 'N_{ur}' refers to the number of use citations in each category and 'N_t' refers to all informants' number of species used for this ailment category. The result of this factor ranged between the values 0 to 1. A high value (nearly 1.0) indicates that a large proportion of respondents uses a relatively small number of taxa. A low value indicates that the informants differ on which taxa to use in treating a disease category. This method is intended to verify the homogeneity of information between users (Ba˘gcı, 2000).

Fidelity level : Fidelity level (FL) is a tool to determine the most frequently used plant species for treating a particular ailment category by the informants in the study area. FL was derived from the following formula of Martin (1995).

$$FL\ (\%) = Np/N \times 100$$

Where 'Np' is the number of use reports cited for a given species for a specific ailment category and 'N' means the total number of use reports cited for any given species. Generally, high FLs are obtained from plants are almost used for all referred use reports, whereas low FLs are obtained for plants that are used for many different purposes.

RESULTS AND DISCUSSION

Demographic profile of informants: The tribal population in this study area is smaller (around 195 families) and there were no well-developed electrical and transport facilities. Therefore, it is necessary to walk 26 km from their villages to the road and have limited bus facilities. Totally, 74 informants were selected and interviewed; they shared their valuable experiences and co-operated well during the documentation of ethnomedicinal information (Table 1). These people have a long history on the traditional use of plants. The conventional medicines of Irulas are still widely practiced throughout the study region and also rapidly disappearing due to modernization. Nowadays, literate healers and investigators frequently have written documents for their medical preparations with the gathered knowledge. Most traditional healers prefer to pass their folklore of medicinal plants orally to family members or helpers, which is a common practice in many other societies around the world.

Medicinal plant diversity: Through this extensive field survey, a large number of 252 plant species among 191 genera belonging to 76 families were recorded from the study area to cure various ailments (Table 2). Out of 252 studied plant species, 237 were dicot, 14 were monocot, and another was a pteridophyte. The information on local name, parts used, therapeutic uses and mode of preparation were also documented for supporting the ailment categories. The documentation of surveyed list contains new plant records for therapeutic use. There were 8 plants namely, *Butea monosperma, Cassia italica, Crotalaria grahamiana, Croton hirtus, Hardwickia binata, Ipomaea nil, Polygala bolbothrix, Pouzolzia zeylanica* were not been previously documented from this study area and surrounding forests (Fig. 1).

Family abundant: The present study indicates that the family Euphorbiaceae stood first by contributing 19 (7.5%) species, followed by Fabaceae 15 (5.9%), Caesalpiniaceae and Rubiaceae (each with 11 sps.) (4.3%) and finally Asclepiadaceae with ten species (3.9%). However, many species belonging to the family Acanthaceae, Convolvulaceae and Capparidaceae (each with 9 sps.) (3.5%) are also frequently used for treating different types of ailments (Table 3). Our present findings agree with some previous studies (Bhatia et al 2014, Kidane et al 2018, Krupa et al 2019) in the family-wise classification of ethnomedicinal plants.

Life form and parts used: In the current survey, 36% (90 species) of the reported species are herbs, followed by 27% trees, 21% shrubs and climbers 6% (Fig. 2). The shrubs have been identified with sub-categories such as climbing shrubs, large shrubs and under-shrubs. Sivasankari *et al*. (2014) reported that herbs (30.20%) were most used life forms, followed by trees (28.05%), shrubs (20.14%) and climbers (10.07%). In the current investigation, 89.28% of the plants are wild, 54.36% are cultivated and 33.33% are ornamental. The part wise plants used for medicinal purposes in this study shows that the leaves (120 reports) are higher followed by the whole plant, roots, barks, fruits, seeds, flowers, stems, pods, stem bark and root bark, rhizome and wood, tubers and latex. Among the plant parts utilized, leaves were most frequently used by Irula tribal community for various ailments (Fig. 3). Xavier et al (2014) found that leaf crude drug preparations are mostly recommended as ethnomedicine followed by entire plant, root, seeds and fruits, stem or bark, flower, rhizome and bulb.

Conservation status of plants: Based on the categories and criteria in the IUCN Red List (version 2020-1), the medicinal plants are categorized into three species types viz., vulnerable (VU) (1.19%), least concerned (LC) (19.04%) and not evaluated (NE) (79.76%). Sivasankari et al (2014) considered three species viz., *Pterocarpus marsupium* Roxb., *Santalum album* L. and *Saraca asoca* (Roxb.) De Wilde. as vulnerable in the study region, this supported the study in a significant way.

Method of preparation: In general, the ethnobotanical studies pointed out that, plant parts were grouped into 6 different preparative methods such as decoction (adding water and filtering with cloth), juice (squeezing the juicy part), paste (pounding), tonic (a clear bitter-tasting drink), powder (a dry substance made up of fine particles) and extract (extraction of liquids by maceration and adding water). In most instances, extremely difficult to separate decoction and infusion procedures (Bonet et al 1999) reported. In the current investigation, the most commonly used herbal preparation was decoction (62%) followed by juice (27%), paste (25%), tonic (15%), powder (10%) and extraction (8%) (Fig. 4). A decoction is the primary form of medicine preparation in certain tribal communities all over the world. Furthermore, the traditional healers are informed that medicine preparation was made by using only one part of a plant or in combination with parts of more than one species (Bahmani et al 2014).

Table 1. Demographic profile of the studied tribal people (Irulas) in Manar beat, Karamadai region of Western Ghats, India

Characteristics	No. of respondent		Total number	Percentage (%)
	Male	Female		
Sex	43	31	74	58:42
Age				
20-30	6	4	10	14%
30-40	7	8	15	20%
40-50	16	6	22	30%
50-60	5	6	11	15%
60-70	4	5	9	12%
70-80	3	4	7	9%
Herbalists (Professional healer)	17	8	25	34%
Local people	33	16	49	66%
Educational level				
Illiterate	16	11	27	36%
Adult education	7	9	16	22%
10^{th}	11	8	19	26%
12^{th}	5	4	9	12%
Graduation	2	1	3	4%
Occupation				
Herbalist	13	7	20	27%
Agriculturist	21	9	30	41%
Driver (Jeep)	7	5	12	16%
Coracle rider	3	2	5	7%
Cattle drover	4	3	7	9%

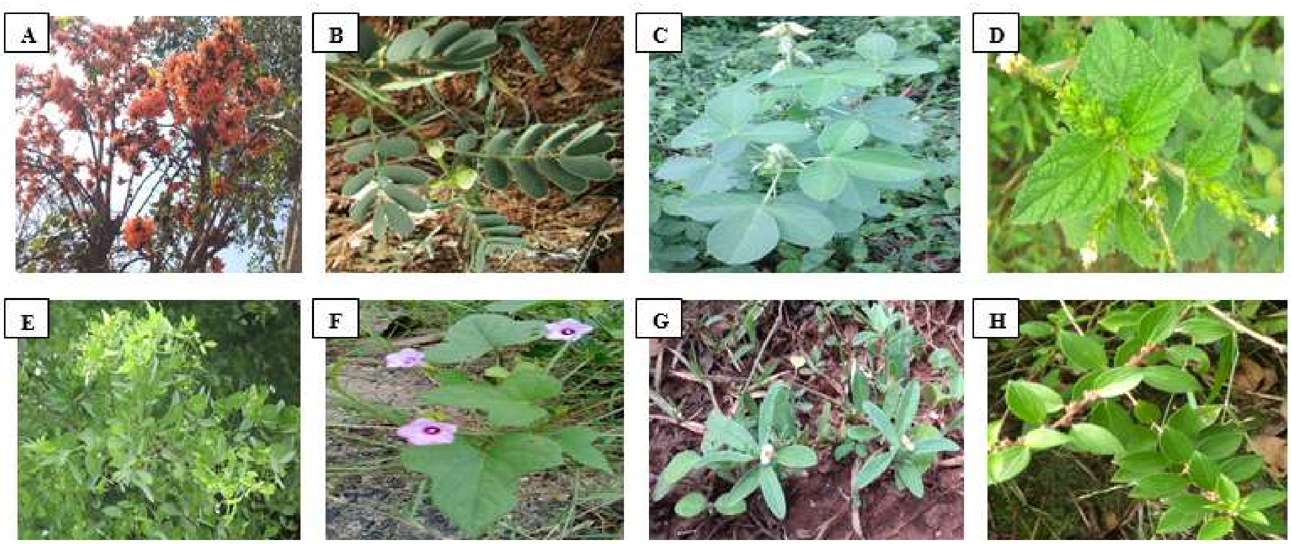

Fig. 1. Some Important Medicinal plants (A-H): A) *Butea monosperma*; B) *Cassia italica*; C) *Crotalaria grahamiana*; D) *Croton hirtus*; E) *Hardwickia binate*; F) *Ipomaea nil*; G) *Polygala bolbothrix*; H) *Pouzolzia zeylanica*

Table 2. Surveyed medicinal plants in Manar beat, Karamadai range, Western Ghats

Botanical name	Family name	Local name	Forest types	Habit	Parts used	Cultivation status	Ecological status	Therapeutic uses	Use value	Mode of preparation
Acacia concinna (Willd.) DC.	Mimosaceae	Shikakai	DDF	CS	Leaves and pods	Wild	NE	DID (General skincare, Wounds); GIA (Constipation); LP (Jaundice); HP (Dandruff)	0.32	Powder, paste and decoction
Acacia Senegal Willd.	Mimosaceae	Incakkai	SJ	T	Leaves and fruit	Wild	NE	RP (Cold)	0.28	Decoction and infusion
Acalypha fruticosa Forssk. BHVCW 01	Euphorbiaceae	Seenaichedi	DDF	S	Leaves, roots and stem	Wild	LC (2018)	Fvr (Fever); RP (Cold); DID (Scabies); PB (Snakebite); GIA (Stomach ache, Constipation); DOC (Tooth ache)	0.36	Paste
Acalypha indica L. BHVCW 02	Euphorbiaceae	Kuppaimeni	DDF	H	Whole plant	Cultivated and wild	NE	SMSD (Headache, Swelling, Joint pain); RP (Asthma); GIA (Stomach ache)	0.12	Decoction
Acalypha paniculata Miq. BHVCW 03	Euphorbiaceae	Malai kuppameni	DDF	H	Leaves	Ornamental and wild	NE	GIA (Stomach ache); GUA (Kidney stone); DID (Pimples)	0.16	Juice
Acanthospermum hispidum DC.	Asteraceae	Mullu Chedi	MDF	H	Leaves and seeds	Wild	NE	Fvr (Fever)	0.20	Paste and juice
Adatoda vasica Nees. BHVCW 04	Acanthaceae	Adatodai	DDF	S	Leaves	Ornamental and wild	NE	RP (Bronchitis)	0.08	Decoction and juice
Adenostemma lavenia O. Kze. BHVCW 05	Asteraceae	Vadakala	SJ	H	Leaves	Cultivated	NE	GIA (Intestinal ulcer); DID (Sunburn)	0.24	Paste
Aegle marmelos (L.) Correa ex Roxb. BHVCW 06	Rutaceae	Vilvam	MDF	T	Leaves, fruits and root	Cultivated and wild	NE	ENT (Earache); ED (Diabetes); GIA (Intestinal ulcer, Stomach ache, Dysentery)	0.44	Decoction and paste
Aerides maculosum Lindl.	Orchidaceae	Fox Brush Orchid	DDF	E	Leaves and flowers	Cultivated	NE	DID (General skincare)	0.08	Decoction
Aerva lanata (L.) Juss. ex Schult. BHVCW 07	Amaranthaceae	Poolai Poo	SJ	H	Leaves and roots	Wild	NE	RP (Cough, Asthma); SMSD (Headache); GUA (Kidney stone); PB (Snakebite)	0.36	Decoction and juice
Aerva tomentosa Forssk. BHVCW 08	Amaranthaceae	Perumpoolai	SJ	H	Roots, seeds and flowers	Wild	NE	SMSD (Rheumatism, Headache); DOC (Toothache); DID (General skincare)	0.12	Decoction and paste
Albizzia amara (Roxb.) Boivin.	Mimosaceae	Thuringil	DDF	T	Leaves, barks and fruit pods	Cultivated, ornamental and wild	NE	RP (Cough); LP (Jaundice); DID (Wounds)	0.24	Decoction
Allamania nodiflora (L.) R. Br.	Amaranthaceae	Kumattikkirai	SJ	H	Leaves and fruits	Wild	NE	GIA (Dysentery, Constipation)	0.04	Paste

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Table 2. Surveyed medicinal plants in Manar beat, Karamadai range, Western Ghats

Botanical name	Family name	Local name	Forest types	Habit	Parts used	Cultivation status	Ecological status	Therapeutic uses	Use value	Mode of preparation
Allophylus serratus Radlk.	Sapindaceae	Siruvalli	MDF	S	Leaves	Wild	NE	GIA (Intestinal ulcer); DID (Wounds)	0.20	Decoction
Aloe vera L. BHVCW 09	Liliaceae	Kathalai	MDF	H	Whole plant	Cultivated, ornamental and wild	NE	ENT (Sore throat); RP (Cough); CSCD (Blood purification); GUA (Kidney stone); GIA (Constipation)	0.44	Juice, tonic and powder
Alysicarpus monilifer DC.	Fabaceae	Kasukkoti	DDF	H	Whole plant	Wild	NE	LP (Jaundice); Fvr (Fever); GIA (Stomach ache); PB (Snakebite); DID (General skincare)	0.44	Paste and decoction
Alysicarpus rugosus DC.	Fabaceae	Heyne's Alyce Clover	MDF	H	Leaves and roots	Wild	NE	RP (Cough); Fvr (Fever)	0.08	Extraction
Alysicarpus vaginalis DC.	Fabaceae	Nilaorila	MDF	H	Whole plant and seeds	Cultivated and wild	NE	RP (Cough); GIA (Dysentery); Fvr (Fever); DID (Wounds)	0.16	Decoction and powder
Anacardium occidentale L.	Anacardiaceae	Munthiri	DDF	T	Leaves, fruit and bark	Cultivated	NE	RP (Cough, Cold); PB (Snakebite); GUA (Kidney stone); DOC (Toothache)	0.32	Juice
Andrographis echioides Nees. BHVCW 10	Acanthaceae	Gopuram Tangi	DDF	H	Whole plant	Cultivated, ornamental and wild	NE	PB (Snakebite, Scorpion sting); ED (Diabetes); RP (Bronchitis); GIA (Dysentery); Fvr (Fever); DID (General skincare)	0.24	Decoction and infusion
Annona reticulata L.	Annonaceae	Ramasita	MDF	T	Leaves, fruits, barks and root bark	Cultivated	LC (2018)	GIA (Intestinal ulcer, Dysentery); DOC (Toothache)	0.24	Paste and decoction
Anodendron paniculatum A. DC.	Apocynaceae	Sarakodi	MDF	C	Leaves and fruits	Wild	NE	GIA (Intestinal ulcer); LP (Jaundice)	0.12	Powder
Anogeissus latifolia Wall.	Combretaceae	Namai	MDF	T	Whole plant	Cultivated and wild	NE	PB (Snakebite, Scorpion sting)	0.04	Decoction and juice
Argemone Mexicana L.	Papaveraceae	Piramathandu	DDF	H	Leaves	Ornamental and wild	NE	RP (Cough, Asthma); Fvr (Fever); LP (Jaundice); SMSD (Headache); DID (General skincare)	0.36	Decoction and juice
Argyreia cuneata Ker-Gawl. BHVCW 11	Convolvulaceae	Kanvalipoo	DDF	S	Leaves and roots	Ornamental and wild	NE	DID (Wounds, General skincare); SMSD (Rheumatism) PB (Scorpion sting)	0.44	Decoction
Artocarpus integrifolia L.	Moraceae	Palamarum	MDF	T	Leaves and roots	Cultivated and wild	NE	GIA (Stomach ache); Fvr (Fever); RP (Asthma); DID (Wounds, General skincare)	0.16	Decoction and tonic
Asclepias curassavica L.	Asclepiadaceae	Neer poo	RV & MDF	H	Root and leaves	Cultivated, ornamental and wild	NE	ENT (Eye pain); DID (Dermatitis); GIA (Dysentery)	0.28	Paste and juice

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Table 2. Surveyed medicinal plants in Manar beat, Karamadai range, Western Ghats

Botanical name	Family name	Local name	Forest types	Habit	Parts used	Cultivation status	Ecological status	Therapeutic uses	Use value	Mode of preparation
Asystasia gangetica T. And.	Acanthaceae	Miti Kirai	MDF	H	Root and leaves	Ornamental and wild	NE	GIA (Piles, Stomach ache); Fvr (Fever); RP (Asthma); PB (Snakebite)	0.24	Decoction, juice and powder
Atalantia monophylla (L.) Correa. BHVCW 12	Rutaceae	KattuElumichai	DDF	S	Fruits	Wild	NE	SMSD (Rheumatism, Joint pain)	0.24	Decoction
Azadirachta indica A. Juss.	Meliaceae	Vembu	DDF	T	Whole plant	Cultivated and wild	LC (2018)	DID (Wounds, Eczema); GIA (Intestinal ulcer); SMSD (Rheumatism)	0.28	Decoction and juice
Bambusa arundinacea Willd.	Poaceae	Mungil	MDF	S	Leaves and roots	Cultivated and wild	NE	GUA (Problems of menopause); GIA (Indigestion); DID (Wounds); SMSD (Joint pain); ENT (Eye cooling)	0.08	Juice
Barleria acuminata Wt.	Acanthaceae	Vellai kurinji	SJ	S	Whole plant	Cultivated and wild	NE	Fvr (Fever); DOC (Toothache); SMSD (Joint pain)	0.12	Juice
Barleria cristata L. BHVCW 13	Acanthaceae	Semmulli	DDF	H	Leaves and seeds	Ornamental and wild	NE	PB (Snakebite); GUA (Swelling)	0.12	Juice
Bauhinia racemosa Lamk.	Caesalpiniaceae	Aatthi	DDF & MDF	T	Whole plant	Wild	NE	RP (Cough)	0.08	Juice and decoction
Bauhinia tomentosa L.	Caesalpiniaceae	Tiruvatti	MDF	S	Flowers and seed	Cultivated, ornamental and wild	LC (2018)	GIA (Dysentery); DID (Wounds)	0.12	Tonic and paste
Begonia malabarica Lamk.	Begoniaceae	Sengurungu	MDF	H	Leaves	Cultivated	NE	DID (General skincare)	0.08	Decoction and paste
Benkara malabarica (Lamk.) Tirveng.	Rubiaceae	Pudan	SJ & MDF	T	Leaves	Cultivated	NE	ENT (Throat pain)	0.08	Juice and paste
Bischofia javanica Bl.	Euphorbiaceae	Thondi	MDF	T	Bark and leaves	Cultivated, ornamental and wild	LC (2018)	GIA (Stomach ache); ENT (Sore throat)	0.20	Decoction
Blepharis boerhaaviaefolia Pers.	Acanthaceae	Creeping Blepharis	DDF	H	Whole plant	Cultivated	NE	SMSD (Muscle pain, Headache, Swellings); ENT (Throat pain); RP (Asthma)	0.28	Juice and paste
Blepharis molluginifolia Pers.	Acanthaceae	Nethirappoondu	SJ	H	Whole plant	Cultivated and ornamental	NE	SMSD (Headache); GIA (Dysentery); PB (Snakebite); ED (Diabetes); DID (Wounds)	0.16	Paste
Boerhaavia chinensis (L.) Rottb.	Nyctaginaceae	Kodi Minnai	DDF & MDF	H	Root and leaves	Wild	NE	DID (Scabies, Itching)	0.12	Extraction
Boerhaavia diffusa L. BHVCW 14	Nyctaginaceae	Sarandai / Saerandaidagu	DDF & MDF	H	Whole plant	Wild	NE	LP (Jaundice); PB (Snakebite); RP (Asthma); GIA (Dysentery, Stomach ache)	0.12	Decoction

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Table 2. Surveyed medicinal plants in Manar beat, Karamadai range, Western Ghats

Botanical name	Family name	Local name	Forest types	Habit	Parts used	Cultivation status	Ecological status	Therapeutic uses	Use value	Mode of preparation
Bridelia stipularis Bl.	Euphorbiaceae	Climbing Bridelia	MDF	S	Bark and leaves	Wild	LC (2019)	RP (Asthma, Cough); GIA (Intestinal ulcer); LP (Jaundice); Fvr (Fever)	0.20	Decoction
Butea monosperma Roxb.	Fabaceae	Muthagai	MDF & DDF	T	Leaves, barks and flowers	Cultivated, ornamental and wild	NE	DID (Wounds)	0.32	Paste
Cadaba trifoliata Wight. & Arn.	Capparidaceae	Kattagatti	DDF	S	Leaves	Cultivated	NE	SMSD (Swellings); Fvr (Fever)	0.20	Paste and juice
Caesalpinia pulcherrima Sw.	Caesalpiniaceae	Mayir-konrai	SJ	S	Leaves and flowers	Ornamental and wild	LC (2018)	RP (Cold); GUA (Kidney stone); Fvr (Fever); GIA (Constipation, Stomach ache)	0.04	Decoction
Calamus rotang L.	Arecaceae	Pirambu	MDF & RV	T	Root	Cultivated	NE	Fvr (Fever); PB (Snakebite)	0.08	Decoction
Canthium umbellatum Wight.	Rubiaceae	Nallamandharam	MDF	T	Leaves and roots	Wild	NE	GIA (Dysentery)	0.04	Decoction
Capparis divaricata Lam. BHVCW 15	Capparidaceae	Thoratti	DDF	T	Leaves and bark	Cultivated and wild	NE	GIA (Intestinal ulcer, Dysentery, Stomach ache)	0.16	Paste and tonic
Capparis grandiflora Hook.f. & Thomson. BHVCW 16	Capparidaceae	Thorattimul / Kevisi	DDF	S	Whole plant and fruit	Wild	NE	GIA (Stomach ache, Gastric complaints, Vomiting); GUA (Menstrual problems); SMSD (Rheumatism)	0.96	Decoction and juice
Capparis sepiaria L. BHVCW 17	Capparidaceae	Kaatukathiri / Aanaikevisi	SJ & DDF	S	Leaves, flowers and roots	Cultivated and wild	NE	PB (Snakebites); Fvr (Fever); DID (General skincare); GIA (Stomach ache)	0.68	Tonic and powder
Caralluma adscendens R.Br.	Asclepiadaceae	Muyal kombu chedi / Ekkaechedi	SJ & DDF	H	Whole plant	Cultivated, ornamental and wild	NE	RP (Cough, Chest pain); SMSD (Swellings); GIA (Indigestion); ED (Diabetes); DID (General skincare); GUA (Kidney stone)	0.08	Decoction
Caralluma bicolor Ramach, S. Joseph, H. A. John & C. Sofiya	Asclepiadaceae	Kattalae	SJ & DDF	H	Stem	Cultivated	NE	DID (Wounds)	0.20	Extraction
Caralluma umbellate Haw. BHVCW 18	Asclepiadaceae	Kallimulaiyaam	DDF	H	Stem	Cultivated and wild	NE	GIA (Stomach ache, Intestinal ulcer); ED (Diabetes)	0.04	Juice
Cardiospermum halicacabum L. BHVCW 19	Sapindaceae	Mudakattan	MDF & SJ	C	Whole plant	Cultivated, ornamental, wild	LC (2020)	SMSD (Rheumatism); GIA (Stomach ache); PB (Snakebites)	0.72	Juice
Carmona retus (Vahl.) Masamune.	Boraginaceae	KuranguVethilai	DDF & SJ	S	Leaves and roots	Cultivated, ornamental and wild	NE	GIA (Stomach ache, Dysentery); PB (Poisonous bites); RP (Cough)	0.16	Decoction
Cassia absus L.	Caesalpiniaceae	Karun kanami	MDF	H	Leaves and seed	Cultivated and wild	LC (2010)	CSCD (Blood purification); RP (Asthma)	0.08	Decoction

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Table 2. Surveyed medicinal plants in Manar beat, Karamadai range, Western Ghats

Botanical name	Family name	Local name	Forest types	Habit	Parts used	Cultivation status	Ecological status	Therapeutic uses	Use value	Mode of preparation
Cassia auriculata L. BHVCW 20	Caesalpiniaceae	Aavaram	SJ	S	Roots, bark and flowers	Cultivated, ornamental and wild	NE	DID (General skincare); SMSD (Rheumatism); ED (Diabetes)	0.04	Decoction
Cassia italica (Mill.) Sperg.	Caesalpiniaceae	Nelatangedu	SJ	H	Leaves, roots, pods and seeds	Cultivated, wild	NE	GIA (Indigestion, Vomiting); Fvr (Fever); LP (Jaundice); GUA (Venereal diseases); DID (General skincare); ENT (Nasal infections)	0.08	Decoction
Cassia javanica L.	Caesalpiniaceae	Konari	DDF	T	Seeds and bark	Cultivated, ornamental and wild	LC (2018)	Fvr (Fever)	0.20	Decoction
Cassia montana Heyne.	Caesalpiniaceae	Malaikkondrai	MDF	S	Stems, roots and leaves	Cultivated, wild	NE	DID (Scabies, General skincare)	0.16	Decoction and juice
Cassia occidentalis L. BHVCW 21	Caesalpiniaceae	Payaverai / Thagarai	MDF	S	Whole plant	Cultivated, ornamental and wild	NE	SMSD (Rheumatism, Headache); RP (Cough, Cold); DID (Eczema); Fvr (Fever); GUA (Kidney stone); ED (Diabetes)	0.16	Tonic
Cassine glauca (Rottb.) Kuntze.	Celastraceae	Kaneera	DDF	T	Leaves, root and root bark	Ornamental and wild	NE	SMSD (Headache, Swellings); PB (Snakebite)	0.24	Paste
Celastrus paniculata Willd.	Celastraceae	Valuluvai	MDF	C	Leaves, barks and stembark	Wild	NE	GIA (Dysentery, Indigestion); PB (Poisonous bites); GUA (Kidney stone)	0.16	Extraction, decoction and juice
Celosia argentea L.	Amaranthaceae	Pannaikeerai	MDF	H	Whole plant	Cultivated, ornamental and wild	LC (2019)	DID (Wounds, Eczema); PB (Snakebite); ED (Diabetes)	0.12	Decoction
Celtis tetrandra Roxb.	Ulmaceae	Kuriyaa	MDF	T	Fruits and seeds	Wild	LC (2018)	GIA (Indigestion)	0.12	Juice
Celtis timorensis Span.	Ulmaceae	Kalluviri	MDF	T	Whole plant	Wild	LC (2018)	Fvr (Fever); GIA (Indigestion)	0.28	Decoction
Cenchrus ciliaris L.	Poaceae	Kollukattaipullu	SJ	H	Leaves	Wild	LC (2017)	GUA (Kidney stone); DID (Wounds)	0.16	Decoction
Centella asiatica Urb. BHVCW 22	Apiaceae	Vallarai	MDF	H	Whole plant	Cultivated and wild	LC (2018)	DID (Wounds); Fvr (Fever)	0.08	Decoction and powder
Cereus pterogonus Lamk.	Cactaceae	Oocikalli	DEF	S	Whole plant	Wild	NE	GIA (Constipation)	0.24	Extraction
Cissus quadrangularis L. BHVCW 23	Vitaceae	Pirandai/ Naralaikodi	SJ & DDF	CS	Barks, leaves, roots and stem	Cultivated, ornamental and wild	NE	SMSD (Rheumatism); DID (Wounds, Burns); GIA (Indigestion)	0.84	Paste and powder

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Table 2. Surveyed medicinal plants in Manar beat, Karamadai range, Western Ghats

Botanical name	Family name	Local name	Forest types	Habit	Parts used	Cultivation status	Ecological status	Therapeutic uses	Use value	Mode of preparation
Citrullus lanatus (Thumb.) Matsum. Nakai.	Cucurbitaceae	Tharpoosani	MDF	H	Fruits	Cultivated	NE	ED (Diabetes)	0.72	Juice and tonic
Cleome feline L.f. BHVCW 45	Capparidaceae	CuvarnaciriTaivelai	SJ & DDF	H	Whole plant	Cultivated and wild	NE	RP (Asthma)	0.24	Paste
Cleome gynandra L. BHVCW 24	Capparidaceae	Taivelai	DDF	H	Whole plant	Cultivated, ornamental and wild	NE	PB (Scorpion sting, Snakebite); Fvr (Fever)	0.16	Decoction and juice
Cleome monophylla L. BHVCW 25	Capparidaceae	Ellukkusakkalathi	DDF	H	Whole plant	Wild	NE	SMSD (Swellings, Headache); RP (Cough); Fvr (Fever)	0.20	Juice, paste and decoction
Coccinia grandis (Linn.) Voigt. BHVCW 26	Cucurbitaceae	Kovai/ Thondai	DDF	C	Whole plant	Cultivated and wild	NE	RP (Asthma, Bronchitis); SMSD (Rheumatism, Headache); ED (Diabetes); LP (Jaundice); Fvr (Fever)	0.24	Juice and decoction
Combretum album Pers.	Combretaceae	White Combretum	SJ	CS	Leaves	Ornamental and wild	NE	Fvr (Fever)	0.40	Decoction
Combretum ovalifolium Roxb. BHVCW 27	Combretaceae	Odaikodi	MDF	CS	Leaves and fruits	Wild	NE	GIA (Dysentery)	0.24	Paste, juice and decoction
Commelina benghalensis L. BHVCW 28	Commelinaceae	Kanavazhai / Kayinai	DDF	H	Whole plant	Wild	LC (2018)	GIA (Stomach ache); ENT (Sore throat); DID (Burns)	0.16	Decoction
Cordia dichotoma G. Forst.	Boraginaceae	Karadisellai	SJ & DDF	T	Leaves and stembark	Cultivated and wild	LC (2018)	SMSD (Swellings, Headache); GIA (Dysentery, Stomach ache); Fvr (Fever)	0.12	Decoction, juice and tonic
Cordia sinensis Lam.	Boraginaceae	Sellai	DDF	S	Leaves, roots and barks	Cultivated, ornamental and wild	LC (2020)	GUA (Abortion); Fvr (Fever); GIA (Stomach ache)	0.04	Decoction
Crataeva adansonii DC.	Capparidaceae	Marvilinga	DDF	T	Roots, leaves and barks	Ornamental and wild	NE	SMSD (Headache, Swellings); LP (Jaundice)	0.20	Decoction, powder and tonic
Crataeva religiosa Forst. BHVCW 29	Capparidaceae	Mavilankai	DDF	T	Flowers, bark and leaves	Ornamental and wild	NE	SMSD (Rheumatism); GIA (Stomach ache); ENT (Earache)	0.68	Decoction and juice
Crotalaria grahamiana W. & A.	Fabaceae	Bushy Rattlepod	SJ	S	Whole plant	Cultivated, ornamental and wild	NE	RP (Cough, Cold); Fvr (Fever); DID (Scabies, General skincare); PB (Scorpion sting); GIA (Stomach ache)	0.04	Decoction and powder
Crotalaria pallida Aiton.	Fabaceae	Kilukiluppai	MDF	S	Whole plant	Cultivated and wild	NE	DID (Wounds, General skincare, Eczema); Fvr (Fever); SMSD (Swellings)	0.16	Paste
Croton hirtus L.	Euphorbiaceae	Hairy Croton	RV	H	Fruits and seeds	Cultivated and wild	NE	Fvr (Fever); RP (Bronchitis)	0.12	Tonic

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Botanical name	Family name	Local name	Forest types	Habit	Parts used	Cultivation status	Ecological status	Therapeutic uses	Use value	Mode of preparation
Croton sparsiflorus Mor.	Euphorbiaceae	Reilpoondu	DDF	S	Whole plant	Wild	NE	DID (General skincare, Wounds)	0.40	Extraction
Cucumis melo L. BHVCW 30	Cucurbitaceae	Thumattikai	MDF	H	Fruits	Cultivated	NE	GIA (Stomach ache); DID (Burns)	0.28	Juice
Curculigo orchioides Gaertn.	Hypoxidaceae	Nilappanakizhangu/ Nilappannai	MDF & SJ	H	Rhizome	Wild	NE	RP (Asthma); GIA (Piles); LP (Jaundice); SMSD (Headache); DID (General skincare)	0.08	Decoction
Cymbidium aloifolium Hk. f.	Orchidaceae	Konkani	MDF	E	Whole plant and pods	Cultivated, ornamental and wild	NE	ENT (Earache); Fvr (Fever); DID (Cuts, Wounds)	0.12	Decoction and paste
Cymbopogon coloratus Stapf.	Poaceae	Kamachipul	MDF	H	Leaves and roots	Cultivated and wild	NE	RP (Cough, Cold); Fvr (Fever); SMSD (Headache)	0.24	Decoction and tonic
Cynodon dactylon (Linn.) Pers. BHVCW 31	Poaceae	Aruhumpul	MDF	CH	Whole plant	Ornamental and wild	NE	RP (Cough); PB (Snakebite); GIA (Dysentery, Stomach ache); SMSD (Headache); DID (Wounds, Itching)	0.60	Juice and decoction
Cyperus rotundus L. BHVCW 32	Cyperaceae	Korai kizhangu	MDF	H	Tubers and roots	Cultivated and wild	LC (2017)	GIA (Stomach ache)	0.28	Paste and tonic
Dactyloctenium aegyptium Beauv.	Poaceae	Kakkakalpul	MDF	H	Whole plant	Wild	NE	GIA (Dysentery)	0.16	Decoction
Dalbergia lanceolaria L. f. BHVCW 33	Fabaceae	Erikai	DDF & MDF	T	Bark	Ornamental and wild	LC (2010)	GIA (Indigestion)	0.16	Tonic and juice
Dalbergia latifolia Roxb. BHVCW 34	Fabaceae	Nukkam	DDF & MDF	T	Bark	Cultivated and wild	VU (1998)	GIA (Indigestion)	0.16	Extraction
Dalbergia sissoo Roxb.	Fabaceae	Nukkam	MDF	T	Leaves	Cultivated, ornamental and wild	NE	DID (Wounds, General skincare)	0.12	Powder
Debregeasia longifolia (Burm.f.) Wedd.	Urticaceae	Kaattunochchi	MDF	LS	Leaves	Wild	LC (2018)	DID (Scabies)	0.40	Juice
Delonix elata Gamb.	Caesalpiniaceae	Vathanarayan	SJ & DEF	T	Leaves	Cultivated, semi-cultivated, ornamental and wild	LC (2011)	DOC (Mouth ulcer)	0.48	Decoction, infusion and paste
Dentella repens Forst.	Rubiaceae	Creeping lickstoop	MDF	H	Leaves and fruits	Wild	LC (2011)	RP (Cough)	0.40	Decoction
Desmodium triflorum DC.	Fabaceae	Sirupullati	MDF	H	Whole plant	Cultivated and wild	LC (2010)	GIA (Dysentery, Intestinal ulcer); DID (Wounds, General skincare)	0.32	Decoction
Dichrostachys cinerea W. & A. BHVCW 35	Mimosaceae	Vadathalla	DDF & SJ	TS	Barks and leaves	Cultivated, ornamental and wild	LC (2009)	GIA (Dysentery); SMSD (Headache); DOC (Toothache); PB (Scorpion sting, Snakebites)	0.36	Decoction and powder

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Table 2. Surveyed medicinal plants in Manar beat, Karamadai range, Western Ghats

Botanical name	Family name	Local name	Forest types	Habit	Parts used	Cultivation status	Ecological status	Therapeutic uses	Use value	Mode of preparation
Digera arvensis Forsk. BHVCW 36	Amaranthaceae	Toya Keerai	DDF	H	Leaves, seeds and flowers	Cultivated and wild	NE	GIA (Indigestion)	0.36	Paste
Digitaria ciliaris (Retz.)	Poaceae	Arisipillu	MDF	H	Whole plant	Wild	NE	GIA (Vomiting)	0.12	Decoction
Diospyros malabarica (Desr.) Kostel. BHVCW 37	Ebenaceae	Tumbika	DDF	T	Barks, seeds and fruits	Cultivated, ornamental and wild	NE	PB (Snakebite); Fvr (Fever); GIA (Dysentery)	0.20	Juice
Dodonaea viscose L. BHVCW 38	Sapindaceae	Vilaari	DDF	LS	Stems, leaves and roots	Ornamental and wild	LC (2018)	RP (Cold); SMSD (Rheumatism, Swellings); GIA (Indigestion, Intestinal ulcer, Constipation); GUA (Menstrual problems); DID (Wounds, Burns)	0.24	Decoction and juice
Drymaria cordata Willd.	Caryophyllaceae	Masipathri	DDF	H	Whole plant	Cultivated and wild	NE	RP (Chest pain, Bronchitis, Cold); GIA (Stomach ache); LP (Jaundice)	0.20	Decoction
Ehretia ovalifolia Wt.	Boraginaceae	Karukamaram	SJ & DDF	T	Bark	Wild	NE	Fvr (Fever); RP (Cough)	0.68	Juice
Emblica officinalis Gaertn. BHVCW 39	Euphorbiaceae	Nelli	DDF & MDF	T	Fruit	Cultivated, ornamental and wild	NE	ENT (Eye pain); ED (Diabetes); SMSD (Joint pain); GIA (Dysentery)	0.04	Decoction, tonic and juice
Entada scandens Benth.	Fabaceae	Anaittellu	MDF	C	Barks and seeds	Wild	NE	Fvr (Fever)	0.72	Paste
Enterolobium saman Prain.	Fabaceae	Thoongumoonjimaram	SJ	T	Bark and seeds	Cultivated, ornamental and wild	NE	DID (General skincare, Eczema); ENT (Sore throat); GIA (Stomach ache)	0.16	Decoction
Erythroxylon monogynum Roxb.	Linaceae	Sembulichan	DDF	LS	Leaves and barks	Wild	NE	GIA (Stomach ache)	0.08	Extraction
Euphorbia thymifolia L.	Euphorbiaceae	Cirramman-pac-carici	MDF	H	Whole plant	Wild	NE	SMSD (Headache); GUA (Venereal diseases); Fvr (Fever)	0.04	Decoction and tonic
Euphorbia tirucalli L. BHVCW 40	Euphorbiaceae	Thirukalli	DDF	S	Whole plant	Cultivated, ornamental and wild	LC (2004)	DID (General skincare, Itching); RP (Cough); PB (Snakebites); SMSD (Rheumatism); DOC (Toothache); ENT (Earache)	0.04	Decoction and juice
Evolvulus alsinoides L.	Convolvulaceae	Vishnu Kiranthi	DDF, MDF & SJ	H	Whole plant	Cultivated	NE	RP (Asthma, Bronchitis); HP (Hair growth); PB (Snakebites)	0.68	Decoction
Evolvulus nummularius	Convolvulaceae	Elikkathuillai	MDF	H	Whole plant	Cultivated and	NE	DID (Cuts, Burns, Wounds); PB (Scorpion sting)	0.36	Paste

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Table 2. Surveyed medicinal plants in Manar beat, Karamadai range, Western Ghats

Botanical name	Family name	Local name	Forest types	Habit	Parts used	Cultivation status	Ecological status	Therapeutic uses	Use value	Mode of preparation
BHVCW 41						ornamental				
Exacum pedunculatum L.	Gentianaceae	Kana Poondu	MDF	H	Whole plant	Cultivated and wild	NE	Fvr (Fever); GIA (Dysentery)	0.20	Decoction
Feronia elephantum Corr. BHVCW 42	Rutaceae	Vilampazam	DDF & SJ	T	Leaves, fruitand bark	Cultivated and wild	NE	GIA (Dysentery, Indigestion); ENT (Sore throat); DID (Itching)	0.76	Paste
Ficus microcarpa Wight.	Moraceae	Kallichchi	MDF	T	Roots, latex and bark	Cultivated, ornamental and wild	LC (2018)	Fvr (Fever); DID (Wounds); SMSD (Headache); DOC (Toothache)	0.04	Extraction
Ficus racemosa L.	Moraceae	Atti	MDF	T	Fruits	Cultivated, ornamental and wild	LC (2018)	ENT (Eye cooling)	0.84	Decoction
Ficus religiosa L.	Moraceae	Arasu	MDF	T	Leaves, barks and roots	Ornamental and wild	NE	DID (General skincare); PB (Poisonous bites); GIA (Intestinal ulcer)	0.64	Decoction
Ficus tomentosa Roxb.	Moraceae	Soft Fig	DDF	T	Leaves and barks	Wild	NE	DID (Wounds, Cuts)	0.08	Paste
Flacourtia indica (Burm. f.) Merr.	Bixaceae	Kodumundi	SJ	S	Leaves and root	Cultivated, ornamental and wild	LC (2018)	Fvr (Fever); RP (Asthma); GIA (kill worms in stomach); GUA (Kidney stone); SMSD (Body pain); PB (Snakebite)	0.04	Decoction and tonic
Fluggea leucopyrus Willd.	Euphorbiaceae	Vellaipoola	SJ & DDF	S	Leaves, fruits and barks	Cultivated, ornamental and wild	NE	GUA (Venereal diseases); Fvr (Fever); GIA (Constipation)	0.72	Decoction
Gisekia pharnaceoides L.	Aizoaceae	Manal Keerai	SJ & MDF	H	Whole plant	Wild	NE	RP (Asthma, Chest pain); SMSD (Swellings)	0.84	Extraction
Givotia moluccana (Linn.) Sreem. BHVCW 43	Euphorbiaceae	Thaalamaram	DDF & MDF	T	Seeds and barks	Cultivated, ornamental and wild	NE	HP (Dandruff); DID (Psoriasis); SMSD (Rheumatism)	0.20	Decoction and paste
Gomphocarpus physocarpus E. Mey.	Asclepiadaceae	Balloon Plant	MDF	S	Root and leaves	Cultivated, ornamental and wild	NE	DOC (Toothache); RP (Cough); GIA (Stomach ache); SMSD (Headache)	0.56	Decoction and paste
Gyrocarpus asiaticus Willd.	Hernandiaceae	Thanakku	DDF	T	Leaves, roots and barks	Wild	NE	DID (Wounds, Scabies); GUA (Kidney stone)	0.80	Decoction
Hardwickia binata Roxb.	Caesalpiniaceae	Aacha	DDF	T	Bark	Wild	LC (2018)	GIA (Indigestion, kill worms in stomach)	0.92	Paste
Helicteres isora L. BHVCW 44	Sterculiaceae	Valampuri/Kavaram pattai	DDF	LS	Root and seeds	Cultivated and wild	NE	GIA (Dysentery, Stomach ache); DID (Scabies)	0.04	Decoction and juice
Heliotropium indicum L.	Boraginaceae	Tetkotukki	MDF	H	Leaves and flowers	Wild	NE	GIA (Dysentery, Stomach ache, Intestinal ulcer); ED (Diabetes); RP (Asthma, Bronchitis)	0.04	Decoction, juice and powder

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Table 2. Surveyed medicinal plants in Manar beat, Karamadai range, Western Ghats

Botanical name	Family name	Local name	Forest types	Habit	Parts used	Cultivation status	Ecological status	Therapeutic uses	Use value	Mode of preparation
Heliotropium strigosum Willd.	Boraginaceae	Bristly Heliotrope	MDF	US	Whole plant	Wild	NE	GIA (Intestinal ulcer); PB (Snakebites); DID (Wounds)	0.36	Juice
Heliotropium zeylanicum Cl.	Boraginaceae	Ceylon Heliotrope	MDF	H	Whole plant	Ornamental and wild	NE	GIA (Stomach ache); PB (Scorpion sting)	0.12	Decoction and tonic
Hemidesmus indicus R.Br. BHVCW 45	Asclepiadaceae	Nannari	SJ	C	Root	Cultivated and wild	NE	CSCD (Blood purification); DID (General skincare); SMSD (Rheumatism, Swellings); Fvr (Fever); RP (Cough)	0.92	Paste and tonic
Hibiscus micranthus L.f.	Malvaceae	Sitraamutti	SJ	S	Leaves	Wild	NE	RP (Asthma)	0.48	Decoction
Hugonia mystax L.	Linaceae	Mothirakanni	MDF & SJ	T	Roots	Wild	NE	PB (Snakebites); SMSD (Swellings)	0.16	Decoction and juice
Ichnocarpus frutescens R.Br.	Apocynaceae	Udarkodi/ Kadambaikodi	MDF & DDF	C	Whole plant	Wild	NE	GIA (Dysentery); RP (Cough)	0.72	Extraction and decoction
Ionidium suffruticosum Ging. BHVCW 46	Violaceae	Orilai Thamarai	DDF	H	Roots, leaves and fruits	Wild	NE	PB (Scorpion sting)	0.40	Decoction and tonic
Ipomaea nil (L.) Roth.	Convolvulaceae	Kakkattan	RV	C	Seeds	Wild	NE	GIA (Constipation)	0.40	Decoction
Ipomaea obscura K-Gawl.	Convolvulaceae	Siruthaali	DDF & RV	C	Leaves and roots	Ornamental and wild	NE	GIA (Dysentery)	0.80	Decoction, paste and powder
Ipomaea staphylina Rome. & Schult. BHVCW 47	Convolvulaceae	Onaankodi	DDF	CS	Roots	Ornamental and wild	NE	PB (Snakebites); ED (Diabetes)	0.56	Tonic
Ixora arborea Roxb.ex Sm.	Rubiaceae	Vedchi	SJ & DDF	S	Whole plant	Ornamental and wild	NE	GIA (Intestinal ulcer, Dysentery); RP (Bronchitis); SMSD (Headache)	0.72	Decoction
Ixora nigricans Br.	Rubiaceae	Utappu	SJ	S	Leaves and flowers	Wild	NE	GIA (Dysentery, Stomach ache)	0.92	Extraction
Jasminum angustifolium (L.) Willd.	Oleaceae	Kattumalligai	SJ	CS	Leaves	Cultivated, ornamental and wild	NE	GIA (Intestinal ulcer, Stomach ache); DID (General skincare)	0.16	Decoction
Jasminum cuspidatum Rottl. & Willd.	Oleaceae	Parcorikkirai	MDF	S	Flowers, roots and leaves	Ornamental and wild	NE	GIA (Intestinal ulcer); PB (Snakebites)	0.12	Decoction
Jatropha curcas L. BHVCW 48	Euphorbiaceae	Kattukkottai	MDF	S	Leaves, root bark and barks	Cultivated and wild	LC (2018)	DID (Wounds, Pimples); SMSD (Rheumatism, Swellings); LP (Jaundice); GIA (Dysentery); HP (Hair growth); Fvr (Fever)	0.08	Paste and juice
Jatropha gossypifolia Linn.	Euphorbiaceae	Siria Amanakku	SJ	S	Leaves, seeds	Cultivated and wild	NE	CSCD (Blood purifier); SMSD (Headache); GIA (Stomach	0.12	Decoction

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Table 2. Surveyed medicinal plants in Manar beat, Karamadai range, Western Ghats

Botanical name	Family name	Local name	Forest types	Habit	Parts used	Cultivation status	Ecological status	Therapeutic uses	Use value	Mode of preparation
					and stems			ache, Piles, Indigestion); GUA (Venereal diseases)		
Justicia tranquebariensis L.f.	Acanthaceae	Punnakupoodu	DDF	S	Leaves	Cultivated	NE	SMSD (Swellings); PB (Snakebites)	0.24	Extraction
Kalanchoe laciniata DC.	Crassulaceae	Ranakalli	DDF & MDF	H	Leaves	Cultivated and ornamental	NE	GIA (Dysentery); PB (Snakebites); RP (Cough, Cold); SMSD (Headache)	0.08	Decoction
Kyllinga triceps Rottb.	Cyperaceae	Veluttanirbasi	RV	H	Whole plant and rhizome	Wild	LC (2010)	PB (Snakebites); Fvr (Fever); RP (Cold, Bronchitis); ENT (Sore throat)	0.16	Juice
Lantana camara L.	Verbenaceae	Unni Chedi	SJ	S	Leaves, flowers and roots	Cultivated, ornamental and wild	NE	RP (Cough, Asthma, Bronchitis); DOC (Toothache); SMSD (Headache); Fvr (Fever); GIA (Constipation); ENT (Eye cooling)	0.04	Decoction and tonic
Lantana wightiana Wall.	Verbenaceae	Indian White Lantana	SJ	S	Leaves	Cultivated	NE	Fvr (Chickenpox); GIA (Intestinal ulcer); RP (Asthma)	0.20	Decoction
Leea indica (Burm. f.) Merr.	Vitaceae	Ottannalam	SJ & MDF	S	Flowers, roots and leaves	Cultivated, ornamental and wild	LC (2018)	RP (Cough, Chest pain); Fvr (Fever); SMSD (Headache); DID (Cuts, General skincare); GIA (Dysentery, Stomach ache)	0.20	Decoction and juice
Leucas aspera Spr. BHVCW 50	Lamiaceae	Thumbai	DDF & MDF	H	Whole plant	Cultivated and wild	NE	DID (Wounds, General skincare); RP (Cough, Cold); Fvr (Fever); ENT (Sore throat); PB (Snakebites); SMSD (Rheumatism)	0.08	Decoction and juice
Leucas longifolia Hook. f. BHVCW 51	Lamiaceae	Irana-peri	MDF & DDF	H	Whole plant	Cultivated and wild	NE	SMSD (Headache); Fvr (Fever); RP (Cough)	0.16	Decoction
Leucas urticifolia (Vahl) Sm.	Lamiaceae	Kannuthumbai	DDF	H	Whole plant	Wild	NE	Fvr (Fever); RP (Asthma)	0.20	Decoction
Litsea scrobiculata Meissn.	Lauraceae	Mulakunari	MDF & EF	T	Whole plant	Cultivated and wild	NE	ED (Diabetes); SMSD (Arthritis); RP (Cold, Asthma)	0.12	Decoction
Lochnera pusilla K. Schum.	Apocynaceae	Nithyakalyaani	DDF	H	Whole plant	Cultivated, ornamental and wild	NE	RP (Asthma); ED (Diabetes); GIA (Constipation, Indigestion); DID (General skin care)	0.20	Decoction
Loranthus longiflorus Desv.	Loranthaceae	Pulluri	DDF	SP	Whole plant	Ornamental	NE	ENT(Cooling); DID (Wounds, General skin care); GUA (Menstrual problems); RP(Asthma); GIA (Intestinal ulcer)	0.04	Decoction and paste

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Table 2. Surveyed medicinal plants in Manar beat, Karamadai range, Western Ghats

Botanical name	Family name	Local name	Forest types	Habit	Parts used	Cultivation status	Ecological status	Therapeutic uses	Use value	Mode of preparation
Ludwigia abyssinica A. Rich.	Onagraceae	-	MDF	H	Leaves and roots	Wild	LC (2018)	GIA (kill worms in stomach); DID (Wounds)	0.02	Decoction
Macaranga peltata Muell. Arg. BHVCW 52	Euphorbiaceae	Vattakanni	MDF	T	Leaves and stem bark	Wild	NE	GUA (Kidney stone); DID (Cuts)	0.40	Decoction and extraction
Maesa perrottetiana A.DC.	Myrsinaceae	Periya-unni	MDF	T	Leaves	Ornamental	NE	Fvr (Fever)	0.12	Decoction and paste
Mallotus philippinensis Muell. Arg.	Euphorbiaceae	KuranguManjanathi	MDF & DDF	T	Leaves, fruits and barks	Cultivated, ornamental and wild	NE	GIA (Intestinal ulcer)	0.08	Decoction
Manilkara hexandra (Roxb.) Dubard.	Sapotaceae	Ulakkai-p-palai	SJ & DDF	T	Bark	Cultivated and wild	NE	Fvr (Fever); LP (Jaundice); GIA (Gastric complaints)	0.88	Decoction
Melhania incana Heyne.	Sterculiaceae	Hairy Melhania	SJ & DDF	H	Whole plant	Cultivated	NE	RP (Cough, Cold); Fvr (Fever)	0.12	Paste
Memecylon umbellatum Burm. f.	Melastomaceae	Sirugasa	MDF	S	Leaves, flowers and roots	Ornamental and wild	NE	GUA (Menstrual problems); ENT(Cooling)	0.04	Decoction
Merremia aegyptia Gamb.	Convolvulaceae	Mochukkodi	SJ	H	Leaves	Ornamental and wild	NE	DID (Burns)	0.20	Paste
Merremia tridentata Hall. f.	Convolvulaceae	Mudiyaakunthal	DDF	H	Leaves and roots	Wild	NE	Fvr (Fever); PB (Snakebites); DOC (Toothache); GIA (Piles); SMSD (Swellings)	0.12	Decoction
Microtropis ramiflora Wt.	Celastraceae	-	MDF	T	Fruits and barks	Cultivated, ornamental and wild	NE	DID (General skincare)	0.28	Extraction
Miliusa tomentosa Bedd.	Annonaceae	Perivuvav	MDF & DDF	S	Barks	Wild	NE	Fvr (Fever)	0.12	Decoction
Mimosa instia L.	Mimosaceae	Seekkai	MDF	T	Flowers and barks	Wild	NE	DID (General skincare, Wounds)	0.16	Decoction and paste
Mimosa pudica L.	Mimosaceae	Thottasinungi	MDF	H	Leaves, seeds and roots	Cultivated, ornamental and wild	LC (2010)	Fvr (Fever); GIA (Piles); LP (Jaundice)	0.08	Tonic
Mitracarpus villosus (Sw.) DC.	Rubiaceae	Kayapoondu	MDF	H	Whole plant	Wild	NE	DID (General skincare); GIA (Intestinal ulcer)	0.12	Paste
Morinda citrifolia L.	Rubiaceae	Nuna	DDF & MDF	T	Roots, fruits and rootbark	Cultivated and wild	NE	RP (Asthma); ED (Diabetes); Fvr (Fever); SMSD (Headache); GIA (Dysentery); DID (General skincare); DOC (Mouth ulcer)	0.16	Decoction, juice and tonic
Morinda umbellate L.	Rubiaceae	Kundalchurukki	SJ, DDF & MDF	C	Leaves and roots	Wild	NE	GIA (Dysentery)	0.32	Decoction

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Table 2. Surveyed medicinal plants in Manar beat, Karamadai range, Western Ghats

Botanical name	Family name	Local name	Forest types	Habit	Parts used	Cultivation status	Ecological status	Therapeutic uses	Use value	Mode of preparation
Murraya exotica L. BHVCW 53	Rutaceae	Vengarai	MDF	S	Leaves	Cultivated, ornamental and wild	NE	GIA (Dysentery, Stomach ache); PB (Snakebites); DOC (Toothache)	0.28	Powder, tonic and decoction
Naravelia zeylanica DC. BHVCW 54	Ranunculaceae	Kattuseekkaaikodi	MDF & SJ	C	Leaves, roots and stems	Wild	NE	RP (Chest pain, Cold); DOC (Toothache); DID (General skincare); GIA (Intestinal ulcer); SMSD (Headache); Fvr (Fever)	0.28	Paste
Neptunia oleracea Lour. BHVCW 55	Mimosaceae	Sundaikkirai	MDF	H	Stem	Cultivated and wild	LC (2018)	ENT (Earache)	0.20	Juice
Oldenlandia herbacea (L.) Roxb.	Rubiaceae	Nonnanampullu	MDF	H	Whole plant	Wild	LC (2011)	Fvr (Fever); RP (Asthma, Bronchitis); GIA (Intestinal ulcer)	0.24	Decoction, powder and tonic
Olea europaea (Wall. ex G. Don.) cif.	Oleaceae	Saidun	MDF	T	Whole plant	Cultivated, ornamental and wild	NE	RP (Asthma)	0.32	Decoction
Opilia amentacea Roxb.	Opiliaceae	Manjandamaram	DDF	CS	Roots, barks and leaves	Wild	NE	SMSD (Headache); Fvr (Fever); RP (Cough); DOC (Toothache); GIA (Stomach ache)	0.20	Decoction
Opuntia dillenii Haw. BHVCW 56	Cactaceae	Mullu Kalli	SJ & DDF	S	Fruit	Cultivated and wild	LC (2009)	ED (Diabetes)	0.16	Juice
Opuntia monacantha Haw. BHVCW 57	Cactaceae	Kalli	SJ &DDF	S	Fruits	Cultivated and wild	LC (2010)	GIA (Intestinal ulcer); ED (Diabetes)	0.16	Juice
Orthosiphon glabratus Benth.	Lamiaceae	Chilannippadam	MDF	H	Leaves	Wild	NE	GIA (Intestinal ulcer)	0.16	Paste
Osbeckia zeylanica Willd.	Melastomaceae	Senthumbai	MDF	H	Flower and leaves	Wild	NE	GIA (Intestinal ulcer); DID (Itching, General skincare)	0.60	Decoction
Oxalis corniculata L.	Geraniaceae	Puliyarai	MDF	H	Whole plant and leaves	Wild	NE	DID (Burns, Pimples); GIA (Stomach ache); Fvr (Fever); SMSD (Swellings); PB (Snakebites)	0.72	Juice
Passiflora leschenaultia DC.	Passifloraceae	-	DDF	CS	Whole plant	Cultivated	NE	ED (Diabetes); DID (Wounds); CSCD (Blood pressure); GIA (Dysentery); GUA (Kidney stone)	0.40	Decoction
Pavonia zeylanica Cav. BHVCW 58	Malvaceae	Sevagan	SJ & DDF	S	Roots, barks and leaves	Ornamental and wild	NE	GIA (Intestinal ulcer); DID (Scabies, Acne); SMSD (Swellings)	0.80	Decoction, powder and tonic
Pedalium murex L.	Pedaliaceae	Yanai nerunjil	DEF	H	Roots and leaves	Wild	NE	GUA (Venereal diseases)	0.56	Decoction and tonic

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Table 2. Surveyed medicinal plants in Manar beat, Karamadai range, Western Ghats

Botanical name	Family name	Local name	Forest types	Habit	Parts used	Cultivation status	Ecological status	Therapeutic uses	Use value	Mode of preparation
Peristrophe bicalyculata Nees.	Acanthaceae	Kara-k-kanciram	MDF	H	Whole plant	Wild	NE	Fvr (Fever); RP (Cough, Cold); PB (Snakebites)	0.72	Powder
Perotis indica O. Ktz. BHVCW 59	Poaceae	Narival	MDF	H	Whole plant	Wild	NE	Fvr (Chickenpox); PB (Snakebites)	0.16	Paste
Phyllanthus debilis Hook. f.	Euphorbiaceae	Arulundi	MDF	T	Whole plant	Wild	NE	LP (Jaundice); GIA (Dysentery, Stomach ache, Intestinal ulcer); DID (Wounds)	0.12	Decoction and juice
Phyllanthus polyphyllus Willd.	Euphorbiaceae	Arunelli	MDF	S	Whole plant	Wild	NE	DID (Wounds, Scabies); GIA (Dysentery); LP (Jaundice)	0.68	Decoction and paste
Phyllanthus virgatus Forst.	Euphorbiaceae	Siru Nelli	MDF	H	Leaves	Wild	NE	GIA (Intestinal ulcer); DID (Itching)	0.16	Juice
Physalis minima L.	Solanaceae	Tholtakkali	DDF	H	Leaves and roots	Wild	VU (2017)	Fvr (Fever); ED (Diabetes); SMSD (Headache); DID (Itching); ENT (Earache)	0.12	Decoction, tonic and juice
Polycarpaea corymbosa Lam.	Caryophyllaceae	Cataicciver	SJ & DDF	H	Leaves	Cultivated	NE	Fvr (Fever); SMSD (Swellings); PB (Snakebites); LP (Jaundice)	0.08	Decoction
Polygala bolbothrix Dunn.	Polygalaceae	Milakunankai	DDF	H	Roots	Wild	NE	RP (Cough, Bronchitis); GIA (Dysentery, Vomiting)	0.12	Decoction
Polygonum chinense L.	Polygonaceae	Actalaree / Neerkapachi	RV	S	Whole plant	Ornamental and wild	NE	GIA (Stomach ache)	0.24	Juice and tonic
Polygonum hydropiper L.	Polygonaceae	Water Pepper	RV	H	Leaves, seeds and roots	Cultivated and wild	LC (2013)	GIA (Piles, Stomach ache); GUA (Menstrual problems); DOC (Toothache)	0.68	Decoction and tonic
Portulaca wightiana Wall.	Portulacaceae	Paruppukeerai	DDF	H	Whole plant	Cultivated, ornamental and wild	NE	GUA (Kidney stone)	0.08	Decoction
Pouzolzia zeylanica (L.) Benn & R.Br.	Urticaceae	Nir-c-cinni	MDF	H	Whole plant and root	Wild	NE	GIA (Dysentery, Intestinal ulcer, Indigestion); Fvr (Fever); DOC (Toothache)	0.08	Juice and paste
Premna tomentosa Willd.	Verbenaceae	Malai Thekku	SEF & DDF	T	Leaves	Wild	LC (2018)	DID (Skin irritation)	0.12	Decoction and tonic
Psychotria flavida Talb.	Rubiaceae	South Indian Wild Coffee	MDF	S	Leaves, roots and barks	Wild	NE	SMSD (Headache); GIA (Dysentery, Intestinal ulcer); DID (Wounds)	0.84	Decoction
Pterygota alata R.Br.	Sterculiaceae	Anathondi	EF & SEF	T	Leaves	Ornamental and wild	NE	PB (Poisonous bites)	0.16	Decoction
Pupalia lappacea var. *velutina* (Miq.) Hook. f.	Amaranthaceae	Adai-otti	SJ	H	Leaves and root	Wild	LC (2006)	RP (Cough); DID (Cuts); GIA (Intestinal ulcer, Constipation); PB (Snakebites)	0.04	Decoction
Pyrenacantha volubilis Hook.	Icacinaceae	-	MDF	CS	Seeds	Cultivated	NE	GUA (Breast pain)	0.04	Extraction and paste
Rhus mysorensis Heyne. BHVCW 60	Anacardiaceae	Neyyikiluvai / Sipilai	SJ	S	Fruits and leaves	Cultivated	NE	GIA (Dysentery, Stomach ache); DID (Itching); ED (Diabetes)	0.16	Decoction, juice and extraction

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Table 2. Surveyed medicinal plants in Manar beat, Karamadai range, Western Ghats

Botanical name	Family name	Local name	Forest types	Habit	Parts used	Cultivation status	Ecological status	Therapeutic uses	Use value	Mode of preparation
Rhynchosia rufescens DC. BHVCW 61	Fabaceae	Hadupudukanam	MDF	S	Roots	Wild	NE	PB (Snakebites); GIA (Dysentery)	0.08	Paste
Rivea hypocrateriformis Choisy.	Convolvulaceae	Musuttai Kodi	DDF & SJ	CS	Whole plant	Wild	NE	RP (Cough); SMSD (Headache); GIA (Piles, Intestinal ulcer)	0.04	Juice and extraction
Santalum album L.	Santalaceae	Chandanam	DDF	T	Wood	Cultivated and wild	VU (2018)	Fvr (Fever)	0.08	Paste
Sapindus emarginatus Vahl. BHVCW 62	Sapindaceae	Ponnankottai	DDF	T	Fruits	Cultivated and wild	NE	RP (Asthma); GIA (Dysentery)	0.20	Paste
Sarcostemma brevistigma W. & A.	Asclepiadaceae	Kodi-Kalli	SJ & DDF	C	Whole plant	Cultivated and wild	NE	SMSD (Arthritis); Fvr (Fever); DID (Wounds); RP (Cough, Cold, Asthma); PB (Snakebites); GUA (Menstrual problems); GIA (Dysentery)	0.16	Decoction
Schleichera oleosa (Lour.) Merr.	Sapindaceae	Kumpatiri / Pulipoosamaram	MDF	T	Seeds and bark	Cultivated and wild	LC (2018)	DID (Wounds, Itching, Acne); GIA (Intestinal ulcer)	0.16	Powder
Sclerocarpus africanus Jacq.	Asteraceae	African Bonebract	MDF	H	Whole plant	Cultivated	NE	GUA (Venereal diseases)	0.24	Decoction
Scutellaria violacea Heyne. BHVCW 63	Lamiaceae	Novupacchilai	DDF	H	Whole plant	Cultivated, ornamental and wild	NE	GIA (Dysentery)	0.16	Decoction
Secamone emetica R.Br.	Asclepiadaceae	Ankaravali	SJ & DDF	CS	Leaves and roots	Wild	NE	RP (Cough); DID (Scabies); GIA (Stomach ache); PB (Snakebites)	0.12	Decoction
Solanum anguivi Lam.	Solanaceae	Forest Bitterberry	MDF	S	Roots and fruits	Ornamental, semi-cultivated and wild	NE	CSCD (Blood pressure); RP (Cough, Chest pain); DOC (Toothache)	0.12	Decoction
Solanum xanthocarpum S. & W.	Solanaceae	Kantankattiri	DDF & MDF	S	Whole plant	Cultivated and wild	NE	RP (Bronchitis, Cough); GIA (Constipation); ENT (Sore throat)	0.28	Decoction, juice and powder
Stachytarpheta indica Vahl. BHVCW 64	Verbenaceae	Seemainayaroovi	DDF	H	Roots	Cultivated and wild	NE	ENT (Eyewash)	0.16	Decoction
Stereospermum colais (*Buch-Ham. ex Dillwyn*) Mabb.	Bignoniaceae	Ampuvakini/ Pathiri	MDF	T	Flowers, roots and barks	Ornamental and wild	NE	Fvr (Fever); GIA (Indigestion)	0.08	Juice
Strychnos nux-vomica L.	Loganiaceae	Yetti / Yettimaram	MDF & DDF	T	Wood and leaves	Cultivated and wild	NE	DID (Wounds, General skincare); GIA (Intestinal ulcer, Dysentery, Constipation); Fvr (Fever); ED (Diabetes)	0.24	Paste and tonic
Strychnos potatorum L.f.	Loganiaceae	Sillamaram	DDF	T	Seeds and roots	Wild	NE	RP (Cold, Cough, Bronchitis); GUA (Venereal diseases); ED (Diabetes)	0.72	Decoction and powder

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Table 2. Surveyed medicinal plants in Manar beat, Karamadai range, Western Ghats

Botanical name	Family name	Local name	Forest types	Habit	Parts used	Cultivation status	Ecological status	Therapeutic uses	Use value	Mode of preparation
Synedrella nodiflora Gaertn.	Asteraceae	MudiyanPachchai	DDF	H	Leaves and roots	Cultivated	NE	SMSD (Arthritis, Swellings)	0.24	Decoction and paste
Syzigium cumini (Linn.) Skeels.	Myrtaceae	Naval / Nagamaram	SJ	T	Barks, leaves and fruits	Cultivated, ornamental and wild	NE	DID (Wounds); GUA (Menstrual problems); GIA (Dysentery); ED (Diabetes); DOC (Mouth ulcer)	0.16	Juice
Tarenna asiatica (L.) Kuntze ex K. Schum.	Rubiaceae	Tharani	SJ & MDF	S	Whole plant	Wild	NE	PB (Snakebites); Fvr (Fever); SMSD (Headache); GIA (Intestinal ulcer, Indigestion, Constipation); DID (General skincare); ED (Diabetes)	0.20	Decoction
Tectona grandis L.f.	Verbenaceae	Thaekku	MDF	T	Roots and bark	Cultivated, ornamental and wild	NE	DID (Eczema); RP (Bronchitis);	0.24	Extraction, paste and tonic
Tephrosia villosa W. & A.	Fabaceae	Hoary Tephrosia	MDF	S	Leaves	Cultivated	LC (2010)	ED (Diabetes)	0.40	Juice
Terminalia arjuna W. & A.	Combretaceae	Kula Maruthu / Mathi	MDF	T	Bark and leaves	Cultivated, ornamental and wild	NE	CSCD (Blood pressure); ENT (Earache)	0.24	Juice and tonic
Terminalia chebula Retz.	Combretaceae	Kadukkaai / Aralae	MDF & DDF	T	Fruits and barks	Cultivated and wild	NE	GIA (Constipation, Dysentery, kill worms in the stomach); RP (Cough, Asthma)	0.16	Tonic
Thespesia populnea Soland. ex Correa.	Malvaceae	Puvarasu	MDF	T	Bark and leaves	Cultivated, ornamental and wild	LC (2017)	DID (Itching, Scabies); GIA (Dysentery, Intestinal ulcer, Indigestion, Constipation); SMSD (Headache); CSCD (Blood pressure); ED (Diabetes); GUA (Breast pain)	0.12	Decoction and juice
Tiliacora acuminata Miers.	Menispermaceae	Perunkattukkoti	MDF	CS	Root	Ornamental and wild	NE	GUA (Kidney stone); PB (Snakebites)	0.04	Paste and decoction
Toddalia asiatica Lam. BHVCW 65	Rutaceae	Kattu-milaku / Erikonthai	SJ	C	Whole plant and bark	Cultivated and wild	NE	Fvr (Fever); GIA (Indigestion); SMSD (Rheumatism); RP (Cough, Asthma)	0.20	Tonic
Trema orientalis Blume.	Ulmaceae	Pey-munnai	DDF & MDF	T	Bark and leaves	Cultivated, ornamental and wild	LC (2017)	GIA (Dysentery); RP (Cough, Asthma, Bronchitis); PB (Poisonous bites); ENT (Sore throat); DOC (Toothache)	0.68	Decoction
Tribulus terrestris L. BHVCW 66	Zygophyllaceae	Nerunci	DDF	H	Stems and fruits	Wild	NE	DID (Psoriasis, Scabies, General skincare); SMSD (Headache); GIA (Stomach ache)	0.04	Decoction and tonic
Trichodesma zeylanicum R. Br.	Boraginaceae	Kalutaikkali	MDF	H	Leaves and roots	Wild	NE	GIA (Stomach ache, Dysentery); PB (Snakebites, Poisonous bites); Fvr (Fever);	0.16	Decoction

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Table 2. Surveyed medicinal plants in Manar beat, Karamadai range, Western Ghats

Botanical name	Family name	Local name	Forest types	Habit	Parts used	Cultivation status	Ecological status	Therapeutic uses	Use value	Mode of preparation
								RP (Cough); DID (Scabies, Wounds)		
Tylophora asthmatica W. & A. BHVCW 67	Asclepiadaceae	Nay-p-palai	SJ	C	Root	Wild	NE	GIA (Dysentery, Stomach ache); RP (Asthma, Bronchitis)	0.12	Decoction
Vernonia albicans DC.	Compositae	Neichati	DDF & MDF	H	Leaves, seeds and roots	Cultivated and wild	NE	GIA (Stomach ache, Piles); DID (Cuts, Wounds, General skincare); Fvr (Fever); CSCD (Blood purification); GUA (Kidney stone); SMSD (Headache, Swellings); PB (Scorpion sting)	0.40	Decoction, paste and juice
Viscum articulatum Burm.	Loranthaceae	Logolai / Leafless Mistletoe	MDF	SP	Whole plant	Cultivated, ornamental and wild	NE	Fvr (Fever); DID (Cuts)	0.28	Paste
Viscum trilobatum Talb.	Loranthaceae	Ottuttutti	DDF & MDF	SP	Leaves	Cultivated, ornamental and wild	NE	RP (Cough, Cold)	0.08	Decoction
Vitex peduncularis Wall. BHVCW 68	Verbenaceae	Mayilei	MDF	T	Leaves, barks and roots	Cultivated and wild	NE	RP (Chest pain); LP (Jaundice); GUA (Menstrual problems); ED (Diabetes)	0.12	Juice
Wattakaka volubilis (L.fil.) Stapf. BHVCW 69	Asclepiadaceae	Kurincha	SJ & MDF	C	Leaves and roots	Cultivated and wild	NE	PB (Snakebites); Fvr (Fever); RP (Cough, Cold); SMSD (Rheumatism, Headache)	0.24	Paste
Withania somnifera L. BHVCW 70	Solanaceae	Amukkuram	MDF	S	Whole plant	Cultivated and wild	NE	SMSD (Swellings); DID (Wounds)	0.28	Paste
Xylia xylocarpa Taub. BHVCW 71	Mimosaceae	Iruvel	MDF	T	Bark and seeds	Cultivated and wild	LC (2018)	GIA (Intestinal ulcer, Piles, Vomiting); SMSD (Rheumatism)	0.16	Decoction
Zizyphus abyssinica Hochst. ex A. Rich.	Rhamnaceae	Kottae	DDF	T	Roots	Cultivated and wild	NE	GIA (Stomach ache); PB (Snakebites)	0.16	Decoction and powder
Zizyphus glabrata W. BHVCW 72	Rhamnaceae	Karukaavu / Karattai	DDF	T	Fruits	Cultivated and wild	NE	Fvr (Fever); RP (Cough); SMSD (Rheumatism)	0.16	Decoction
Zizyphus jujuba Lam. BHVCW 73	Rhamnaceae	Ellanthai	DDF	T	Fruits, leaves and roots	Cultivated and wild	NE	GIA (Stomach ache, Intestinal ulcer); RP (Bronchitis); CSCD (Blood purification); Fvr (Fever); DID (Wounds)	0.12	Decoction, powder and tonic
Zizyphus lotus (L.) Lam.	Rhamnaceae	Jharberi	DDF	S	Leaves	Wild	NE	DID (Wounds); ED (Diabetes)	0.40	Decoction and powder
Zizyphus oenoplia	Rhamnaceae	Suraimullu /	DDF &	CS	Roots,	Cultivated	NE	DID (Cuts, Wounds); GIA	0.16	Decoction,

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Table 2. Surveyed medicinal plants in Manar beat, Karamadai range, Western Ghats

Botanical name	Family name	Local name	Forest types	Habit	Parts used	Cultivation status	Ecological status	Therapeutic uses	Use value	Mode of preparation
Mill. BHVCW 74		Soolikodi	MDF		bark and fruits	and wild		(Stomach ache, Indigestion)		paste and juice
Zizyphus rugosa Lamk.	Rhamnaceae	Totari	DDF	TS	Barks	Wild	NE	DOC (Worms in gums and teeth, Toothache)	0.32	Paste
Zornia diphylla Pers.	Fabaceae	Chirupalatai	DDF	H	Whole plant	Wild	NE	GUA (Venereal diseases); GIA (Dysentery)	0.08	Extraction
Actiniopteris radiata (Sw.) Link.	Pteridaceae	Fan leaf Fern	DDF	H	Whole plant	Ornamental and wild	NE	Fvr (Fever)	0.04	Decoction

Note: DDF – Dry Deciduous Forest; **MDF** – Moist Deciduous Forest; **SJ** – Scrub Jungle; **RV** – Riparian Vegetation
H – Herb; **S** – Shrub; **C** – Climber; **T** – Tree; **LS** – Large Shrub; **CS** – Climbing Shrub; **US** – Under Shrub; **ST** – Small Tree; **CH** – Climbing Herb; **TS** – Thorny Shrub; **E** – Epiphyte; **SP** – Semi-Parasite
NE – Not Evaluated; **LC** – Least Concern; **R** – Rare; **EN** – Endangered; **Ex** – Extinct; **EW** – Extinct in the Wild; **CR** – Critically endangered; **VU** – Vulnerable; **NT** – Near Threatened; **E** – Endemic

Novel Formulations of the Present Study Plants

1. The juice obtained from the leaves of *Leucas aspera* was mixed with the milk of *Calotropis procera* and applied topically on the center and back portion of the throat around the neck for the treatment of prolonged cough.
2. Decoction of crushed *Cyperus rotundus* tuber was used orally on empty stomach to cure prolonged fever.
3. The overnight macerated (copper vessel) *Aegle marmelos* leaves and the water taken in an empty stomach for seven days is used to treat peptic, gastric and duodenal ulcers.
4. Juice obtained from the leaves of *Solanum nigrum* is taken for seven days on an empty stomach to cure peptic ulcer disease (PUD).
5. Decoction of crushed *Tribulus terrestris* whole plant in empty stomach is taken orally to treat renal calculus.
6. Immatured fruits of *Psidium guajava* and *Manilkara zapota* are used orally to cure dysentery.
7. Decoction of *Anethum graveolens* powder taken orally for the treatment of dysentery.

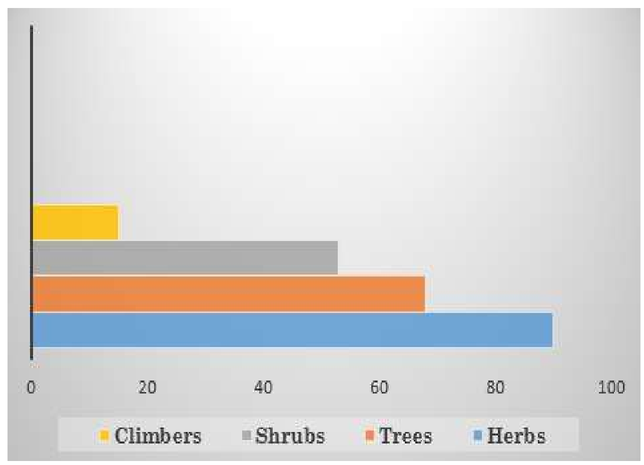

Fig. 2. Life forms of the reported plant species used by Irulas in Manar beat

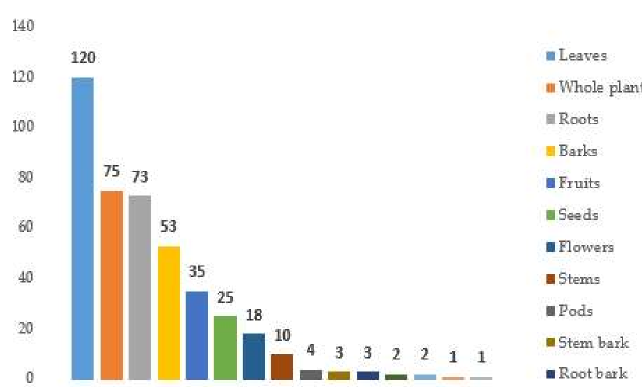

Fig. 3. Parts of plants used for the preparation of folk medicine

8. Seeds of *Papaver somniferum* are mixed with fresh cow milk or buttermilk and are taken for dysentery.
9. Seeds of *Trigonella foenum-graecum* are crushed and taken with curd for dysentery disorder.
10. The extract obtained from the rhizome of *Zingiber officinale* thrice a week is taken against vomiting also taken for the treatment of diabetes.
11. Three pieces of *Allium sativum* bulb were heated in an open fire were taken by chewing was a better remedy for atrioventricular (AV) block.
12. Decoction of *Foeniculum vulgare* seeds was taken orally for the treatment of flatulence.

The root bark of *Pergularia daemia* is thoroughly mixed with cow's milk and used as a purgative in treating rheumatism (Senthilkumar et al 2006) and the fresh leaves of *Pergularia daemia* were boiled and inhaled to treat headaches (Poongodi et al 2011). The whole plant powder of *Cissus quandrangularis* is taken orally with cow milk in treating asthma (Alagesaboopathi, 2009). In contrast, the same plant was used in treating wounds, burns, rheumatism, and indigestion in our survey.

Quantitative analysis of data: During the interview, the majority of the data collected in this study were analyzed through quantitative descriptions. Further, the collected ethnobotanical data were processed using essential tools such as use value, informant consensus factor and fidelity level.

Use value: Use value is the purport associated with the usage by the people that may be high due to good results through their experience. Some of them with low use value may be due to lack of communication or a minimum activity. High-value plants are used to cure rheumatism and poisonous stings that are the common disease categories often encountered by the inhabitants of this study area. They share their knowledge among themselves to treat these diseases. The present study demonstrated that some plants have a high use value (Table 2). *Capparis grandiflora* was reported by all the interviewed informants in the study area and gives the highest UV of 0.96 due to its potential effectiveness in treating various diseases. It was followed by *Hardwickia binata* (0.92), *Ixora nigricans* (0.92), *Manilkara hexandra* (0.88), *Gisekia pharnaceoides* (0.84), *Cissus quadrangularis* (0.84), *Ficus racemosa* (0.84), *Pavonia zeylanica* (0.80), *Ipomaea obscura* (0.80), *Feronia elephantum* (0.76) and *Cardiospermum halicacabum* (0.72). At the same time, *Ludwigia abyssinica* revealed a low use value (0.02). Similar to present study, Shil et al (2014) and Krupa et al (2019) also reported certain plant species with shallow use values (<0.20).

Informant consensus factor: In ethnobotanical studies, the consensus factor provides a definitive measure of any claim which provides reliable evidence. The Fic product ranges between 0 to 1. A high-value Fic denotes the agreement of taxa selection among informants, whereas a low value indicates a disagreement (Ragupathy et al 2008). To determine the informant consensus factor values (ICF), all the recorded 58 ailments were grouped into 13 major ailments according to their body parts treated. More than 100 use-reports were obtained for certain ailment categories viz., skeleto-muscular system disorders (288 use-reports, 71 species), dermatological infections (252 use-reports, 99 species), gastro-intestinal ailments (200 use-reports, 145 species), respiratory problems (147 use-reports, 83 species) and fever (118 use-reports, 77 species). Together, their Fic values were ranged between 0.10 and 1.0 (Table 4). This study obtained a high Fic value for skeleto-muscular system disorders (0.76), whereas a lower Fic was obtained for circulatory system / cardiovascular diseases (0.11). A higher ICF value suggests that informants strongly agree that a certain species should be used to treat a particular ailment. A similar higher informant consensus was recorded by other workers based on their ailment categories (Ragupathy et al 2008, Ayyanar and Ignacimuthu 2011, Venkatachalapathi et al 2015). The informant consensus factor was abbreviated as "FIC" and "ICF" in the previous articles (Kaval et al 2014, Polat et al 2015). The results showed that these disease categories had many use reports among the Irula tribals with average Fic values.

Fidelity level: The fidelity level of each studied species has been calculated. It indicates the choice of informants for each ailment and the potential for disease-related species. The fidelity level values in this study varied from 25 to 100% (Table 5). Thirteen species had the 100% (highest) fidelity level from the available information, most of which were used in one disease category with multiple informants. For this analysis, the plants with less than three use reports were not

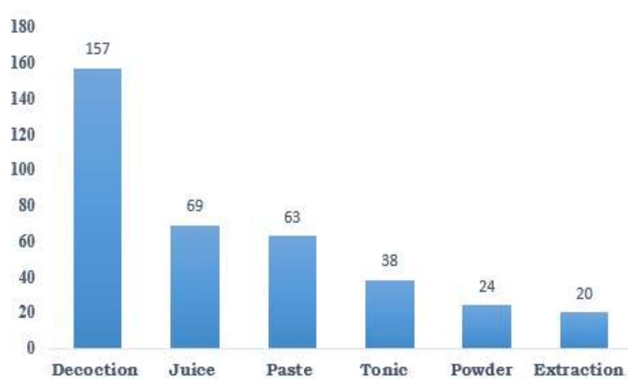

Fig. 4. Mode of preparation of herbal medicines by the informants

Table 3. Diversity of medicinal plant species belonging to individual plant family in Manar beat, Karamadai region of Western Ghats

Plant families	No. of plant genera	Percentage of genera	No. of plant species	% of species
Euphorbiaceae	12	6.25	19	7.54
Fabaceae	10	5.21	15	5.95
Caesalpiniaceae	5	2.60	11	4.37
Rubiaceae	9	4.69	11	4.37
Asclepiadaceae	8	4.17	10	3.97
Acanthaceae	7	3.65	9	3.57
Convolvulaceae	5	2.60	9	3.57
Capparidaceae	4	2.08	9	3.57
Boraginaceae	5	2.60	8	3.17
Mimosaceae	6	3.13	8	3.17
Poaceae	7	3.65	7	2.77
Amaranthaceae	5	2.60	6	2.38
Verbenaceae	5	2.60	6	2.38
Rhamnaceae	1	0.52	6	2.38
Combretaceae	3	1.56	5	1.98
Lamiaceae	3	1.56	5	1.98
Moraceae	2	1.04	5	1.98
Rutaceae	5	2.60	5	1.98
Sapindaceae	5	2.60	5	1.98
Asteraceae	4	2.08	4	1.59
Solanaceae	3	1.56	4	1.59
Others	78	40.63	85	33.73
Total	192	100	252	100

Table 4. Informant consensus factor for certain ailment categories

Ailment categories	Diseases reported in the present study	No. of use reports (N_{ur})	No. of taxa (N_t)	F_{ic}
Circulatory System / Cardiovascular Diseases (CS / CD)	Blood purification (6), Blood pressure (4)	10	9	0.11
Dental and oral Care (DOC)	Toothache (29), Mouth ulcer (13), Worms in gums and teeth (4)	46	23	0.51
Dermatological Infections / Diseases (DID)	General skincare (77), Wounds (69), Scabies (13), Pimples (9), Sun burn (5), Dermatitis (3), Eczema (6), Itching (30), Burns (17), Cuts (9), Psoriasis (12), Acne (2)	252	99	0.61
Ear, Nose, Throat problems (ENT)	Earache (27), Sore throat (19), Eye pain (2), Eye cooling (3), Throat pain (29), Nasal infections (4), Cooling (8)	92	25	0.74
Endocrinal Disorders (ED)	Diabetes (29)	37	29	0.22
Fever (Fvr)	Fever (97), Chickenpox (21)	118	77	0.35
Gastro-Intestinal Ailments (GIA)	Constipation (17), Stomach ache (50), Intestinal ulcer (39) Dysentery (54), Piles (9), Indigestion (21), Gastric complaints (2), Vomiting (5), Kill worms in stomach (3)	200	145	0.28
Genito-Urinary Ailments (GUA)	Kidney stone (16), Problems of menopause (1), Swelling (23), Menstrual problems (8), Venereal diseases (8), Abortion (1), Breast pain (2)	59	37	0.38
Hair Problem (HP)	Dandruff (11), Hair growth (1)	12	4	0.73
Liver Problems (LP)	Jaundice (24)	24	19	0.22
Animal / Poisonous Bites (PB)	Snakebite (45), Scorpion sting (19), Poisonous bites (26)	90	56	0.38
Respiratory Problems (RP)	Cold (20), Cough (49), Asthma (53), Bronchitis (18), Chest pain (7)	147	83	0.44
Skeleto-Muscular System Disorders (SMSD)	Headache (56), Swelling (23), Joint pain (35), Rheumatism (98), Muscle pain (19), Body pain (4), Arthritis (53)	288	71	0.76

considered. Plants with the highest FL of 100% were *Atalantia monophylla*, *Zizyphus oenoplia* (DID), *Adenostemma lavenia* (ENT), *Digera arvensis*, *Pavonia zeylanica*, *Tribulus terrestris* (GIA), *Rhynchosia rufescens*, *Wattakaka volubilis* (PB), *Kalanchoe laciniata*, *Scutellaria violacea* (RP), *Aerva tomentosa* and *Capparis grandiflora* (SMSD). The maximum FL for the plants as mentioned above indicated that 100% of the informants were interviewed for the treatment of certain diseases, which could indicate their healing potential. In support of our study, 100% FL was reported in *Capparis grandiflora* for rheumatism among the herbal healers in Manar beat. Following the present findings, the species viz., *Acacia nilotica, Cassia auriculata, Cissus quadrangularis and Tridax procumbens* has been previously reported to have 100% fidelity in Tirunelveli hills (Ayyanar and Ignacimuthu 2011).

Table 5. Fidelity level (FL) for certain interesting medicinal plants in the study area

Ailment categories	Important plants	FL (%)
Circulatory System/ Cardiovascular Diseases (CS /CD)	*Aloe vera*	25
	Barleria cristata	60
	Centella asiatica	75
Dental and Oral Care (DOC)	*Acalypha fruticosa*	50
	Murraya exotica	60
Dermatological Infections /Diseases (DID)	*Atalantia monophylla*	100
	Jatropha curcas	55.55
	Naravelia zeylanica	66.66
	Zizyphus oenoplia	100
Ear, Nose, Throat problems (ENT)	*Adenostemma lavenia*	100
	Commelina benghalensis	83.33
Endocrinal Disorders (ED)	*Argyreia cuneata*	50
	Caralluma umbellate	50
Fever (Fvr)	*Andrographis echioides*	60
	Macaranga peltata	50
	Zizyphus glabrata	66.66
Gastro-Intestinal Ailments (GIA)	*Digera arvensis*	100
	Pavonia zeylanica	100
	Tribulus terrestris	100
	Zizyphus oenoplia	100
Genito-Urinary Ailments (GUA)	*Cissus quadrangularis*	83.33
	Vitex peduncularis	83.33
Hair Problem (HP)	*Adenostemma lavenia*	50
	Givotia moluccana	50
Liver Problems (LP)	*Andrographis echioides*	40
	Emblica officinalis	83.33
Animal/Poisonous Bites (PB)	*Crataeva religiosa*	87.5
	Dichrostachys cinerea	85.71
	Rhynchosia rufescens	100
	Wattakaka volubilis	100
	Actiniopteris radiata	60
Respiratory Problems (RP)	*Kalanchoe laciniata*	100
	Scutellaria violacea	100
	Tylophora asthmatica	80
Skeleto-Muscular System Disorders (SMSD)	*Aerva tomentosa*	100
	Capparis grandiflora	100
	Cleome gynandra	71.42
	Withania somnifera	50
	Zizyphus glabrata	50

CONCLUSION

The present investigation quantifies the vast knowledge by Irulas about various medicinal plants existing in their surroundings. However, very few professional healers were identified within the study area, which allowed this traditional knowledge to be preserved before it disappeared from this generation. The current ethnic observation on medicinal plants with the highest use values in this study indicates valuable metabolites' possible occurrence. Also, the tribal people (informants) in the study area used several plants to prepare folk medicines with the appropriate training acquired from their ancestors and some elders. Among the tribal people, the male informants had more knowledge than females. However, some of the surveyed plant species include *Crotalaria grahamiana*, *Capparis grandiflora*, *Croton hirtus, Dentella repens*, *Exacum pedunculatum*, *Heliotropium zeylanicum*, *Ipomoea nil, Melhania incana* and *Polygala bolbothrix* were prescribed for further ethnopharmacological studies that are reported with high UV, ICF and FL values. This study was undertaken to provide a baseline for further phytomedicine and phytochemical studies. Also, there are urgent protective measures needed to prohibit ethnomedicinal plants frequently used to develop potential new drugs to treat various human ailments.

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Received 17 February, 2022; Accepted 20 May, 2022

Indian Journal of Ecology (2022) 49(3) (SI): 1197-1202
DOI: https://doi.org/10.55362/IJE/2022/3644

Manuscript Number: 3644
NAAS Rating: 5.79

Ethnobotanical Study of Medicinal Plants among Local Tribes of Rajaji Tiger Reserve Haridwar

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***Abstract*:** Ethnobotanical study had been conducted during 2019-2021 in Chilla range (S1) and Chandi Devi Hills (S2) in Rajaji tiger reserve during the survey through personal interview, group discussion and questionnaire with informants. A total of 68 plant species belonging to **32** families collected, identified and documented with associated traditional knowledge.

***Keywords*:** Ethnobotany, Medicinal plants, Traditional knowledge, Tribals, Haridwar

Medicines prepared with ethnobotanical knowledge plays a vital role to cure the variety of diseases in human. According to WHO, 80% of world population mainly depend on traditional medicine system. In India, almost 70% of the people in rural areas depends upon Ayurvedic system and medicinal plants to meet their primary health care needs (Sharma et al 2020). This indigenous knowledge of plants having medicinal values is learnt by them from their ancestors and mostly transfers from one generation to next orally and verbally (Sharma et al2021). The oral and verbal method of moving this treasured ethnic knowledge is highly vulnerable to diminished with the ongoing passage of time and generations. Ethnobotanical studies disclosed that traditional knowledge is still in extensive use in different regions of Himalayas particularly among the old aged people, tribes and traditional medicine healers. Utilization of plants as a source of medicine has been inherited from generation to generation and is an important component of health care system in India. Due to remoteness and inaccessible areas, the local community largely depends on these medicinal plants (Sharma et al 2020). Due to extensive exploitation the plants are on the verge of extinction and so conservation is must for these plant species. Some plant species of high medicinal values require further phytochemical and pharmacological studies (Sharma et al 2020). Therefore, the aim of the present study was to documentation of traditional knowledge and study of medicinal plants used by the local inhabiting community of Chilla range and Chandi Devi hills of Shyampur range of Rajaji Tiger reserve in Haridwar, Uttarakhand.

MATERIAL AND METHODS

Study area: The study was investigated in Chilla range and Chandi Devi hills of Shyampur range in Haridwar. It is situated at foot hills of Shivalik or sub-Himalayan ranges (Fig. 1). Chandi Devi hills are located between latitude 29.9338° N and longitude 78.1805°E; Chilla Forest range are located between latitude 29.9450°N and longitude 78.2260° E. Winter season start from November to February when the days are pleasant (20-25^{0}C), nights cold and humidity is low. Temperature rises rapidly to 40-45^{0}C in the summer season (March to June) and rainfall increases with the occasional thunderstorm. Humidity is high in the rainy season (July to October). Annual rainfall ranges from1200-1500mm. Soils are generally poor and infertile, with accumulation of humus at few places. Chandi Devi Hills is situated between Bilvaand Neel Parvat. It comprises a total of 510-hectareforest reserve in Shyampur range and situated on the eastern bank of river Ganga on national highway. The Chandi Devi hill is one of the sacred grooves of Uttarakhand due to the temple of Goddess Chandi. The vegetation of the areas is classified under the northern tropical dry deciduous forest type. This region is a mixed forest and is very rich in medicinal plants.

Ethnobotanical field survey: The survey of the selected sampling zones was conducted on monthly basis in each zone from January 2020 to May 2021. The actual information was gathered by conducting interviews, group discussions and questionnaires, we had covered all the Deras of Gujjars and collected information also from local inhabitants such as Garhwali and Kumauni people. The information collected included common diseases, local name of plant species, habit, wild/cultivated, plant part used, ethnomedicinal use, method of preparation and mode of administration of drugs.

Collection and identification of medicinal plants: Field surveys of the selected sampling zones were scientifically planned and carried out monthly. The proper field number was assigned to each collected sample specimen for identification purposes. Plant voucher samples along with more than 250 digital photographs were taken during the field investigation and samples were processed following herbarium techniques proposed by Jain and Rao (1977). Twenty deras in localities were visited to complete the questionnaires prepared for the survey and data analysis. Hakim, Vaid, medicine men and herdsman were consulted for investigation. People of age group between 15 and above years (including male & female) were consulted during the survey. The ethnobotanical information was collected from the experts and well experienced herbal practitioner, local faith healers and traditional medicine men. The plants were also identified with the help of standard flora of Himalayas. The identified medicinal plants were confirmed by consulting the herbaria of different standards keys like "Flowers of the Himalaya", Flora Britannica and Flora of Haridwar. The herbarium was deposited to the Department of Botany and Microbiology, Gurukula Kangri (Deemed to be University) Haridwar.

RESULTS AND DISCUSSION

During the field survey a total of **68** plants from **32** families had been collected, identified and their traditional uses have been recorded. A total of 23 plant species from Chilla range like *Acacia catechu*, *Albizia lebbeck*, *Bombax malabarica*, *Centella asiatica, Catharanthus roseus* and 14 plant species from Chandi Devi Hills are *Acacia Arabica*, *Bombax ceiba*, *Buchanania lanzan*, *Butea monosperma*, *Crataeva nurvala*, *Erythrina suberosa, Euphorbia hirta*are only present in these particular sampling areas. 31 plants species collected were present in both the selected sampling zone i.e., *Anogeissus latifolia, Azadirachta indica, Boerhavia diffusa, Calotropis procera, Cassia fistula, Datura metel, Emblica officinalis, Ricinus communis, Solanum nigrum* (Table 1). The dominant families in the study areas are Caesalpiniaceae (6 plant species), Fabaceae (5 species), Mimosaceae, Asteraceae, Combretaceae, Euphorbiaceae (4species), Rutaceae, Acanthaceae, Myrtaceae, Moraceae, Lamiaceae (3 species).

Major life forms: The maximum numbers of plant species recorded in Chilla range were herbs with 13 species followed by trees with 6 species and shrubs with 3 species while in Chandi Devi Hills the maximum number of plant species were trees followed by herbs and shrubs (3 species). The maximum number of plant species present in both the ranges are trees (16 species) followed by herbs (8 species) and shrubs (5 species) respectively (Fig. 2).

In Chilla range, the maximum plant part used were leaves39%,fruits and bark/stem 18%, flower 13%, roots, whole plants and seeds with 4 % each respectively. On comparison with Chandi Devi Hills, leaves38%,fruits, bark/stem and roots 14% each, flower 10%, whole plants and

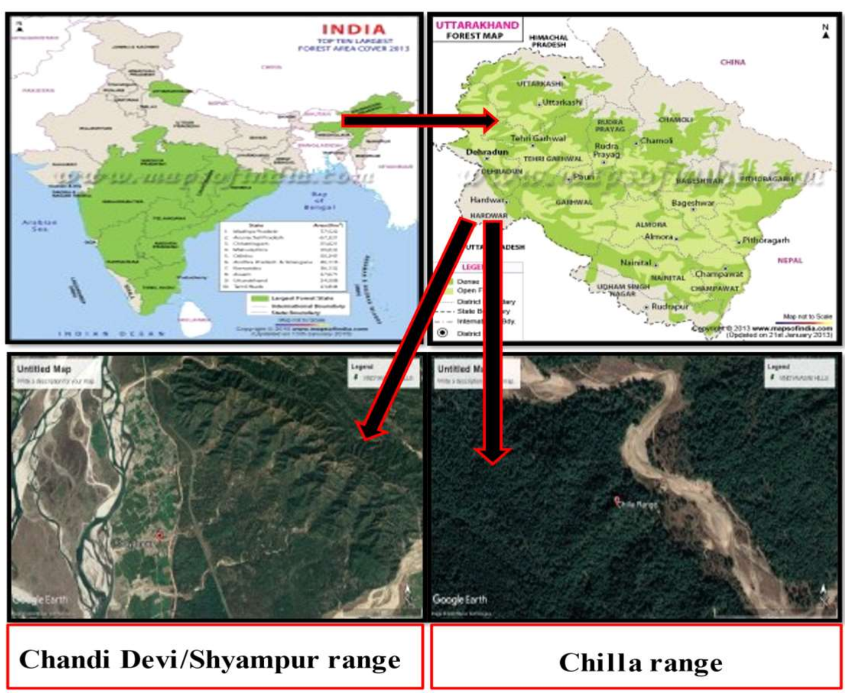

Fig. 1. Google earth images of selected sampling zones Chilla range (S1) and Chandi Devi Hills/Shyampur range(S2) of Rajaji Tiger Reserve

Table 1. Ethnobotanical plants documented in Chilla zone and Chandi Devi Hills

Botanical name	Family	Chilla range (S1)	Chandi Devi Hills (S2)	Ethnobotanical uses	Mode of administration o /e
Acacia catechu (L.f.) Wild.	Mimosaceae	+	-	The bark of the plant is boiled in water and used for gargling	o
Acacia Arabica Wild.	Mimosaceae	-	+	The bark of this plant is specifically used for tooth cleaning. Regular use of babul makes your tooth stronger, gums healthier, and additionally reduces plaque accumulation.	o
Acacia nilotica (L.) Del.	Mimosaceae	+	-	Dried fruit along with seed is taken, grind it to make fine powder. One tea spoon powder taken with water daily in the morning.	o
Achyranthes aspera Linn.	Amaranthaceae	+	+	Take 10-2-ml of Juice with honey or water	o
Aegle marmelos (L.) Corr.	Rutaceae	+	+	Take leaves and grind it with water. Mix jaggery give it twice in a day	e
Adhatoda vasica Nees.	Acanthaceae	+	+	Roots are crushed and taken with water once in a day	o,e
Ageratum conyzoides Linn.	Asteraceae	+	+	Leaf's juice is applied on cut, it stops bleeding immediately and heal the wound.	o
Albizia lebbeck (L.) Benth.	Fabaceae	+	-	Bark decoction is used with water for better results	o, e
Anogeissus latifolia Roxb.exDC	Combretaceae	+	+	The decoction of leaves is mixed with honey and taken twice in a day	o
Argemone Mexicana Linn.	Papaveraceae	+	+	The powder of the seed used with water once in a day	o
Azadirachta indica A.juss.	Meliaceae	+	+	Leaves are boiled in water and put one or two drops in ear. Juice of leaves is used to treat skin problems	o
Boerhavia diffusa Linn.	Nyctaginaceae	+	+	Root paste of this plant is used to cure bloody dysentery	o
Bombax malabarica DC.	Bombacaceae	+	-	Flowers and Gum are used in digestive disorder and piles	o, e
Bombax ceiba L	Bombacaceae	-	+	Gum is applied on piles	o
Buchanania lanzan Spreng.	Anacardiaceae	-	+	However, seeds can also be roasted or fried to enhance the flavour and cure diseases.	o
Butea monosperma O. kuntze.	Fabaceae	+	+	Seed, gum and flowers are used to treat diseases.	o
Calotropis procera R. Bl.	Asclepiadaceae	+	+	One fresh flower is taken daily with water for ten days continuously to control fast breathing during Asthma.	o
Cassia fistula Linn.	Caesalpinaceae	+	+	Grind bark with raw turmeric and mix little amount of alum in it, then boil in water to make a paste. This paste is applied on painful area twice a day.	o
Cassia tora Linn.	Caesalpinaceae	+	+	Burn the seeds into ash. Mix coconut oil in it and apply on itching area.	o, e
Cassia occidentalis L.	Caesalpinaceae	+	+	Give its flower with jaggery regularly.	o
Carica papaya L.	Caesalpinaceae	+	-	Give its ripened fruit with black salt thrice a day.	o
Cissampelos pareira Linn.	Menispermaceae	-	+	The root decoction is used twice a day with luke warm water.	o
Crataeva nurvala Ham.	Capparidaceae	-	+	Leaves and root paste along with desi ghee twice a day	o
Cuscuta reflexa Roxb.	Convolvulaceae	+	+	Boil its creeper with salt then tie it on stomach and wrapped with cotton cloth.	o,e
Caesalpinia bonduc (L.)	Caesalpiniaceae	+	-	Prepare decoction of its leaves.	o

Cont...

Table 1. Ethnobotanical plants documented in Chilla zone and Chandi Devi Hills

Botanical name	Family	Chilla range (S1)	Chandi Devi Hills (S2)	Ethnobotanical uses	Mode of administration o /e
Catharanthus roseus (L.) G. Don	Apocynaceae	+	-	Dry its leaves in shade, grind it to make powder. Dry its leaves in shade, grind it to make powder in the morning.	o
Centella asiatica (L.) Urbans	Apiaceae	+	-	Leaf's paste is applied on forehead, and used as memory enhancer	o
Citrus maxima (Burm.) Merr	Rutaceae	+	-	Fresh fruit is taken with black salt daily.	o
Clitoria ternatea L.	Fabaceae	+	-	Jaundice Seed is grinding to make powder. One spoon full powder is taken with honey.	o
Cuscuta reflexa Roxb.	Convolvulaceae	+	-	Boil its creeper with salt then tie it on stomach and wrapped with cotton cloth.	o,e
Cynodon dactylon (L.) Pers	Poaceae	+	-	Grind leaves with black salt and give it twice a day	e
Cyperus rotundus L	Cyperaceae	+	-	Decoction of roots	e
Datura metel L.	Solanaceae	+	+	Grind leaves and apply the paste on wound area. Tie it with cotton cloth.	o
Desmodium gangeticum DC.	Fabaceae	-	+	Leaves of the plant can be used to prevent diseases.	o
Eclipta alba (L.) Hassk	Asteraceae	+	+	Put two to three drops of leaves juice in ear opposite to aching tooth	o
Emblica officinalis Gaertn.	Euphorbiaceae	+	+	Fruit's powder is taken with water two to three times a day.	o
Erythrina suberosa Roxb.	Fabaceae	-	+	The bark ash mixed with coconut oil applied on wound	o
Euphorbia hirta L.	Euphorbiaceae	+	-	Whole plant is crushed and paste is made. This paste is applied on affected area.	o
Eugenia jambolana	myrtaceae	-	+	Raw fruits are consumed.	o, e
Ficus bengalensis Linn.	Moraceae	+	+	Dried root powder mix with honey in equal proportion is taken twice a day to cure Asthma.	o
Ficus racemosa Linn.	Moraceae	+	+	Take raw fruits and make it like vegetable, eat it daily till cure.	e
Ficus religiosa L.	Moraceae	+	-	Grind the bark with water and apply paste on affected area	e
Hibiscus rosa- sinensis L.	Malvaceae	+	-	Flower juice is put in ear, one or two drops to get relief.	o
Holarrhena ant- idysenterica (Roth.) DC.	Apocynaceae	+	+	Grind bark, then boil in water till water evaporate and paste is left. Paste is dried in shade then mix with jaggery and prepare small pills.	e
Holoptelia integrifolia Planch.	Ulmaceae	-	+	Paste is dried in shade then mix with jaggery and prepare small pills. One pill is taken early in morning with milk.	o
Justicia adhatoda L.	Acanthaceae	+	-	Leaves are boiled in water to prepare decoction. Two spoons full is given twice a day	o
Justicia gend-arussa Burm. f	Acanthaceae	+	-	Take its leaves in an earthen pot. Heat the pot over cow dung cakes. Take the ash and mix with honey, give this mixture twice a day	o
Lantana camara Linn.	Verbenaceae	+	+	Leaf's juice of plant is mix with onion juice and water. One tea spoon of juice is given.	o
Leucas aspera Spreng.	Asteraceae	-	+	Paste made from leaves	o
Litsea chinensis Lam.	Lauraceae	+	+	Bark is grinding to make paste. This paste applied on fracture area and tie it with cotton cloth.	o

Cont...

Table 1. Ethnobotanical plants documented in Chilla zone and Chandi Devi Hills

Botanical name	Family	Chilla range (S1)	Chandi Devi Hills (S2)	Ethnobotanical uses	Mode of administration o /e
Mallotus philippinensis Muell.	Euphobiaceae	-	+	Leaves and fruit powder along with milk or curd is consumed.	o
Melia azedarach Linn.	Meliaceae	-	+	Flower paste mixed in water given twice a day for one week.	o
Moringa oleifera. Lam	Moringaceae	+	+	Grind its leaves with equal amount of mustered oil, heat it and apply the paste on painful area.	o
Mimosa pudica L.	Mimosaceae	+	-	Give leaves juice with jaggery regularly within a week it cures Jaundice.	e
Murraya koenigii (L.) Spreng.	Rutaceae	+	-	Use its stem to brush the teeth and chew stem.	o
Nyctanthes arbor tristis L.	Oleaceae	+	+	Leaves are boiled in water to prepare decoction. Half cup is taken twice a day.	o
Ocimum sanctum L.	Lamiaceae	+	+	Fresh leaves are boiled in water to prepare decoction. One cup is taken twice a day.	o
Origanum vulgare L.	Lamiaceae	+	-	Take eight to ten leaves and grind them with small amount of cumin seeds. Give this mixture orally	o
Ricinus communis Linn.	Euphorbiaceae	+	+	Warm its leaves with mustard oil and tie them on affected area	o
Solanum nigrum Linn.	Solanaceae	+	+	Fresh leaves are boiled in water. One tea spoon is given with mother milk.	o
Syzygium cumini (L.) Skeels	Myrtaceae	+	+	Chew some leaves, it relieves toothache.	o
Tagetes erecta L.	Asteraceae	+	-	Leave paste is apply on wound area.	o
Tamarindus indica L.	Caesalpiniaceae	+	-	Crush its fruits in water and strain the solution. Add sugar, salt and cumin in it. One cup is given.	o
Terminalia arjuna (Roxb. ex DC.) Wt. & Arn	Combretaceae	+	+	Grind bark, then boil in water till water evaporate and paste is left. This paste is applied on injured area and tie with cotton cloth	o, e
Terminalia belarica Roxb.	Combretaceae	+	+	Grind dried Bahera and Amla fruit to make powder. Take one tea spoon of this powder with water daily	o
Terminalia chebula Retz.	Combretaceae	-	+	Take one tea spoon of this powder with water daily	o
Tinospora cordifolia (Willd.)	Menispermaceae	+	+	Prepare decoction of its stem. Take one cup twice a day.	e
Vitex negundo Linn.	Lamiaceae	-	+	Powder is given to cure diarrhoea	e

+Present; – Absent; S1 Chilla Range; S2 Chandi Devi Hills, o/e- Mode of administration, Oral/external

seeds with 5 % each respectively. While on both Zones (S1+S2), leaves39%,bark/stem 23%, roots 16%, seeds 10%, flower 6%, whole plants and fruit with 5 % each respectively (Fig. 3).

Diseases cured: The major diseases and ailments curedin the study area in Chilla range were dysentery, diarrhoea, malaria. On contrary to Chandi Devi hills were diarrhoea, wound healing, asthma, joint pain, constipation, diabetes. A very decent percentage of medicinal plant species are available in both zones for the treatment of dysentery, diarrhoea, malaria, toothache, jaundice, other diseases like fever, snake bite, digestive problem, spider bite, piles urinary disorders (Fig. 4).

The ethnobotanicals tudy shows a high degree of novelty and the use of plants among the tribes and Gujjars reflects the revival of interest in traditional folk culture. The local peoples, tribal, nomads and Gujjars have a magnificent knowledge about the use of plants for curing various diseases and ailments as a part of their healing methods (Akash et al 2021, Tewari et al 2015, Singh et al 2020). By evaluating thoroughly, the cause for endangerment status of the plants used in the traditional medicine, we put our approval that folk utilization is not the main reason for the deterioration of wild resources but may be vast collection for industrial purpose cause rapidly depletion of the wild plant resources. Regardless of the species richness of medicinal plants in the sampling zones the tradition of this valuable culture is facing a severe threat, mainly due to the rapid development of modern medicine. The ageing of herbalists without inheritors results in the rapid loss of valuable knowledge. In addition, the knowledge of traditional medicinal plants inherited via the oral mode and the accuracy of inheritance are difficult to determine. Unfortunately, the traditional use of plants is declining and accordingly knowledge is mainly restricted to the elderly. Therefore, it is must to document this valuable traditional knowledge concentrated in these peoples inhabiting in the remote and wild regions.

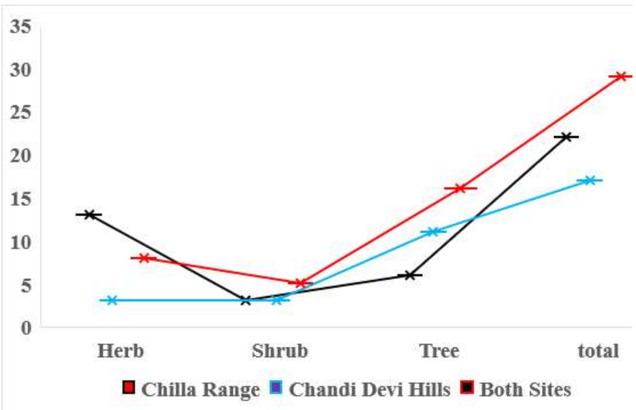

Fig. 2. Graphical representation of life forms of ethnobotanical plants

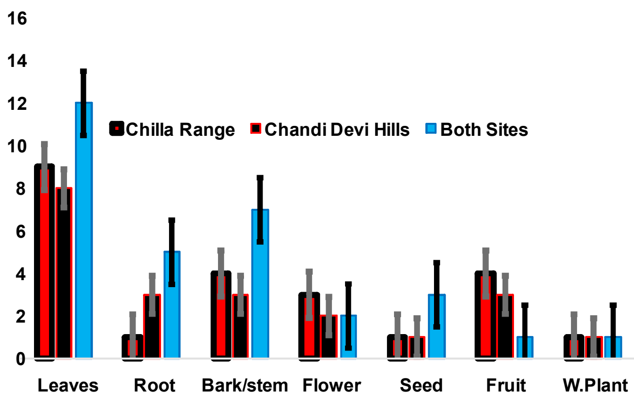

Fig. 3. Preference wise plant parts used by local peoples in selected sampling zone

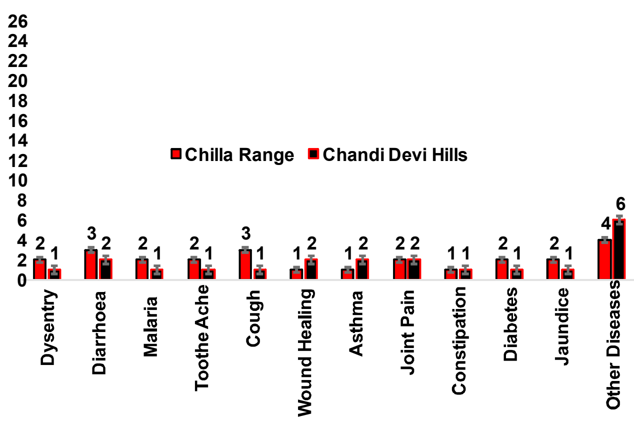

Fig. 4. Various diseases cured by ethnobotanical plants in selected sampling zones

CONCLUSION

A total of 68 plants from 32 families had been collected, identified and their traditional uses have been recorded. It was concluded that the study areas have present rich diversity of medicinal plants species with extensive ethno medicinal properties used in curing various diseases.

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Received 10 March, 2022; Accepted 20 May, 2022

Indian Journal of Ecology (2022) 49(3) (SI): 1203-1207
DOI: https://doi.org/10.55362/IJE/2022/3645

Manuscript Number: 3645
NAAS Rating: 5.79

Mutation Studies in Critically Endangered Temperate Medicinal Species *Swertia chirayita*- Evaluation of M_1 Mutants

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***Abstract*:** The present studies demonstrated the effect of gamma rays on morphology of *Swertia chirayita*. The studies focused on the impact of the gamma doses tested (2-30 kr at a dose interval of 2kr) on the growth performance of main shoot and beyond up to complete senescence. Eight induced variants based on morphological and growth features like (A) plants with suckering habit showing perennial nature, (B) plants without main shoot development, (C) lamina bifurcation, (D) leathery textured lamina, (E) whorl of 3 leaves at a node (as against a pair of such leaves under normal condition), (F) plants with more no. of costae per lamina, (G) flower colour change) and (H) vigorous plants were identified. These variants also showed variation in amaroswerin and amarogentin content with the levels either increasing or decreasing vis-a-vis untreated ones. The induced variant with suckering habit after vegetative splitting have again resprouted, produced main cauline shoots, flowers and also capsules (2^{nd} reproductive cycle) This variant with suckering habit holds promise of developing a perennial type of *Swertia chirayita* with more than one reproductive cycle.

***Keywords*:** *Swertia chirayita,* Gamma rays, Variant, Amarogentin, Amaroswerin

Swertia chirayita (family Gentianaceae), commonly known as chirata or chirayita is a critically endangered, temperate Himalayan species occur at an altitude of 1200-3000 m, from Kashmir to Bhutan and 1200-1500 m in Khasi hills. It is a pluriannual plant (that remains in radicle leaf stage for a year and produce cauline shoot in next year; completing its life cycle in near about two and half years. The plant is well known for its bitterness, antihelmintic, and antipyretic properties due to the presence of amarogentin (the bitterest compound isolated from any plant till date) Keil et al (2000). The plant also contains compounds of xanthone derivatives like chiratanin, chiratol and iridoid glycosides like amaroswerin and tri-terpenoid alkaloids like swerchirin, gentianine, swertiamarin that have high medicinal value for curing diseases (Patil et al 2013). *S. chirayita* is a highly prized herb in India and used either alone or as one of constituents in some polyherbal formulations. It is official in Indian Pharmacopoeia and was formerly also official in British and American Pharmacopeia as tincture and infusion. (Joshi and Dhawan 2005). Whole plant is used in traditional medicine, however the root is mentioned to be the most powerful part. In Indian medical systems, chirayita is used as a remedy for bronchial asthma, liver disorders, chronic fever, anaemia, stomachic and diarrhea. In Ayurveda, *S. chirayita* is used as antipyretic, anthelmintic, antiperiodic, laxative, in asthma and leucorrhea. Chirayita is also used as one of the ingredients in “Chandra Prabati” which is an ayurvedic drug for cancer. The plant is best known in India as the main ingredient in mahasudarshana churna, a remedy containing more than 50 herbs (Encyclopedia of medicinal plants). Herbal medicines such as Ayush-64, Diabecon, Mensturyl syrup and Melicon-V ointment contain chirayita extract in different concentrations for its antipyretic, hypoglycemic, antifungal and antibacterial properties. *S. chirayita* has an established domestic (India) and international market(Joshi and Dhawan 2005). As per National Medicinal Plant Board (NMPB), New Delhi, the annual demand shortfall for the raw material of *S. chirayita* was 965.2 tonnes in 2001-2002 which has increased to 1284.7 tonnes in 2004-05 at the rate of 10% per year (http:/nmpb.nic.in). The plant is harvested from wild only for meeting the market requirements which is posing a great threat to its existence. So, due to unsustainable wild extraction as well as almost absent cultivation activity have contributed to its demand shortfall (Tabassum et al 2012). In addition, existing populations of *S. chirayita* have diminished considerably. Being a critically endangered as well as high commercial demand species, cultivation is the only option available for its sustainable utilization. However, for making its cultivation economical, there is need of improved varieties/strains with high biomass as well as active content. Persual of literature reveals that there exist no characterized varieties/strains in this species that hampers any genetic improvement work. Due to considerably small size of its population, the overall range of variability is also limited. To increase genetic variation, induced mutations using gamma rays tried.

MATERIAL AND METHODS

Open pollinated healthy seeds of *S.chirayita* were irradiated with different doses of γ-rays i.e. 0 to 30 kr doses at a dose interval of 2 kr from a Co^{60} source using Gamma chamber- 900 (manufactured by Board of Radiation & Isotope Technology, Dept. of Atomic Energy, Govt. of India). The seeds treated with different doses of mutagens with 15 treatments, along with one control, were sown in a randomized (G_1 to G_{15}) block design with 3 (G_0) replications in the experimental at Medicinal and Aromatic Plants Research Farm Shilly (altitude 1550m amsl, latitude N 30^0 54' 30'' and longitude E 77° 07'30'') in April 2010. Discriminating morphological features with respect to type, shape and size of various plants parts were determined as per standard literature (Robin et al 1964, Collett 1971, Weberling 1989, Nath 1996). The M_1 generation was evaluated and variants based on aberrant morphological features were identified. The M_2 generation was raised from the seeds obtained from selfing of M_1 plants.Leaf, stem and root samples from the identified variants of M_1 generation of Swertia chirayita were collected from the field after complete senescence and analysed for bitter compounds (Amarogentin and amaroswerin content) through standardized HPLC (High Performance Liquid Chromatography).

RESULTS AND DISCUSSION

The studies revealed the impact of gamma rays on the growth and development of M_1 plants on various parameters like plant habit, plant height, leaf shape and size, stomatal index and size, flower size and colour, phenological characters, pollen size and stainability, seed set and changes in active content. Based on aberrant morphological features, eight interesting induced variants were identified in M_1 generation namely (variant A)showing suckering habit plant, (variant B) with no main shoot development, (variant C) with some lamina bifurcation, (variant D) with leathery textured lamina, (variant E) with a whorl of three leaves at a node,, (variant F) with increased no. of costae, (variant G) showing altered floral colour and (variant H) showing more vigorous growth. The detailed features of these variants as follows:

Variant A (Suckering habit): After the normal development of aerial shoot, one plant each in treatments G_4, G_7, G_{10} and G_{13} were observed to have developed underground root suckers (after completing the reproductive phase), hence named as A_1, A_2, A_3 and A_4 respectively. In none of the untreated plants, this feature was noticed (Fig. 1-4).

These underground suckers were physically split and the splits were replanted. Almost all the splits developed aerial growth in next season. Some of these sprouts after developing cauline leaves slowly and gradually died. However three such plants have survived and they have successfully completed the reproductive phase.

Variant B (No main shoot development) - These types of plants did not grow beyond radicle leaf stage and failed to produce main shoot by the end of October when they died. Most of such plants were noticed in G_2 and G_3 treatment while few such plants were observed in G_6 and G_{10}also (Fig. 5).

Variant C (Lamina bifurcated) -This type of variant was observed in G_{10} treatment growing under pot condition. One or more leaves of this variant was bifurcated up to the lamina base. Initially the splitting of the lamina was observed at the tip region which gradually extended almost up to the base of the midrib. One of the branches of this variant also borethree leaves at a node arranged in a whorl (Fig. 6).

Variant D (Leathery textured lamina) - Some plants of G_4, G_6, G_8, G_{11}, G_{13}, G_{14} treatment (under polyhouse conditions); G2, G_4, G_8, G_{12} and G_{14} (under pot conditions); G_1, G_2, G_3, G_9

Fig. 1-2. Plants showing suckers at the end of 1st growth phase (October-2012); Variant A

Fig. 3-4. Suckers producing flowers in September/October 2013 (2nd cycle); Variant A

and G_{10} (under field conditions) were found with leathery textured lamina. These leathery textured leaves were bore on the main shoot only and were absent on the lateral branches which bore normal non- leathery textured lamina (Fig. 8).

Variant E (3 leaves at a node)- The variant E represents the plants having one of its branches with three leaves at a node whereas the other lateral branches on the plant were with normal single opposite pair of leaves. The plants showing this type of variation were in the treatments G_1, G_2, G_4, G_{10}, G_{13} and G_{14}. Besides this some untreated plants also exhibited this character which however did not set seed even after flowering (Fig. 10, 11 and 12).

Variant F (More no. of costae) – These types of plants exhibited a higher range of main costae/lamina (9-11) and were observed in all the treatments. The untreated plants were observed with the range of 5-7 no. of costae (Fig. 9).

Variant G (Flower colour change) - A single plant of G_6 treatment growing under polyhouse condition exhibited change in colour of streaks present on inner surface of petals. In untreated as well as other flowers of treated plants, the colour of streaks was dark purple which however was very light purple in this case (Fig. 13).

Variant H (Vigorous plants) - Vigorous plants were observed in G_4, G_6, G_7, G_9 and G_{11} treatments. These plants showed vigorous aerial growth in comparison to other treatments as well as untreated plants (growing under all the three conditions). Amongst three plants, plants of G_7 and G_{11} set viable seeds (Fig. 7). These eight induced variants were analyzed for active content (amarogentin and amaroswerin) in leaves, stems and roots and considerable enhancement in bitter content was observed in few variants.

Leaves: The maximum amarogentin content of 0.304% was f in leaves of variant H (Vigorous plants) and the minimum of 0.112% was in variant F (More no. of veins). The maximum amaroswerin content of 0.308% was in variant H(vigorous plants) and the minimum was observed in variant A (0.105%).

Fig. 5. Variant B (No main shoot development)

Fig. 6. Variant C (Lamina bifurcated)

Fig. 7. Variant H (Vigorous Plants)

Fig. 8. Variant D (Leathery textured lamina)

Table 1. Effect of gamma rays on amarogentin and amaroswerin content in leaves, stems and roots

Induced variants	Leaves		Stems		Roots	
	Amarogentin content (%)	Amaroswerin content (%)	Amarogentin content (%)	Amaroswerin content (%)	Amarogentin content (%)	Amaroswerin content (%)
A (Suckering habit)	0.237 (0.859)	0.105 (0.778)	0.269(0.877)	0.024 (0.724)	0.026 (0.725)	0.113 (0.783)
B (No main shoot development)	0.267 (0.876)	0.174 (0.821)	No stem	No stem	0.038 (0.733)	0.041 (0.736)
C (Lamina bifurcation)	0.206 (0.840)	0.134 (0.796)	0.275 (0.880)	0.021 (0.722)	0.041 (0.735)	0.018 (0.720)
D (Leathery textured lamina)	0.259 (0.871)	0.195 (0.833)	0.305 (0.897)	0.107 (0.779)	0.014 (0.717)	0.005 (0.711)
E (3 leaves at a node)	0.211 (0.843)	0.202 (0.838)	0.110 (0.781)	0.026 (0.725)	0.018 (0.720)	0.004 (0.710)
F (More no. of costae)	0.112 (0.782)	0.132 (0.795)	0.129 (0.793)	0.054 (0.744)	0.004 (0.710)	0.003 (0.709)
G (Flower colour change)	0.291 (0.890)	0.208 (0.841)	0.217 (0.847)	0.028 (0.727)	0.045 (0.738)	0.017 (0.719)
H (Vigorous plants)	0.304 (0.897)	0.308 (0.899)	0.208 (0.842)	0.025 (0.725)	0.060 (0.748)	0.022 (0.722)
Untreated plants	0.146 (0.804)	0.125 (0.790)	0.166 (0.816)	0.034 (0.731)	0.021 (0.722)	0.007 (0.712)
CD (p=0.05)	(0.046)	(0.057)	(0.037)	(0.016)	(0.013)	(0.004)

*Figures in parenthesis are transformed values

The untreated plants were with a amarogentin content of 0.146% and amaroswerin of 0.125% (Table 1).

Stems: Amongst the isolated variants, the variant B (no main shoot development) could not be analysed for amarogentin and amaroswerin content due to the fact that such plants did not produce main shoot. The maximum amarogentin content of 0.305% was observed in variant D (leathery textured lamina) and minimum of 0.110% in variant E (3 leaves at a node). The maximum amaroswerin content (0.107%) was observed in variant D (Leathery textured lamina) and the minimum (0.021%) in variant C (Lamina bifurcation). The untreated plants were observed with amarogentin content of 0.166% and the amaroswerin content of 0.034%(Table 1).

Roots: In roots, the maximum amarogentin content was in variant H (vigorous plants) (0.060%) and minimum in variant F (more no. of veins)(0.004%). The maximum amaroswerin content of 0.113% was in variant A (suckering habit) and the minimum of 0.003% was in variant F (more no. of veins). The untreated plants were observed with a amarogentin content of 0.021% and the amaroswerin content of 0.007% (Table 1).

In spite of great demand, supplies of *S. chirayita* still depend on wild sources which are becoming critical on account of over harvesting of its plants (generally before seed dispersal) leading to progressive clearance of their habitats). Low seed germination, long gestation period and delicate field handling requirements are some of the factors which discourage its commercial cultivation (Badola and Pal 2002 and Raina et al 2013). However, successful cultivation shall only be assured if better strains in terms of biomass/ active content but no improved strains are there in this species. Due to narrow genetic base and restricted distribution, any improvement programme is need relook. With this background, this work was started and its seeds were subjected to various doses of gamma rays and M_1 progeny raised. This species is a pluriannual (once flowering herb) (Clarke 1885) completing its life cycle in about 30 months (Shah 2008, Raina et al 2013). The growth and developmental stages in this species can be broadly sub-divided into two phases; i) radicle leaf stage (upto about 20 months after seed sowing) and ii) reproductive phase (20-30 months after seed sowing). Eight interesting types based on morphological variations were identified. Amongst these, four such variants were leaf based, three on the basis of plant type and one flower colour variant. Behera et al (2012) generated 142 genetic variants of *Asteracantha longifolia* (through EMS induced in vitro mutagenesis) of which 24 mutant lines including 4 dwarf mutants, 7 leaf mutants and 13 flower mutants were analysed at morphological level. Similarly remarkable variations in the leaf shape, plant height, leaf colour, tuber yield and forskolin content was observed in *Coleus forskholii* after subjecting to gamma irradiation (1 to 15 kr) followed by evaluation for three generation under field conditions (Srinivasappa et al 2010). Flower colour in the M_1 plants that progressed upto flowering stage was the least affected as most of these M_1 plants developed flowers that were similar to untreated plants in

Fig. 9. Variant F (More no. of costae)

Fig. 10-12. Variant E(3 leaves at a node)

Fig. 13. Variant G (Flower colour change)

terms of its colour. However one plant of 12 Kr treatment did produce flowers with altered colour pattern (light coloured purple streaks on inside surface of petals) as compared to untreated ones (dark coloured purple streaks on the under surface of petals). Similar changes have been observed in *Chrysanthemum morifolium* wherein due to gamma rays (0.5 to 1 Gy), the normal grey red flower colour was modified into yellow colour under culture conditions (Mishra et al 2003) and in *Pelargonium graveolens* 'Dark Mozart' cultivar with improved flower colour in contrast to 'Mozart' after X- ray treatment has been released (Maluszynski et al 2000).

CONCLUSIONS

The induced variant observed during the present studies were the plants showing suckering habit. The plants of *S. chirayita* are once flowering completing their life cycle in about 28-30 months. After seed setting these plants die without any scope of vegetative propagation. However, in case of plants showing suckering habit (Variant A), the observed plants developed suckers at the base which once split and replanted in 2012, sprouted and produced flowers again (2nd cycle) during 2013. Such plants can open a new opportunity of developing perennial strain of S. chirayita which can have immersed advantage in terms of substantial production of raw material avoiding repeated growing cycles after every seed setting stage. Breeding programmes aimed at developing perennial grain crops have been initiated in wheat, sorghum, sunflower, etc. as perennial store more carbon, maintain better soil/water quality and manage nutrients more conservatively than do annual plant communities besides having greater biomass as well as resource management capacity. Isolation and multiplication of plants of *S. chirayita* showing suckering habit (and thereby potential perennial habit) is an opportunity to circumvent repeated cycles of sowing and growing and may ultimately prove beneficial in successful domestication of *S. chirayita.*

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Received 07 March, 2022; Accepted 20 May, 2022

Indian Journal of Ecology (2022) 49(3) (SI): 1208-1213
DOI: https://doi.org/10.55362/IJE/2022/3646

Manuscript Number: 3646
NAAS Rating: 5.79

Effect of Microbial Bio-Elicitors on Yield and Chemical Composition of Essential Oil in *Pelargonium graveolens* L.

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Abstract: The effect of arbuscular mycorrhiza fungi (AMF) and plant growth-promoting bacteria (PGPB) namely *Azotobacter*, *Advenella spp*, NPK liquid consortia (*Azotobacter, Azospirillum,* phosphate solubilizers and potassium solubilizers), and zinc solubilizing bacteria on rose scented geranium was evaluated under pot culture study. The microbial bio-elicitors significantly influenced all growth related parameters, aerial and root biomass, soil fertility status, microbial enzymes, oil yield and quality. Dual inoculation of AMF with *Advenella spp* has resulted in the highest synergistic effect as evidenced by the highest crop growth indices like plant height, number of branches and enhanced dry herb biomass and oil yield significantly higher than non-inoculated control. GC-MS studies showed that citronellol (23.15%-32.56%), geranial (8.48%-12.85%), citronellyl formate (5.94%-9.89%), isomenthon (6.16%-7.96%) and 10-epi-ϒ-Eudesmol (3.72%-6.98%) were the major components.

Keywords: *Pelargonium graveolens*, AMF, PGPB, Essential oil, Chemical composition

Rose scented geranium (*Pelargonium graveolens* L.) (Geraniaceae) is a commercially important perennial aromatic plant (Fekri et al 2021). This plant species is commercially cultivated mainly in Algeria, Egypt, Morocco, India and China (Verma et al 2016). It is among the top 20 essential oils produced worldwide, with important applications in aromatherapy and pharmaceutical corporations (Rao 2002). Rose scented geranium has the medicinal property to cure dysentery, diarrhoea and colic disorders (Shawl et al 2006) and menorrhagia (Verma et al 2014). Presently, India requires about 200 tonnes of geranium oil annually but invests a lot of foreign currency in its import as its domestic production is only about 20 tonnes (Nilofer et al 2018). Therefore, there is a need to enhance both yield and essential oil quality in case of rose scented geranium, but through low cost eco-friendly technologies. Microbial bio-elicitors improves the growth rate of plants and soil health as act as plant strength, phyto-stimulator, plant health improvement and have the potential to improve soil fertility status (Babalola 2014). The most widely used biofertilizers which contribute nitrogen, phosphorus, and potassium to plants are *Azotobacter, Azospirillum* and PSB. Rhizospheric soil of several species of medicinal plants has a symbiotic association with AMF (Assis et al 2020). They play a crucial role in mineralization and cycling of nutrients in plants (Jansa et al 2019), reducing the chemical fertilizer dose by 25-50% (Rana et al 2012). The decrease in input cost of geranium by adopting eco-friendly nutrient management practices particularly through using microbial inoculants for increasing bioavailability of nitrogen, phosphorus and potash can be a viable option. The present investigation was carried out to evaluate the role of dual inoculation of AMF and PGPR inoculants as microbial bio-elicitors on enhancing yield and chemical composition of rose scented geranium.

MATERIAL AND METHODS

Experimental site: The experiment was conducted at CSIR–Central Institute of Medicinal and Aromatic Plants (CIMAP), which is situated at 26°5´ N latitude and 80°5´ E longitude with an altitude of about 120 m above MSL at Lucknow, Uttar Pradesh, India. The site's climate is defined by scorching summers, relatively cold winters and an average annual precipitation of 1000 mm. The soil in the experimental field was alkaline having a pH of 8.03 and classified as loamy sand with N, P, and K content of 202.10, 52.06, and 152.24 kg ha^{-1} respectively and soil organic carbon content of 3.21 g kg^{-1} soil.

Experimental details: Randomized complete block design (RCBD) pot experiment with four replicates was set up. In an earthen pot with a diameter of 20 cm and a capacity of ten litters, nine kg of air dried soil and sieved using 2 mm sieve was placed. The treatments consisted of four different combinations of plant growth promoting bacteria with AMF. The microbial inoculants used in the experiment are *Azotobacter* (nitrogen fixer), NPK liquid consortia (*Azotobacter, Azospirillum,* phosphate solubilizers and potassium solubilizers), Arbuscular mycorrhiza fungi, Zinc solubilizing bacteria and CRC-4 (*Advenella spp).*

The microbial strain CRC-4 (Advenella *spp)* was obtained from the NCBI GenBank (HQ995501). The bacterial culture was multiplied in Pikovskayas broth. The bacterial suspension was centrifuged at 5000 rpm for 20 minutes. The supernatant was discarded and the pellet is collected. After collection, the pellet was added to 80% NaCl solution. The NaCl + Pellet solution was added to autoclaved vermicompost which is used as a carrier for the bioinoculant. The other bioinoculant *Azotobacter* (nitrogen fixer), NPK liquid consortia (*Azotobacter, Azospirillum,* phosphate solubilizers and potassium solubilizers), Arbuscular mycorrhiza fungi and zinc solubilizing bacteria were taken and added to water separately. Planting material of equal size with healthy, erect shoots and roots of *Pelargonium graveolens* was taken and dipped into the water containing the bioinoculant for 40 minutes to allow the bioinoculant to colonize the root and then after 40 minutes the planting material were taken from the bioinoculant solution and transplanted in pots.

Crop raising: Quality planting material of *Pelargonium graveolens* L. was collected from the CSIR CIMAP gene bank in Lucknow. During cropping periods, routine agronomic practices for crop cultivation were followed. Twenty five days old, healthy and uniform seedlings of *Pelargonium graveolens* L. var. CIM-BIO-171 were procured from the nursery area of CSIR-CIMAP, Lucknow and transplanted on flat beds at 50 cm x 45 cm spacing in 2ndweek of January 2020, respectively. A light irrigation was provided immediately post transplantation. In all pots about 20 g each of AMF and bacterial cultures were applied as per treatments. All the recommended cultural practices like irrigation, weeding and hoeing were followed according to the requirement during crop growth period. Non inoculated control pots were fertilized with required amount of N, P, K through vermicompost.

Evaluation of growth and yield: At maturity, observation related to plant growth parameters were recorded per plant. Plant height was recorded from the base to the tip of the stem. Number of branches per pot was also counted. Fresh geranium biomass was observed from each treatment during harvesting, and the weight of the sampled plant was also included to the treatment.

Essential oil extraction: The oils were extracted from 200 g of each sample by hydro-distillation using Clevenger-type apparatus for 3 h. For the experiment, a 2 l flask was used (Clevenger 1928). The water volume had ratio of 1:10 (w/v), with the water condensation maintained between 12 and 15°C using the same refrigeration system (Oliveira et al 2019) for each oil. The resulting oils were centrifuged for 5 min at 3000 rpm, dried using anhydrous sodium sulfate (Na_2SO_4), then centrifuged again under the same conditions, after which the solutions for chromatographic analysis were immediately prepared. Total oil yields were expressed as essential oil (g) / dried material (g).

Quality analysis: The quality analysis of essential oil was done by gas chromatography (Helwlett Packard G.C.; H.P-5890) using FID and 15mmx 0.53 mm, B.P-20 capillary columns. Oven temperature was maintained from 40 and 220°C @ 5/ min. with initial hold of 5min. and hydrogen gas was used as a carrier at 30 ml/min. Temperature of injector and detector were maintained at 200 and 240°C, respectively. H.P.3396 integrator was used for data processing. The retention index was calculated for all volatile constituents using a homologous series of n-alkanes (C8 - C20), and were identified by comparing the experimentally obtained mass spectra and retention indices to those found in literature (Adams 2007). Major compounds viz., Linalool, isomenthon, citronellol, geranial, citronellyl formate, geranyl formate and 10-epi-Y-eudesmol were identified based on the retention time of standard compound.

Soil analysis: For determination of nutrient balance of soil, the initial and post harvest phase soil samples were collected from depth of 0-15 cm separately for microbial and soil nutrient analysis from three randomly selected sited from each plot. Freshly obtained samples of soil were used for microbial and enzymatic activity as well as rest soil samples were mixed, homogenized, air dried, crushed properly, sieved (2mm) and a amalgamated sample of approximately 550 g obtained. For determination of enzymatic activity in soil viz., soil dehydrogenase activity was tested (Casida et al 1964) as well as acid and alkaline phosphatase test (Tabatabai and Bremmer 1969, Eivazi and Tabatabai 1977). Soil microbial biomass carbon (SMBC) was determined by fumigation-extraction method (Vance et al 1987). The concentration of elements in soil samples and its physical and chemical properties were measured. Organic carbon was determined (Walkley and Black 1934), available nitrogen of soil was measured by Kjeldal method (Subbiah and Asija 1956), available phosphorus by Olsen method (Olsen et al 1954), available potassium by normal ammonium acetate using flame photometer (Jackson 1973).

Statistical analysis: Statistical data analysis was analyzed by using OPSTAT statistical software package.

RESULTS AND DISCUSSION

Soil biological properties: Initial count of bacteria, fungi and actinomycetes were 27.3 x 10^4, 20 X 10^6 and 10 x 10^4, respectively before any treatment was applied in soil of experimental pot. At 30 days after inoculation (DAI), the highest bacterial population was in the rhizosphere soil of treatment T1 having AMF + CRC-4 as microbial inoculants i.e. 15.35 x 10^5 Cfu /g of soil, which was significantly higher than non inoculated control (12.8 x 10^5 Cfu /g of soil).

Soil microbial enzymes: The soil nutrient status as well as microbial enzymes were significantly influenced by co-inoculation of different plant growth promoting bacteria with arbuscular mycorrhiza fungi (AMF). T1 treatment (co inoculation of AMF and CRC-4) recorded the highest soil microbial biomass carbon (SMBC) which was (162.68 µg g^{-1} soil), while all other treatments also recorded significantly higher SMBC than non inoculated control (28.43 µg g^{-1} soil). Soil microbial biomass is necessary to sustain soil functions because it serves as a source of soil enzymes that govern the transformation processes essential elements in soil and also regulates the accumulation and decomposition of organic materials, as well as the breakdown of organic residues, and acts as an early marker of soil management changes. The microbial biomass is a living component of soil that aids in nutrient transformation and cycling and also serves as a chief source of C, N, P, and sulphur, as well as enhances the physico-chemical characteristics of soil. The higher values of SMBC in soil with microbial inoculation indicate a positive trend. Dehydrogenase is a respiratory chain enzyme of soil microorganism, which is an indicator of biological redox system and microbial activity (Suryavanshi et al 2016). Dehydrogenase enzyme was significantly higher in all the treatment combinations ranging from 155.6 µg TPF g^{-1} in T4 (coinoculation of AMF and azotobacter) to 151.7 µg TPF g^{-1} soil h^{-1} in T3 (coinoculation of AMF and azotobacter) as compared to non-inoculated control (109.9 µg TPF g^{-1} soil h^{-1}). Dehydrogenase (DHA), which is primarily an intracellular enzyme, acts as a measure of metabolic activity undertaken by microbial community in soil. Acid and alkaline phosphatase also followed similar trend where all treatments recorded significantly higher values than non inoculated control.

Table 1. Effect of microbial bio-elicitors on general microbial population of soil at 30 days after inoculation in rhizospheric soil

Treatments	Population of microbes in rhizospheric soil (Cfu /g of soil)
T1(AMF +CRC4)	15.35
T2 (AMF +NPK consortia)	14.05
T3 (AMF + Zinc solubilizing bacteria)	13.65
T4 (AMF +Azotobacter)	13.80
Non inoculated control	12.80
CD (p=0.05)	0.88

Soil nutrient status: Available nutrients in soil was significantly influenced by microbial inoculants. The available N ranged from 455 kg ha^{-1} in T4 to 155 kg ha^{-1} in non-inoculated control (Table 2). Similarly all the inoculated treatments recorded significantly higher available P, K and organic carbon than control. The maximum organic carbon content was also recorded in T1 i.e. inoculation of AMF with CRC-4 (0.72 kg ha^{-1}) and the lowest were in control (0.53 kg ha^{-1}). Ravikumar et al (2012) observed that simultaneous application of biofertilizers helped in improving the availability and absorption of nutrients by the plants, resulting in the highest NPK status and uptake in plants. Enhanced activity of microbial enzymes might have lead to increased accessibility of nutrients (N, P and K). Increase in microbial biomass carbon due to dual inoculation of AMF with plant growth promoting bacteria perhaps resulted in increased organic matter content. Plant growth promoting bacteria might have stimulated better root growth leading to enhanced nutrient availability.

Crop growth parameters: The tallest plants were recorded in T1 treatment i.e., co-inoculation of AMF with CRC 4

Table 2. Effect of microbial bio-elicitors on nutrient status and soil microbial enzymes after harvesting rose scented geranium

Treatment	Available nutrients (kg ha^{-1})				Soil microbial enzymes			
	N	P	K	OC	Dehydrogenase (µg TPF g^{-1} soil h^{-1})	Acid phosphates (µg PNP g^{-1} soil h^{-1})	Alkaline phosphatase (µg PNP g^{-1} soil h^{-1})	SMBC (µg g^{-1} soil)
T1	325	17.95	200.24	0.725	153.45	98.90	170.3	162.68
T2	315	19.50	214.48	0.71	136.9	82.28	164.74	161.82
T3	378	22.18	154.84	0.65	151.7	71.13	173.8	94.39
T4	455	18.06	180.6	0.61	155.6	55.05	164.4	76.47
Control	161	10.37	125.44	0.53	109.9	32.11	85.53	28.43
CD (p=0.05)	1.1	0.03	0.3	5.7	2.7	5.7	0.6	0.4

(50.0cm), which was significantly higher than control (30.0 cm) (Table 3). Plants of T2, T3 and T4 were of almost similar height. Number of branches per plant also followed similar trend. The crop of the control plots resulted in production of plants with least height which were significantly inferior to other treatments. This might be due to fact that co-inoculation of AMF with plant growth-promoting bacteria may have increased the rate of mineralization of plant nutrients in soil, resulting in improved crop nutrition and consequently increased plant height. Similar results were reported on potato by Talwar et al (2016) in onion and Thakur et al (2016) in calendula.

Dry matter yield: Inoculation with microbial bio-elicitors significantly enhanced the dry matter production of rose scented geranium over non inoculated control (Table 4). T1 (AMF+CRC 4) recorded the highest total dry matter yield (23.79 g/plant) closely followed by T2 (18.52 g/plant), while the lowest dry matter yield was recorded in non inoculated control (9.22 g/plant). Improvement in herb yield was accredited to sustained availability of macro and micronutrients for longer period of crop growth which is related to enhanced activity of microbial enzymes. The co-inoculation of AMF with plant growth promoting bacteria recorded relatively larger percentage of dry matter integrating into leaves in comparison with untreated control at harvest stage. The results indicated the need of microbial inoculation for improving dry matter partitioning into the geranium leaves. This could be because colonization with AMF increased nutrient and water intake, resulting in increased absorbing area via mycelium infiltration of the soil and an increased soil volume for the plant, resulting in higher photosynthesis, plant development, and plant weight gain (Smith et al 2003).

Essential oil yield: Oil content of microbial inoculated plants ranged from 0.35% in T1 to 0.28% in T4, which were significantly higher than non inoculated control (0.19%). Co-inoculation of CRC-4 with AMF was very effective in increasing oil yield of geranium. This might have happened due to increased availability of nitrogen and phosphorus in rhizosphere of inoculated plants. Higher photosynthetic activity might stimulate enhancement in production of essential oil yield, which is a secondary metabolite. Copetta et al (2006) also reported increase in essential oil yield due to changes in phytohormones leading to higher number of pellate grandular trichomes in the leaves as a result of inoculation. Similarly, Bajeli et al (2016) in Japanese mint and Singh et al (2014) in basil reported an increase in essential oil yield due to application of organic manure.

Oil composition: GC-MS results reported the major components of geranium oil as citronellol (23.15-32.56%), geranial (8.48-12.85%), citronellyl formate (5.94-9.89%),

Table 3. Effect of microbial bio-elicitors on aerial and root dry matter and essential oil content of rose scented geranium

Treatment	Height (cm)	No. of branches /plant	Dry matter (g/plant)			Total dry biomass (g/plant)	Essential oil percent (%) per 200 g plant biomass
			Aerial shoot		Below ground		
			Leaf	Stem	Root		
T1	50.0	13	18.85	4	0.94	23.79	0.35
T2	41.25	10.5	14.75	2.9	0.85	18.50	0.31
T3	40.25	10.5	11.3	2.8	0.58	14.68	0.30
T4	39.75	9.75	15	1.25	0.50	16.75	0.28
Control	32.0	9.0	7.9	1.0	0.32	9.22	0.19
CD (p=0.05)	0.23	0.12	1.0	1.04	1.2	0.003	0.09

Table 4. Effect of microbial bio-elicitors on chemical composition of essential oil of rose scented geranium

Compound	T_1	T_2	T_3	T_4	Control
Linalool	1.02	0.87	1.80	1.00	2.06
Isomenthon	6.16	7.92	7.96	7.28	6.65
Citronellol	32.56	23.15	32.62	31.24	26.56
Geranial	12.85	8.48	10.67	9.43	8.43
Citronellyl formate	9.32	5.94	9.77	9.89	7.51
Geranyl formate	2.83	1.68	2.39	2.81	1.11
10-epi-Ƴ-Eudesmol	6.98	5.99	6.08	6.90	3.72

isomenthon (6.1-7.96%), 10-epi-Ɣ-Eudesmol (-6.98%) and linalool (0.87-2.06%). Co inoculation of plant growth promoting bacteria along with AMF gave encouraging results. T1, T3 and T4 recorded almost similar amount of citronellol, citronellyl formate, geranyl formate and 10-epi-Ɣ-Eudesmol, which was significantly higher than untreated control. As citronellol content defines the commercial value of geranium oil, co-inoculation of AMF with CRC-4 (T1), Zinc solubilizing bacteria (T3) and Azotobacter (T4) had synergistic effect which resulted in improvement in desirable constituent in oil. Root colonization with AMF enhanced the EO content and composition as reported by Morelli et al (2017) in basil and Trindade et al (2019) in *Piper nigrum*.

CONCLUSION

Natural bio-elicitors, such as dual inoculation of arbuscular mycorrhizal fungi with plant growth promoting bacteria, can help preserving the ecological balance of the soil while enhancing yield and quality of essential oil of rose scented geranium. As a result, the use of microbial inoculants in conjunction with inorganic chemical fertilizers can minimize reliance on inorganic chemical fertilizers, potentially paving the way for sustainable and organic production of aromatic and medicinal plants.

ACKNOWLEDGEMENT

Authors acknowledge the funding support from CSIR AROMA Mission (HCP 007) for providing necessary funding.

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Received 22 March, 2022; Accepted 20 May, 2022

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Indian Journal of Ecology (2022) 49(3) (SI): 1214-1219
DOI: https://doi.org/10.55362/IJE/2022/3647

Manuscript Number: 3647
NAAS Rating: 5.79

Studies on Ashwagandha [*Withania somnifera*] Elite Genotypes for Root Yield and Attributes under Heat Stress Condition

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Abstract: Present investigation was carried out to assess the impact of environment on Indian ginseng (ashwagandha) root yield and its associated traits under semi-arid condition. Twenty-two elite genotypes of ashwagandha (*Withania somnifera*) were evaluated under normal and cold stress environment conditions for root yield and other associated traits. Analysis of variance, cold stress index and correlation, analysis were performed using the mean data. Analysis of variance revealed that the genotypes differed significantly under normal as well as under stress environment for all the plant traits studied. Best performing genotypes for root yield (kg/ha) under both conditions were HWS105 (433 kg/ha), HWS 153 (399 kg/ha), HWS1333 (396.3 kg/ha), HWS120 (372.4 kg/ha), HWS206 (308.1 kg/ha) and HWS 8-18 (304.1 kg/ha). Further, in correlation analysis, root yield had the significant positive association with root length and root diameter. Therefore, these characteristics can be exploited to improve dry root yield in ashwagandha genotypes and there is also scope for the selection of promising genotypes (based on the stress susceptibility index) from the present germplasm for cultivation under stress environment. Under stress condition, genotype HWS 153 exhibited good potential for commercial cultivation as well as it showed less reduction in root yield and low in SSI, but before recommendation for commercial cultivation to be tested over time and space.

Keywords: *Withania somnifera*, Ashwagandha, Environment stress, Root yield, Susceptibility Index

Indian is home of herbal medicines which are found in different hotspots including these three biodiversity centers i.e., the Himalayas, the Western Ghats, and the Indo-Burma. India covers about 11 percent of the global diversity of plants (Sakachep and Rai 2021). Ashwagandha (*Withania somnifera* (L.) Dunal (2n=48), Indian ginseng is one of the most valuable medicinal plant used in the Indian and Unani systems of medicine since ancient times (Kaileh et al 2007, Mishra 2014). The roots of ashwagandha have properties similar to ginseng roots; hence it is also known as Indian ginseng (Singh and Kumar 1998). It is also known as gooseberry or winter cherry and belongs to the family Solanaceae. The India, North-Western and Central partsin Africa, the Mediterranean region are the native palaces of ashwagandha. The most suitable climatic region for its growth and development is the dry and subtropical type. In India, it is mainly cultivated in the states of Madhya Pradesh, Rajasthan, Gujarat, Maharashtra, Punjab, and Uttar Pradesh. India is also an exporter of ashwagandha roots in the international market. According Zauba (2020), India sales maximum ashwagandha to USA of amounting about USD 883,780 followed by New Zealand (USD 101,606) and China (USD 90,552).

In Ayurvedic era, it was mainly consumed as a health tonic for fitness, longevity and vitality (Singh *et al.*2010).It is also very important stimulation of the human body immune system cells, phagocytes and lymphocytes, which also assist to manage the effects of stress and encourage wellness (Singh et al 2001, Singh et al 2003). Sirvastava et al (2018) observed that roots are also utilized to treat asthma, bronchitis, emaciation, dementia, insomnia, inflammation, neurological disorders, and Parkinson's disease. The total alkaloid content in the Indian ginseng roots vary from 0.13 to 0.31%, however, in some genotypes it also reported up to 4.3% (CSIR 1982; CCRUM 2007). The main chemical constituents are alkaloids and steroidal lactones. The medicinal properties of the plant are due to the presence of withanolides (withaferin A and withanolide D) (Sharma et al 2011). As per Indian chemotype, it has 12 types withanolides, five unknown alkaloids, several free amino acids, glycosides, tannins, chlorogenic acid, glucose, and several flavonoids in the leaves (Khare 2007). Earlier, the medicinal herbs and shrubs were available effortlessly in the nearby jungles and on mountains. Presently, due to constant utilization of these natural plants with alarming speed reduced their accessibility. Therefore, it is an insistent need to evolve the high yielding superior cultivars of essential medicinal flora to manufacture the superior quality raw drugs in order to meet out the local requirements of Ayurvedic practitioners as well as the international demands of medicine manufacturing agencies. Moreover, sufficient genetic diversity is available in this crop (Yadav et al 2008, Reddy et al 2012), and very little work has been done on its genetic improvement in spite of the long history of its domestication. A large portion of it still comprises wild, semi-wild plants or primitive cultivars which have not acquired genes for high productivity under cultivation and have great potential to improve the yield and quality. Medicinal plants are generally cultivated under harsh climatic conditions; therefore, identification of the superior genotypes for high temperature tolerance is essential for effective manipulation through breeding techniques (Yadav et al 2013). Therefore, keeping the above points in view, the newly developed elite genotypes of Ashwagandha were evaluated for heat stress under semi-arid conditions.

MATERIAL AND METHODS

To conduct the field experiment, 22 newly developed elite genotypes (Table 1) of Ashwagandha (*Withania somnifera* (L.) were grown in RBD on 7thSeptember 2017 (normal sown) during cropping season 2017-18 and on 28 October 2018 (late sown) during cropping season 2018-19 at Research Farm of MAP Section, Department of Genetics and Plant Breeding, Chaudhary Charan Singh Haryana Agricultural University, Hisar (Haryana, India) located 29º10′ N latitude and 75º46′ E longitude with an elevation of 215.2m above the mean sea level. The plot size was 4.0 m x 1.2 m with spacing 30 cm x 10 cm. The fertility status oil of field soil was sandy loam in texture, medium in organic carbon (0.46 %), available nitrogen (141.0 kg/ha), available phosphorus (14.0 kg/ha) and available potassium (240.0 kg/ha). Weekly weather parameters data recorded from research area during 2017-18 and 2018-19 given in Figure 1 & 2. All the recommended package of practices was carried out to raise a good crop. Data were recorded on five randomly selected plants for plant height (cm), branches/plant, root length (cm), dry root yield (kg/ha). The roots were dug out 200 DAS, washed with fresh water, and dried in an electric oven up to 7-8% moisture content.

Statistical analysis: The analysis was carried out using Statistical Software, available online on CCS Haryana Agricultural University, Hisar website (Sheoran et al 1998). The pooled mean data of all the characters over the location were used to make the comparison. Heat susceptibility index (HSI) was calculated for root yield and other quantitative

Table 1. Elite genotypes with source and their morphological marker characters

Elite genotypes	Source	Morphological marker characters
HWS105	CCS HAU, Hisar	Plant type semi-erect, berry colour orange, root texture starchy, high seed yield
HWS108	CCS HAU, Hisar	Plant type erect, berry colour orange, root texture woody, medium seed yield
HWS116	CCS HAU, Hisar	Plant type semi-erect, berry orange, root texture woody, medium seed yield
HWS118	CCS HAU, Hisar	Plant type semi-erect, berry colour orange, root texture woody, high seed yield
HWS119	CCS HAU, Hisar	Plant type erect, berry colour orange, root texture woody, high seed yield
HWS120	CCS HAU, Hisar	Plant type semi-erect, berry colour orange, root texture woody, high seed yield
HWS121	CCS HAU, Hisar	Plant type erect, berry colour orange, root texture woody, high seed yield
HWS128	CCS HAU, Hisar	Plant type erect, berry colour yellow, root texture woody, high seed yield
HWS138	CCS HAU, Hisar	Plant type erect, berry colour red, root texture woody, low seed yield
HWS140	CCS HAU, Hisar	Plant type semi-erect, berry colour red, root texture woody, low seed yield
HWS206	CCS HAU, Hisar	Plant type semi-erect, berry colour red, root texture woody, medium seed yield
HWS219	CCS HAU, Hisar	Plant type semi-erect, berry colour red, root texture woody, low seed yield
HWS224	CCS HAU, Hisar	Plant type semi-erect, berry colour red, root texture woody, low seed yield
HWS229	CCS HAU, Hisar	Plant type semi-erect, berry colour yellow, root texture woody, high seed yield
HWS240	CCS HAU, Hisar	Plant type erect, berry colour red, root texture woody, low seed yield
HWS1320	CCS HAU, Hisar	Plant type semi-erect, berry colour red, root texture woody, low seed yield
HWS1321	CCS HAU, Hisar	Plant type erect, berry colour red, root texture woody, medium seed yield
HWS1333	CCS HAU, Hisar	Plant type semi-erect, berry colour red, root texture woody, medium seed yield
HWS 153	CCS HAU, Hisar	Plant type erect, berry colour orange root texture woody, high seed yield
JA134	Mandsaur, M.P.	Plant type semi-erect, berry colour orange, root texture woody, low seed yield
RAS-16	RAU, Bikaner	Plant type semi-erect, berry colour yellow, root texture woody, medium seed yield
HWS8-18	CCS HAU, Hisar	High in root yield, berry colour yellow orange, medium in plant height, high in Withanolide-A content

traits over high temperature stress (late sown) and non-stress environment (normal sown) (Fisher and Maurer 1978). HSI = [l-YD/YP]/D Where, YD = mean of the genotypes in stress environment. YP = mean of the genotypes under non-stress environment. D = 1-[mean YD of all genotypes/mean YP of all genotypes].

RESULTS AND DISCUSSION

Plant height: The average plant height of both the years was maximum (116.1cm) in HWS1321 followed by HWS116, HWS219, HWS128, HWS8-18, HWS224, HWS229, HWS138, HWS108 and HWS140 (96.3 cm). Above finding were in agreement with the recent studies in terms of variation with earlier researchers (Mishra 2014, Yadav et al 2008, Dubey 2010).

Number of branches/plant: On the basis of average of both the years, the number of branches per plant was maximum in HWS120) followed by HWS119 HWS219, HWS224, HWS1321, HWS140, HWS229, HWS8-18, HWS118, HWS1320 and RAS-16. Similar variation was also obtained with different genotypes (Mishra 2014, Yadav et al 2008, Dubey 2010).

Root length (cm): On the basis of average of both the years, thelongest root length (cm) was observed in HWS 153 (67.5) followed by HWS105, HWS8-18, HWS1320, HWS121, JA134, HWS120, HWS1333, HWS128, HWS116 and HWS108. Mishra (2014), Yadav et al (2008) and Dubey (2010) also evaluated different genotypes of Ashwagandha for root length and reported significant variations.

Root diameter (cm): On the basis of average of both the years, themaximum root diameter (cm) was observed in HWS1333 (3.9 cm), followed by HWS120, HWS206, HWS138, HWS1321, HWS105, HWS118, HWS219, HWS224, HWS229 and HWS240 (2.7 cm).

Root yield (kg/ha): The yield was maximum in HWS105 (433 kg/ha), followed by HWS 153, HWS1333, HWS120, HWS206, HWS8-18, HWS121, HWS1320, HWS118, HWS138 and HWS140 (247.9 kg/ha).

Percent reduction in seed yield under stress: Heat stress imposes challenges for crops and has deleterious effects on the morphology, physiology, and reproductive growth of plants. High-temperature stress at the time of the reproductive stage is becoming a severe limitation for economic yield as the cultivation expands to warmer environments and increase in temperature variability due to climate change (Arya et al 2014, 2020). However, behavior of different genotypes under the heat stress was not uniform; some genotypes were adversely affected while the other genotypes were able to combat the stress. In present investigation, some genotypes exhibited the lower percent reduction in root yield which were JA134 (10.13 %) followed by RAS-16, HWS240, HWS229, HWS 153, HWS224, HWS1321, HWS119, HWS120, HWS108, HWS1320, whereas, some genotypes exhibited high percent reduction in root yield which were HWS8-18 followed by HWS128, HWS140, HWS116, HWS1333, HWS206, HWS219, HWS105, HWS138, HWS121, HWS118.

Heat susceptibility index: Heat susceptibility index (HSI) is also an important tool to identify the heat tolerant genotypes (Suresh et al 2018). In the present investigation, minimum HSI was in JA134 (0.36) and closely followed by RAS-16, HWS240. The other genotypes HWS229, HWS 153, HWS224, HWS1321, HWS119, HWS120 and HWS108 exhibited relatively higher. Therefore, the genotype JA134 and RAS-16 considered heat tolerant and may be utilized in crop improvement programme for the development of heat stress tolerant cultivars. The genotypes, HWS8-18, HWS128, HWS140, HWS116, HWS1333, HWS206, HWS219, HWS105, HWS121, HWS138, HWS1320 and HWS118 were susceptible to heat stress. Research on high temperature tolerance or susceptibility and its association with root yield and other related traits would help in the development of heat tolerant genotypes (Yadav et al 2013). High temperature stress at later stages, may adversely affect photosynthesis, respiration, water relations and membrane stability, and also modulate levels of hormones and primary as well as secondary metabolites (Arya et al 2014). Furthermore, throughout plant ontogeny, enhanced expression of a variety of heat shock proteins, other stress-related proteins, and production of reactive oxygen species (ROS) constitute major plant responses to heat stress (Wahid et al 2007). In order to cope with heat stress, plants implement various mechanisms, including maintenance of membrane stability, scavenging of ROS, production of antioxidants, accumulation and adjustment of compatible solutes, induction of mitogen-activated protein kinase (MAPK) and Ca-dependent protein kinase (CDPK) cascades, and, most prominently, chaperone signaling and transcriptional activation. All these mechanisms, which are regulated at the molecular level, may also be responsible for JA134 (0.36) and RAS-16 (0.39) genotypes to thrive under heat stress.

Correlation analysis: The results of studies on characters association of ashwagandha root yield and contributing traits is presented in. The present study revealed that under normal conditions, root yield was significantly associated with root length and root diameter. Likewise, under stress condition, root yield was significantly associated with root length and root diameter (Table 3). However, under stress

Table 2. Mean performance of root yield and its contributing traits during 2017-18 & 2018-19

Genotype	Plant height (cm)			No. of branches /plant			Root length (cm)			Root diameter (cm)			Root yield (kg/ha)		
	2017-18	2018 -19	Mean	2017 -18	2018-19	Mean	2017-18	2018-19	Mean	2017-18	2018-19	Mean	2017-18	2018-19	Mean
HWS105	110.0	79.2	94.6	4.3	3.7	3.9	59.7	43.6	51.6	2.8	2.8	2.8	506.6	359.4	433.0
HWS108	112.0	80.6	96.3	4.3	3.4	3.8	38.0	27.7	32.9	2.3	2.3	2.3	262.2	189.7	226.0
HWS116	120.0	86.4	103.2	3.0	2.3	2.7	38.3	28.0	33.1	2.2	2.1	2.2	256.2	176.1	216.2
HWS118	105.3	75.8	90.6	4.7	3.6	4.2	35.3	25.8	30.5	2.8	2.7	2.8	293.3	211.1	252.2
HWS119	110.0	79.2	94.6	8.0	6.2	7.1	35.0	25.6	30.3	2.5	2.5	2.5	262.5	192.4	227.4
HWS120	109.7	79.0	94.3	9.3	7.3	8.3	39.7	29.0	34.3	3.6	3.6	3.6	432.0	312.8	372.4
HWS121	101.0	72.7	86.9	3.3	2.6	2.9	40.7	29.7	35.2	2.5	2.5	2.5	308.7	221.8	265.2
HWS128	117.3	84.5	100.9	3.3	2.7	3.0	38.3	28.0	33.2	2.4	2.2	2.3	279.4	187.2	233.3
HWS138	113.3	81.6	97.5	3.7	2.9	3.3	30.3	22.1	26.2	3.2	3.2	3.2	291.2	209.2	250.2
HWS140	112.0	80.6	96.3	5.3	4.2	4.7	36.0	26.3	31.1	2.7	2.6	2.6	294.8	201.0	247.9
HWS206	106.0	76.3	91.2	3.7	2.9	3.3	34.0	24.8	29.4	3.6	3.4	3.5	363.1	253.2	308.1
HWS219	120.0	86.4	103.2	5.7	4.4	5.0	29.7	21.7	25.7	2.9	2.8	2.8	255.5	180.0	217.7
HWS224	115.0	82.8	98.9	5.5	4.3	4.9	28.5	20.8	24.7	2.8	2.8	2.8	235.1	174.8	205.0
HWS229	115.0	82.8	98.9	5.0	3.9	4.5	30.0	21.9	26.0	2.8	2.9	2.8	249.3	190.5	219.9
HWS240	108.3	78.0	93.2	4.0	3.1	3.6	33.7	24.6	29.1	2.6	2.8	2.7	262.5	202.7	232.6
HWS1320	106.7	76.8	91.7	4.7	3.6	4.1	43.0	31.4	37.2	2.4	2.3	2.3	304.4	219.4	261.9
HWS1321	135.0	97.2	116.1	5.5	4.3	4.9	29.0	21.2	25.1	2.9	3.0	2.9	252.3	187.4	219.8
HWS1333	82.5	59.4	71.0	3.0	2.3	2.7	39.0	28.5	33.7	4.0	3.8	3.9	468.0	324.6	396.3
HWS 153	77.5	55.8	66.7	4.0	3.1	3.6	78.0	56.9	67.5	2.0	2.0	2.0	456.3	341.6	399.0
JA134	70.3	62.6	66.5	4.7	3.1	3.9	36.7	32.2	34.4	2.2	2.2	2.2	158.0	142.0	150.0
RAS-16	83.7	65.8	74.8	3.3	4.6	4.0	28.7	33.6	31.1	1.9	1.5	1.7	178.4	159.2	168.8
HWS8-18	110.0	89.2	99.6	4.7	4.1	4.4	38.0	40.4	39.2	2.1	2.4	2.2	376.4	231.8	304.1
Mean	107.0	77.9	93.3	4.7	3.8	4.3	38.3	29.3	34.0	2.7	2.7	2.7	307.0	221.3	266.2
CD (5%)	9.25	3.62		0.42	0.39		3.32	3.15		NA	NA		26.3	23.5	
CV(%)	4.66	3.09		6.22	5.87		7.44	6.87		68.4	60		12.4	11.5	

Table 3. Correlation analysis of ashwagandha root yield and contributing traits

Characters	Environment	Root yield	Plant height	Number of branches/ plant	Root length	Root diameter
Root yield	Normal	1.000	-0.122 NS	0.035 NS	0.674**	0.432*
	Stress	1.000	-0.288 NS	0.039 NS	0.690**	0.429*
Plant height	Normal	-0.122 NS	1.000	0.257 NS	-0.404 NS	0.159 NS
	Stress	-0.288 NS	1.000	0.239 NS	-0.497*	0.142 NS
Number of branches/ plant	Normal	0.035 NS	0.257 NS	1.000	-0.122 NS	0.212 NS
	Stress	0.039 NS	0.239 NS	1.000	-0.153 NS	0.183 NS
Root length	Normal	0.674**	-0.404 NS	-0.122 NS	1.000	-0.230 NS
	Stress	0.690**	-0.497*	-0.153 NS	1.000	-0.312 NS
Root diameter	Normal	0.432*	0.159 NS	0.212 NS	-0.230 NS	1.000
	Stress	0.429*	0.142 NS	0.183 NS	-0.312 NS	1.000

* Significant at 5% probability level
** Significant at 1% probability level
NS = Non-Significant

condition, plant height was also significantly negatively correlated with root length.The earlier findings also revealed the significant association of root yield with root length, root diameter; however, they also reported significant correlation of root yield with plant height and number of branches per plant. In the present study, the plant height and number of branches per plant were not significantly associated with root yield (Yadav et al 2008, Dubey 2010, Mishra 2014). The present study was made to assess the root yield of elite genotypes under normal and heat stress environment for the identification of high yielding genotypes for semi-arid regions. The genotypes JA134 and RAS-16 were identified as heat tolerant. A drastic reduction was noticed in high root yielding genotypes whereas very less reduction was noticed

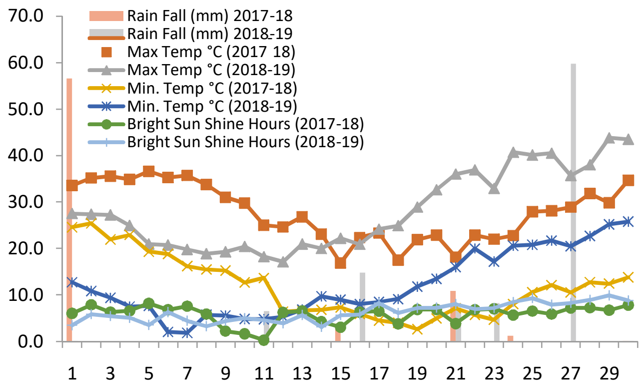

Fig. 1. Weekly weather parameters data recorded at Hisar during cropping season 2017-18 & 2018-19

A. Indian Ginseng growth under normal environmental condition

B. Indian Ginseng growth under stress environmental condition

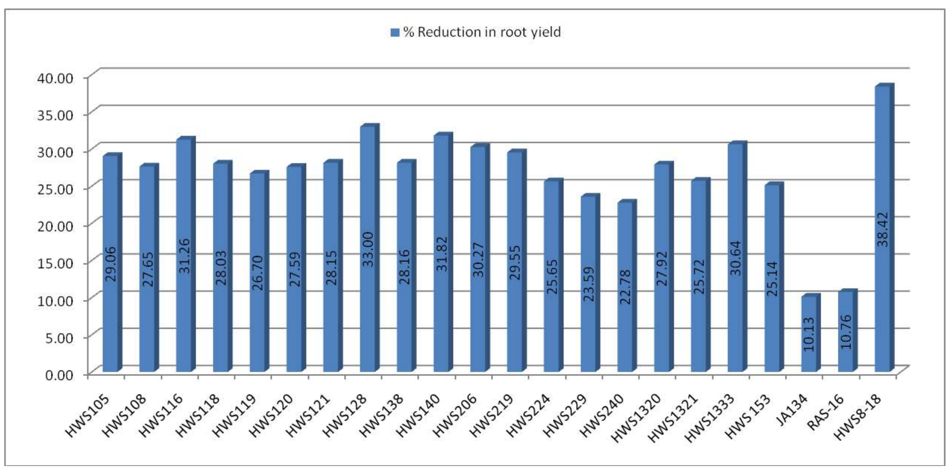

Fig. 2. Percent reduction in root yield in ashwagandha elite genotypes due to heat stress at Hisar

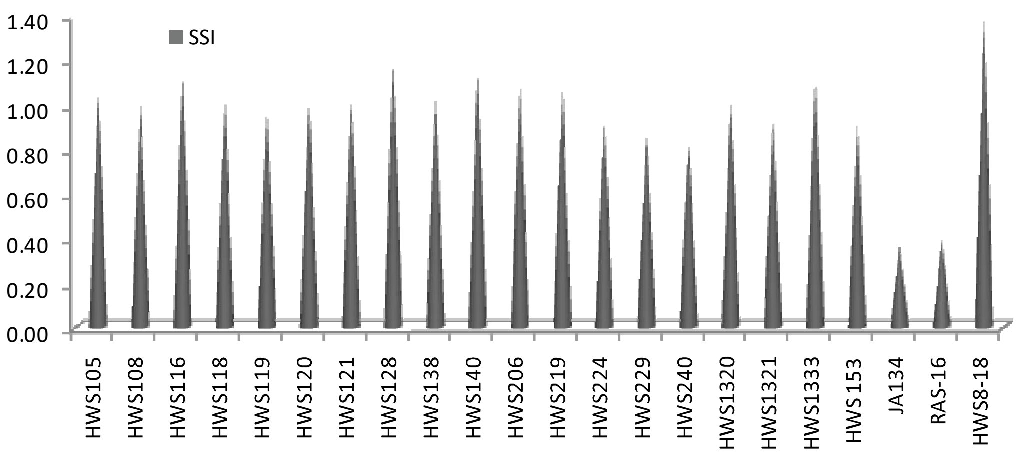

Fig. 3. Stress susceptibility index in seed yield in ashwagandha elite genotypes due to heat stress at Hisar

in poor yielding genotypes. It is concluded from the present study that genotypes HWS 105, HWS 1333, HWS 153 and HWS 120 are suitable for normal as well as heat stress conditions. Although, the percent reductions in root yield under stress in above genotypes varied from 25 to 30%. Even after such a reduction in root yield, they were also top performer in heat stress condition also. The ashwagandha genotypes, JA 134 and RAS-16 were low yielder but exhibited least percent reduction in root yield as well as lowest in HSI. Therefore, breeding among high yielding genotypes (HWS 105 and HWS 1333) and stress tolerant genotypes (JA 134 and RAS-16) may lead to development of transgressive segregants of ashwagandha, having the potential of high root yield as well as heat tolerant characteristics.

CONCLUSION

Best performing genotype for root yield (kg/ha) under both conditions wasHWS105 (433 kg/ha). To improve dry root yield in ashwagandha genotypes and there is scope for the selection of promising genotypes (based on the stress susceptibility index). Under stress condition, HWS 153genotype performed good potential for cultivation. It revealed less reduction in root yield and low in SSI, but before recommendation for commercial cultivation to be tested over time and space.

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Indian Journal of Ecology (2022) 49(3) (SI): 1220-1224
DOI: https://doi.org/10.55362/IJE/2022/3648

Manuscript Number: 3648
NAAS Rating: 5.79

Investigation on Biometric and Engineering Properties of Tapioca

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Abstract: Various biometric, engineering and frictional properties of tapioca (*Manihot esculenta*) were investigated. The plant height, stem girth diameter, tuber depth, tuber spread and weight of tuber soil clump were determined as 2390 mm, 31.02 mm, 250.3 mm, 501.3 mm and 15.46 kg, respectively. The major diameter, intermediate diameter, minor diameter, geometric mean diameter and arithmetic mean diameter of tapioca roots were 52.76 mm, 49.60 mm, 33.36 mm, 42.50 mm and 45.24 mm. The sphericity and surface area were 0.81 per cent and 5869.73 mm^2, respectively. The tuber volume and bulk density observed was 425.8 cm^3 and 0.57 g/cm^3, respectively. The angle of repose of tapioca roots was 34.62° and the coefficient of friction on three different material surfaces varied from 0.55 to 0.79 on wood, 0.41 to 0.67 on galvanized sheet and 0.30 to 0.55 on stainless steel. The moisture content varied from 74.22 to 68.20 per cent (w.b.).

Keywords: Tapioca, tuber, Biometric properties, Stem girth diameter, Harvester

Roots and tubers play an important role in the global food chain, particularly in the developing countries. Tropical root and tuber crops consist of both dicots like sweet potato (*Ipomoea batatas*), cassava/tapioca (*Manihot esculenta*), monocots like yams (*Dioscorea spp.*), edible aroids like taro (*Colocasia esculenta*) and elephant foot yam (*Amorphophallus spp.*). Tapioca is the most significant tuber crop in the tropical region, and it ranks fourth, after rice, sugarcane, and maize. It is the most important source of calories in the human diet and major carbohydrate food for around 500 million people throughout the world (Oriola and Raji 2014). Globally, tapioca is grown in an area of 18.51 million ha with a production of 276.65 million tonnes. India acquires significance in the global tapioca scenario due to highest productivity of 27.92 t/ha. It is cultivated in an area of 0.26 million ha in country with a production of 7.2 million tonnes. Kerala state currently contributes about 31 per cent of total production in the country (Anonymous 2018). Tapioca is a perennial tuber crop which is propagated by stem cutting and the root grows into a long and tapered tuber with firm homogeneous flesh encased in a detachable bark, rough and brown on the outside. The tuber shape tapers from top to bottom divided into three sections: the periderm, the cortex and the central portion (Nwachukwu and Simonyan 2015).

Tapioca grows and produces best under warm humid tropical conditions where rainfall is well distributed and fairly abundant and roots are ready to harvest 9-10 months after planting (Anonymous 2016). Harvesting is a major constraint for cultivation of tapioca due to bigger size and goes deeper into the soil. Manual harvesting is a time-consuming activity, stressful and involves drudgery, especially during the dry season. In designing a machine for digging and separating of tuber, physical properties such as weight, mean and major diameter, shape factor, depth and coefficient of friction on different surfaces are important parameters. In recent years, many researchers have reported physical and mechanical properties of various crops relevant to different machines. But there are few studies on the physical properties of tapioca roots for mechanical harvesting. The determination of physical properties of agricultural materials is important to design machines and processes for harvesting, handling and storage of these materials. This research is focused on the objective to study the biometric and engineering properties of tapioca roots. Moreover, the results from this research will be useful for further research in developing a tractor operated tapioca harvester.

MATERIAL AND METHODS

The biometric and engineering properties relevant to the research were measured for tapioca root. The biometric properties are number of leaves, plant height, stem girth diameter, number of roots per plant, tuber depth, tuber spread, weight of tuber soil clump, tuber weight, plant density, plant spacing and engineering properties includes both physical and frictional properties of tapioca *viz.,* size, sphericity, surface area, aspect ratio, tuber volume, bulk density, angle of repose and coefficient of friction.

Biometric properties: Biometric properties of tapioca root are important for the design of soil engaging components of tuber harvester. These properties were measured at the time of harvest using standard test procedure.

Number of leaves: The crop canopy is indicated by number of leaves on the plant. Twenty beds of 10 m length were randomly selected and number of leaves was counted.

Plant height: The height of the plant was the deciding factor for design of throat and total length of soil separator unit for proper soil separation. Twenty five plants were selected randomly and plant height was measured using measuring tape and the mean value was determined.

Stem girth diameter: Crop stem girth diameter is an important parameter which influences the design of crop handling unit of the tuber harvester. Twenty five plants were randomly selected and stem girth diameter was measured using vernier caliper with 0.01 mm least count.

Number of roots per plant: The total number of roots per plant influences the volume of crop to be handled. The number of roots was counted from twenty five harvested hills selected at random.

Tuber depth: The volume of soil to be handled by digging unit of the harvester was indicated by tuber depth. Twenty five plants were selected randomly and the depth of tuber was measured using a 30 cm steel rule and flat plate. Vertical soil section was first cut along the plant to expose the tuber of a standing plant. A flat plate was kept on the level ground and a scale was placed vertically to the soil up to the bottom of tuber root (Basavaraj and Jayan, 2020).

Tuber spread: The spread of tuber in soil lateral and vertical directions varied with respect to the plant variety (Fig. 1). Tuber spread affects the design of digging unit. The spread of twenty five clumps were selected at random and measured using a scale by digging the soil adjacent to the plant on the raised bed.

Weight of tuber soil clump: Soil is adhered around the tuber when it was dug out and hence the complete weight was measured. The tuber weight without soil was weighed separately and the difference in weight was recorded as weight of the soil. The overall weight of tuber soil clump determines the material handling capacity of the machine.

Plant density: The plant density is an important parameter in determining the volume of crop handled by the machine per unit width of blade per unit time. Average value of plant density in one square meter area at ten different locations was measured randomly.

Engineering properties of tapioca: The determination of some engineering properties of tapioca roots was carried out for designing the tuber harvester. 25 samples of tapioca roots were selected randomly and the engineering properties *viz.*, size, sphericity, surface area, aspect ratio, bulk volume and bulk density were determined according to established standards and procedure.

Determination of moisture content of samples: Moisture content of tuber is an important parameter which has direct impact on harvesting and quality of the tuber. The moisture content of randomly selected and cleaned tubers was measured by gravimetric method. The cleaned tubers were sliced transversely with a knife. The moisture content was determined by dehydrating the samples at 105 ºC for 24 h in a drying oven. The moisture content was calculated using the formula given by Jahanbakhshi et al (2018).

$$MC_{wb} = \frac{M_w - M_d}{M_w} \times 100$$

where, MC_{wb} is the moisture content of tapioca root on wet basis (%), M_w is the mass of tapioca root before drying (g), M_d is the mass of tapioca root after drying (g).

Size: The root size in terms of the major diameter (a), intermediate diameter (b) and minor diameter (c) and length (d) of the roots were measured using a digital caliper with the precision of 0.01 mm (Fig. 2).

The geometric mean diameter, arithmetic mean diameter and aspect ratio for 25 tapioca roots were calculated using the formula given by Bahnasawy (2007) and Chainarong et al (2020).

$$GMD = (a \times b \times c)^{1/3}$$

$$AMD = \frac{(a \times b \times c)}{3}$$

$$Ar = b/a$$

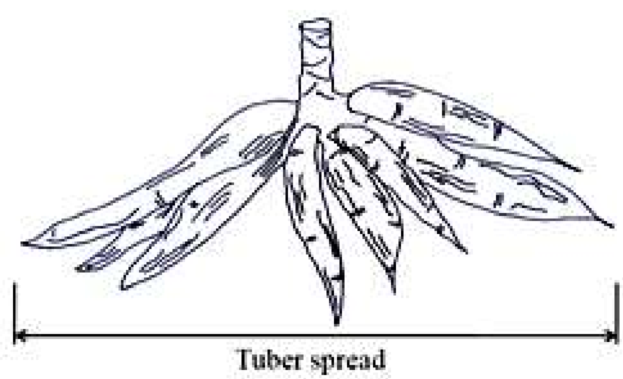

Fig. 1. Schematic diagram of tuber spread measurement of tapioca root

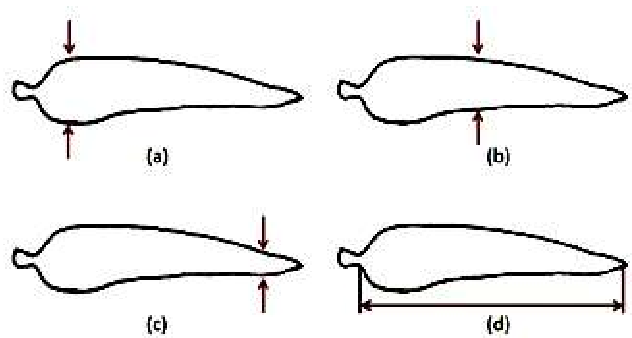

Fig. 2. Size measurement of Tapioca root

where, GMD is geometric mean diameter (mm), AMD is arithmetic mean diameter (mm), a is major diameter (mm), b is intermediate diameter (mm), c is minor diameter (mm), Ar is Aspect ratio.

Sphericity and surface area: The sphericity and surface area of tapioca roots was determined by using the formula given by Basavaraj and Jayan (2020).

$$\text{Sphericity} = \frac{GMD}{a}$$

$$S_a = \pi \times GMD^2$$

where, GMD is geometric mean diameter, S_a is surface area (mm^2)

Tuber volume: The tuber volume of tapioca roots was determined experimentally using water displacement method. The sample was immersed in a measuring cylinder containing known volume of water, thus leading to an increase in the volume of water. The difference between the final level of water in the measuring cylinder and the initial level of water was recorded as the volume of the tuber. This was done for 25 samples.

Bulk density: The bulk density of tapioca roots was determined by weighing the tubers packed in a container of known weight and volume. The tubers were placed in such a way that it filled the container to the brim and then it was weighed using the electronic weighing balance. The volume of the container was determined. The bulk density of the tapioca roots was calculated by using the formula given below.

$$\rho b = \frac{M_b}{V_c}$$

where, ρ_b is bulk density of the tubers (g/cm^3), M_b is mass of the tubers (g), V_c is volume of the container (cm^3).

Frictional Properties of Tapioca

Angle of repose: The angle of repose is an angle made by tapioca roots with the horizontal surface when heaped from a known height. A bag containing 30 kg of tapioca roots was heaped over a horizontal surface. The slant height of the heap was determined and radius of the heap was calculated from the circumference of the heap. The angle of repose was calculated by using the formula given by Basavaraj and Jayan (2020).

$$\mu = \frac{F}{N}$$

where, θ is Angle of repose (deg), h is height of the heap of tapioca roots (mm) and l is bottom diameter of heap formed by the tapioca roots (mm).

Coefficient of friction: The coefficient of friction apparatus consists of a horizontal plane and a pan to add weights. The experiment was determined on three test surfaces namely stainless steel, galvanized sheet and wood. The tapioca roots were placed parallel to the direction of motion and the weights were added in the pan and at the instant at which the pan weight exceeds tuber weight; tuber starts to slide movement. The force at which tuber begin to slide was observed and repeated three times for each material. The coefficient of friction was calculated by using the equation given by Chowdareddy and Dronachari (2014).

$$\theta = \tan^{-1}\left(\frac{h}{1}\right)$$

where, μ is Coefficient of friction, F is Frictional force (force applied) and N is Normal force (weight of the tuber).

RESULTS AND DISCUSSION

Crop parameters such as biometric, engineering and frictional properties were studied for the tapioca roots. The biometric properties include number of leaves, plant height, stem girth diameter, number of roots per plant, tuber depth, tuber spread, weight of tuber soil clump, tuber weight, plant density, plant spacing. The data related to these parameters were used in the design of functional components of the tuber harvester.

The number of leaves per plant varied from 438 to 346 for tapioca. The plant height of tapioca ranged from 2480 to 2280 mm and stem girth diameter varied from 36.50 to 24.00 mm. The number of roots per plant is an important parameter as it determines the volume of crop to be handled by the machine. The number of roots per plant ranged from 14 to 12. The depth of tuber in soil varied from 270 to 230 mm with an average value of 250.30 mm. The tuber spread of tapioca plant ranged from 546 to 458 mm. The weight of tuber soil clump is an important parameter which determines the total volume of crop to be handled by the machine. The weight of tuber soil clump ranged from 16.48 to 14.53 kg whereas, the tuber weight varied from 10.40 to 7.20 kg. The plant density of

Table 1. Biometric observations of tapioca crop

Parameter	Range	Mean
No. of leaves per plant	438-346	392
Plant height, mm	2480-2280	2390
Stem girth diameter, mm	36.50-24.00	31.02
No. of roots per plant	14-12	13
Tuber depth, mm	270-230	250.30
Tuber spread, mm	546-458	501.30
Weight of tuber soil clump, kg	16.48-14.53	15.46
Tuber weight, kg	10.40-7.20	8.81
Plant density, no. of plants/m^2	2.00	2.00
Plant to plant distance, mm	1200-800	950
Row to row distance, mm	1600-1400	1460

Table 2. Engineering properties of tapioca roots

Parameters	Unit	Minimum	Maximum	Mean	Standard deviation
Diameter					
Major diameter (a)	mm	35.73	71.68	52.76	10.68
Intermediate diameter (b)	mm	29.69	69.99	49.60	10.42
Minor diameter (c)	mm	17.50	50.48	33.36	8.10
Length (d)	mm	110.00	420.00	256.60	86.97
Geometric mean diameter	mm	25.63	58.60	42.50	8.13
Arithmetic mean diameter	mm	27.64	61.70	45.24	8.64
Aspect ratio		0.69	1.48	0.95	0.16
Sphericity	%	0.69	1.01	0.81	0.08
Surface area	mm^2	2061.86	10784.24	5869.73	2232.94
Tuber weight	g	174.00	1075.50	464.37	225.91
Tuber volume	cm^3	150	985	425.8	210.59
Bulk density	g/cm^3	0.55	0.58	0.57	0.01

Table 3. Frictional properties of tapioca roots

Parameters	Unit (°)	Minimum	Maximum	Mean	Standard deviation
Angle of repose		33.35	37.72	34.62	1.88
Coefficient of friction					
Wood		0.55	0.79	0.68	0.09
Galvanized sheet		0.41	0.67	0.52	0.09
Stainless steel		0.30	0.55	0.44	0.07

tapioca crop was found to be 2 numbers per square meter. Plant to plant spacing of tapioca crop varied from 1200 to 800 mm whereas, row to row spacing varied from 1600 to 1400 mm. The moisture content of tuber is an important parameter which has direct impact on harvesting and quality of the tuber. The moisture content varied from 74.22 to 68.20 per cent (w.b.). The engineering properties of tapioca roots *viz*., size, sphericity, surface area, aspect ratio, bulk volume and bulk density are presented in Table 2.

The major, intermediate and minor diameter of tapioca roots was 52.76, 49.60 and 33.36 mm. The length of the tapioca roots varied from 110 to 420 mm. Accordingly, geometric mean diameter, arithmetic mean diameter and aspect ratio was found out as 42.50, 45.24 mm and 0.95. Sphericity and surface area ranged from 0.69 to 1.01 and 2061.86 to 10784.24 mm^2. Sphericity values of most agricultural produce have been reported to range between 0.32 and 1.00 and the more regular an object is, the lower the sphericity (Basavaraj and Jayan 2020). The average tuber volume and bulk density were found out as 425.8 cm^3 and 0.57 g/cm^3 respectively.

The major frictional properties of tapioca roots affecting the tuber harvester *viz.,* angle of repose and coefficient of friction were determined. The range of angle of repose for tapioca roots was 33.35 to 37.72° with an average of 34.62°. The angle of repose is the determining factor in the design of soil separation unit. The coefficient of friction of tapioca roots for wood, galvanized sheet and stainless steel surface varied from 0.55 to 0.79, 0.41 to 0.67 and 0.30 to 0.55, respectively. The average coefficient of friction for wood, galvanized sheet and stainless steel surface were 0.68, 0.52 and 0.44, respectively.

CONCLUSION

In the present research, biometric parameters of tapioca crop such as number of leaves, plant height, stem girth diameter, number of roots per plant, tuber depth, tuber spread, weight of tuber soil clump, tuber weight, plant density and plant spacing were studied which influence the design of tuber harvester. Engineering and frictional properties of tapioca roots such as diameter (major, intermediate and minor), length, geometric mean, arithmetic mean, aspect ratio, sphericity, surface area, tuber weight, tuber volume, bulk density, angle of repose and coefficient of friction were studied which plays an important role in selecting the proper design components of the harvester.

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Received 16 May, 2022; Accepted 30 June, 2022

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Indian Journal of Ecology (2022) 49(3) (Supplementary Issue)

Indian Journal of Ecology

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Date of Publication 30.06.2022