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Threatened and Near Threatened Underutilized Edible Fruit Species of Southern India for Food Security and Diversifying Agroecology

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Abstract: Southern India (SI) is bestowed with several threatened and near threatened (TNT) underutilized edible fruit species (UEFS) that contributes to food and nutritional security, particularly to the indigenous people. Unfortunately, information related to these natural products is fragmentary and least researched. The PRISMA Protocol was used to conduct a systematic review of the TNT-UEFS of the SI. The study confirmed that, of the total of 69 species of TNT-UEFS recorded, most of the species were reported to have medicinal, economical, and many other values, which need instant sustainable initiatives for conservation, consumption and cultivation. Among these species, 10 (14.5 %) were near threatened (NT), and 59 (85.5 %) were threatened. According to the IUCN Red List, the threatened species were further divided into three categories: Vulnerable (31 species), Endangered (20 species), and Critically Endangered (8 species). The provision of various ecosystem services is aided by integrating native and naturalised TNT-UEFS in various ecosystem restoration efforts through afforestation and reforestation. Consecutively, it helps India meet its commitment to the Sustainable Development Goals (SDGs) and neutralise land degradation by 2030. Hence, the study will provide baseline information for future research and be useful for policymakers to develop region-specific, scientific, and sustainable policies for SI.

Keywords: IUCN Threatened list, Wild fruits, Food security, Agroecosystem, Restoration ecology

Southern India (SI), also known as Peninsular India or South India, includes mainly five Indian states such as Andhra Pradesh, Karnataka, Kerala, Tamil Nadu and Telangana. SI covers around one fifth of India's land area and population (Census of India 2011). This region is diverse with two mountain ranges, the Western and Eastern Ghats and drained by several perennial rivers like Bharathappuzha, Godavari, Kaveri, Krishna, Tungabhadra and many more (Pullaiah and Rao 2002). Generally, climate of the SI is tropical and receiving monsoon rainfall of 400 to 1700 mm annually. The temperature normally ranges from 10° to 15°C during winter and 25° to 32°C during summer (Renuka 2020). SI still fails to address its complete food and nutritional security despite markedly sustained growth in per-capita income and economy. The average operational land holdings in all the states of SI were markedly reducing (Agriculture Census Division 2019). Most of the farmers are in the marginal and small categories, with an average land holding of ≤ 2 hectare, posing challenges to use of mechanization and expensive inputs that are economically non-viable. Most of the SI practices rain-fed agriculture with supplementary irrigation. Crops like jowar, cotton, sugarcane, bajra, pulses and oilseeds are predominantly grown in the semi-arid region with black cotton soils (Agriculture Census Division 2019). Arecanut, banana, paddy and sugarcane are cultivated in the sub-humid and humid region. Though, SI is blessed with an environment and resources favourable for agricultural practices but fragmentation of land, land degradation, urbanization and other anthropogenic activities result in farmers' reluctance to achieve food and nutritional security.

According to the state of food security and nutrition in the world, 2020 report India is still suffering from hunger and malnutrition though it holds the distinction of being the world's second-largest producer of fruits. In the food security index-2020, India ranked 71 out of 113 major countries. Though there is a remarkable advance in science and technology, we still fail to meet the food demand of a growing population for adequate, nutritious, safe and sustainable food. Nowadays,

soil degradation is becoming a global challenge as it poses a high risk on land productivity, food and livelihood security. The worst impact of soil degradation includes poverty, malnutrition, disease, forced migration, increased conflicts and cultural damage. Some parts of Eastern and Western Ghats are still pristine and rich in floral biodiversity with a high occurrence of UEFS. Among these UEFS, species like *Eugenia argentea*, *Garcinia imberti*, *Madhuca insignis*, *Myristica fragrans*, *Syzygium travancoricum*, etc., were reported to be threatened in the IUCN Red list. These are native and naturalized, unique and underutilized rare minor fruits that are collected from the wild and consumed mostly by the native population during different seasons (Suresh et al 2014). UEFS are the most important component in agriculture, forestry and other land use (AFOLU) systems, contributing to dietary needs, food security, livelihood and diverse ecosystem services. These are rich sources of antioxidants, fibers, minerals, polyphenols, and vitamins; consumption of these fruits lowers the risk of various diseases and illnesses while also enhancing human health and nutrition (Suresh et al 2014, Shankar et al 2020). It has the potential to play a significant role in eliminating hunger and malnutrition as well as eradicating poverty. These fruit species integrated LUS also helpful in the conservation and utilization of indigenous or underutilized fruit resources, reducing pressures on remaining forests and effectively tackling forests resource overexploitation. Most of these UEFS are native, easy to grow with less cultural and technical inputs and hardy in nature. Some of these UEFS are integrated with the farming systems for large-scale plantation and other ecosystem restoration programs (Suresh et al 2014). Unfortunately, due to a lack of awareness, discontinuity in traditional culture and knowledge, intensive agriculture, limited research, insufficient policy support, western influence, and urbanisation, diminished the utilisation of local UEFS (Shankar et al 2020). Even though, they have many advantages but received less attention on research or extension and they have been largely neglected. Hence, it is an alarming sign to conserve the country's biodiversity and maintain ecological balance. This systematic review aims to survey, summarize and annotate the published information related to TNT-UEFS of SI to assess potentiality, conservation, cultivation and sustainable utilization, particularly to diversify agroecology and improve the socio-economical status of SI community.

MATERIAL AND METHODS

Study location and protocol: This study implements the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) protocol (Moher et al 2009, Liu et al 2021) to review the published information pertaining to the angiospermic native and naturalized TNT-UEFS of SI (Fig. 1). Study provides implications for the cultivation assisted conservation, institutional and policy support, future research etc., for improving farmers' income and diversifying agroecology. A systematic review was executed using the flow diagram (Fig. 2, adapted from Moher et al 2009). A precise explanation and categorization of fruits may be challenging due to their complexity and it dependents on several aspects like availability, awareness, consumption, distribution, exploitation, knowledge, popularity, production, and use (Suresh et al 2014). The definition of UEFS excludes species that fall under widespread to moderate commercial importance category and species that have been widely naturalized, cultivated and well known in SI. However, this review includes only a lesser known, lesser distributed, underutilized, undomesticated and wild edible fruit species from forests, agroforestry systems, gardens, vacant and other marginal lands.

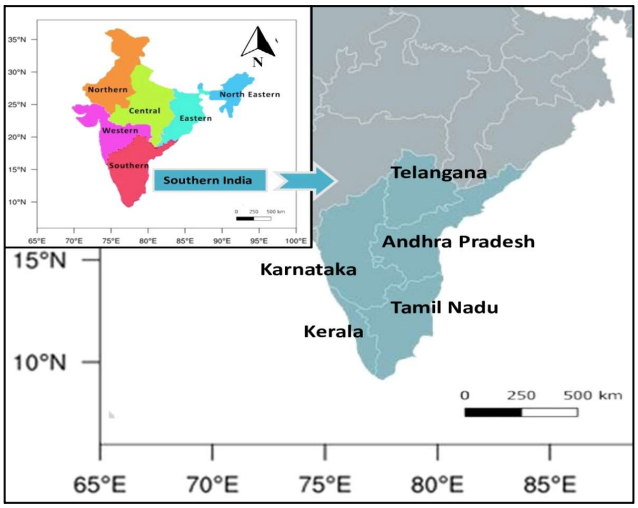

Fig. 1. Outline map of the study area

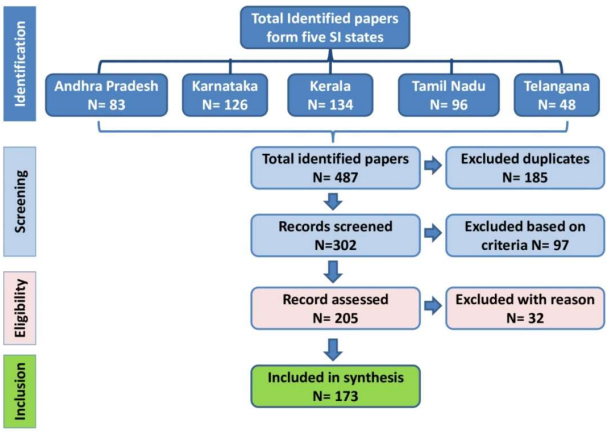

Fig. 2. Flow diagram of TNT-UEFS of SI

Survey and analysis: Analysis was focused on angiospermic native and naturalized TNT-UEFS of SI and reviewed the published articles, book chapters, and scientific reports to analyze the ethno medicinal/ traditional/ indigenous use, growth pattern and seasonal availability of TUEFS in SI. The search keywords considered are forest fruits, wild edible fruits, underutilized fruits and lesser-known fruits in the search engines like Google, Google Scholar, J-gate, Scopus and Web of Science, for all time. A total of 302 articles were screened which includes the UEFS conservation, documentation, ecology, economics and ethnobotany in topics of agriculture, botany, environment, forestry and climate change studies, food science, horticulture, medicinal and aromatic plants, social science, and urban studies. On the other hand, articles related to nutrient composition, evolution, genetics, chemistry, pharmacology, toxicology, immunology, medicine, etc., of UEFS were screened further and considered as an accessory literature. Finally, 173 articles were included in the synthesis (Fig. 2). Similarly, for TNT-UEFS, completely threatened and Near Threatened (NT) species were considered, whereas Non-threatened category species were excluded. The recorded threatened species were divided into three categories as per the IUCN conservation status namely Vulnerable (VU), Endangered (EN) and Critically Endangered (CR) and verified from the IUCN website https://www.iucnredlist.org/search. The published scientific names of the TNT-UEFS were verified from online sources like http://www.the plantlist.org (Plantlist) and http://www.ipni.org (International Plant Names Index). The information from the literature found in the mentioned sources was used to prepare a comprehensive list of species with scientific names, common names, family, life form, origin, flowering and fruiting time, state-wise distribution, nutritional status, uses, products, other significance, IUCN status and sources (Table 2). An Excel spread sheet and the IBM SPSS version 2020 were used to analyze the recorded data using descriptive statistics.

RESULTS AND DISCUSSION

Diversity of the UEFS of SI: Analysis showed a repository of 394 fruit species belonging to 216 genera in 83 families. Further, the habit-wise analysis has revealed that around 224 species (57 %) were trees, 80 species (20 %) were shrubs, 31 species (8 %) were herbs and 58 species (15 %) were climbers. Among these fruit species, 359 species (91 %) were native and 34 species (9 %) were naturalized to SI. Study confirmed that, of the total 394 species of UEFS recorded, most of the species reported to have medicinal, economic and many other values, which need immediate sustainable initiatives for conservation, consumption and cultivation. Around, 7000 species of UEFS were documented worldwide (Grivetti and Ogle 2000). Out of which, 1200 species were identified in Africa, 1000 species in America and 800 species in Asia (Verheij et al 1991). Out of the 800 documented species in Asia, around 394 species (present study) were prevalent in the SI.

Diversity of the TNT-UEFS of SI: From the recorded 394 species of UEFS, 69 species were categorized into TNT-UEFS. Among these species, 59 species (85.5 %) were threatened and 10 species (14.5 %) were NT (Fig. 3). The threatened species were further divided into three categories

Table 1. Constraints and solutions of TNT-UEFS of SI

Criteria	Constraints	Solutions
Lesser-known	Poor availability and utilization.	Awareness, research and extension activities are vital.
Lesser-knowledge	Lack of cultivation practices, economical, nutritional and medicinal knowledge.	Linking practitioner, researcher and policymaker. Training and capacity building.
Less researched	Lacking of mass cultivation, nutrition, pest and disease management.	Research on nutrition, preference and genetic improvement are vital
Less technology	Un availability of quality planting materials, varieties, production, post harvest technologies.	Need of certification, grading, processing, value addition, packaging and adequate storage.
Less popular	Long gestation period, poor yield, less economic, no value addition and awareness.	These issues can be dealt with the application of scientific interventions and policy support.
Less utilized/exploited	Less market, lower commercial exploitation and perishable. Low consumer preference, improper economics, policy and institutional arrangements.	Low preference can be optimized by natural ripening and genetic improvement. Processed into value added products by using traditional and advanced techniques.
Less production	Poor yield and quality	Application of scientific and technological interventions, and genetic improvement.
Less distribution	Confined, storage and processing constraints	Creating awareness, research and extension activities through training and capacity building.
Less conservation	Genetic erosion, over exploitation and habitat loss.	Linking society, economics and ecology, and cultivation assisted conservation are needed.

Table 2. General account on reported TNT-UEFS, significance, IUCN status and references

Scientific name and family	Common name	L F and origin	Flowering - fruiting	State	Phytochemicals and utility	IUCN status	References
Aegle marmelos (L.) Correa.; Rutaceae	Bael	Tree; Native	March - May	KL, KA, TN, AP, TS	Aeglemarmelosine, beta sitosterol; Digestive, anti-diarrheal	NT	Vizhi and Lohidas 2020
Aglaia perviridis Hiern.; Meliaceae	Cheruchokla	Tree; Native	April - Sep	KL	Sesquiterpenoid, diterpenoid; Nutrient dense pulp is used	VU	Med 2017
Ampelocissus latifolia (Roxb.) Planch.; Vitaceae	Kaadu drakshi	Climber; Native	Sep - June	KA	alkaloids, flavonoids, reducing sugars and gums; folk medicine	VU	Kalaivani and Sumathi 2018
Antidesma menasu (Tul.) Miq. ex Muell.-Arg.; Euphorbiaceae	Pali eechi	Tree; Native	May - Sep	KL	Fleshy and sour taste pericarps are separated from seeds and consumed	VU	Med 2017
Aphananthe cuspidata (Bl.) Planch.; Ulmaceae	Kodithani	Tree; Native	Feb - May	KA	Phenols, lactones, flavonoid, and ascorbic acid; folk medicine	VU	Gunaga et al 2015
Aporosa acuminata Thw.; Euphorbiaceae	Vetti	Tree; Native	Jan -June	KL	Rich in minerals; folk medicine	VU	Med 2017
Aporosa lindleyana (Wight) Baill; Euphorbiaceae	Lindley's Aporosa	Tree; Native	Jan - June	KL, KA	Antioxidants and flavonoids; antimicrobial and antifouling	VU	Sathish et al 2017
Artocarpus hirsutus Lam.; Moraceae	Hebbalasu	Tree; Native	Dec - Mar	KA	Thiamine, riboflavin and niacin; reduces constipation	VU	Gangaprasad et al 2019
Baccaurea courtallensis (Wight) Mull. Arg.; Phyllanthaceae	Mootikaya	Tree; Native	Jan - June	KL, KA	Tannin, terpenoid and phenols; diarrhoea, dysentery and skin infection	NT	Narayanan et al 2011
Borassus flabellifer L.; Arecaceae	Palmyra palm	Tree; Native	March -Sep	KL, TS, AP	Anti-oxidant Anti-inflammatory and antibacterial	EN	Narayanan et al 2011
Buchanania lanceolata Wight; Anacardiaceae	Kulamavu	Tree; Native	Nov -March	KL, TS, AP	Flavanoids, tannins and sterols; Seeds are eaten by roasting	VU	Raj et al 2020
Canthium dicoccum (Gaertn.) Merr.; Rubiaceae	Ceylon boxwood	Tree; Native	Nov -March	KL, KA, TN	Antidiabetic, nephroprotective, antifungal and antibacterial property	VU	Sathish et al 2017
Carissa carandas; Apocynaceae	Kalakai	Shrub; Native	March-July	KL,KA, TN, TS, AP	Vitamins and minerals; heart disease and digestive trouble	VU	Vizhi and Lohidas 2020
Cassia senna ; Fabaceae	Nilaavaarai	Tree; Native	March - April	TN	Rhein,aloe-emodin, kaempferol; folk medicine	EN	Sivasankari et al 2014
Citrus latipes (Swingle) T. Tanaka; Rutaceae		Shrub; Naturalized	June -Jan	KL	Flavonoids, phenolics, limonoids; folk medice and cosmetics	NT	Singh 2017
Citrus medica; Rutaceae	Lungamu	Shrub; Native	Mar-Feb	TS, AP	Fruits are stomachic and have potent anti-scorbutic activity	NT	Pendem saidulu et al 2015
Corallocarpus epigaeus (Rottl.) C.B.Clark; Cucurbitaceae	Haavina kodda	Climber; Native	Dec -Mar	KA	Amino acids, vitamins; laxative, hypoglycemic, anti-inflammatory and analgesic	EN	Narayan 2016
Cycas circinalis L.; Cycadaceae	Sago-palm	Palm; Native	Dec -Feb	KL	Neurotoxin, cycasin; high doses are Carcinogenic	EN	Haridas and Kunhikannan 2020
Dimocarpus longan Lour.; Sapindaceae	Dragon's eye	Tree; Naturalized	March -Aug	KL, KA	Glucopyranose, gallic acid and ellagic acid; antioxidant	NT	Singh 2017
Diospyros candolleana Wight; Ebenaceae	Karemara	Tree; Native	April -Mar	KA	Minerals, carotene and vitamins; anti-inflammatory and antipyretic	VU	Gowthami et al 2021
Diospyros discolor Willd.; Ebenaceae	Velvet apple	Tree; Native	April -July	KL	Alkaloids, flavonoids, tannin, terpenoid and essential oils	VU	Maridass et al 2008

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Diospyros ferrea (Willd.) Bakh; Ebenaceae	Philippine Ebony	Tree; Native	Feb -May	KA	alkaloids, flavonoids, terpenoids and essential oils; Folk medicine	EN	Ved et al 2016
Diospyros malabarica (Desr.) Kostel.; Ebenaceae	Toopura	Tree; Native	Feb -Nov	KA, AP	diarrhea, hemorrhoids, diabetes, skin diseases, fever	EN	Gowthami et al 2021
Diospyros melanoxylon Roxb.; Ebenaceae	Tendu	Tree; Native	Sep -Dec	KL, KA	Tannin, alkaloids, glycosides, proteins, phenolics; stomach, skin	NT	Kumawat et al 2019
Diospyros vera (Lour.) A.chev; Ebenaceae	Gaura koli	Tree; Native	June -july	TS, AP	Rich in sugars, fat, minerals and vitamin; Folk medicine	EN	Pendem saidulu et al 2015
Dysoxylum binectariferum Hook. f. ex Bedd.; Meliaceae	Kempu Devadaru	Tree; Native	Mar -Jan	KA	Minerals and vitamins; Treatment of Osteomylitis, cancer	EN	Arya et al 2017
Dysoxylum malabaricum Bedd. ex C. DC.; Meliaceae	Bili Agilu	Tree; Native	Feb -June	KA, TS	Flavopiridol; Medicinal properties and immuno- modulatory properties	EN	Bodare et al 2013
Ehretia microphylla; Boraginaceae	Vetrilai	Shrub; Native	March- May	TN, TS	Vitamins and minerals rich; Cough, diarrhea and dysentery	NT	Vizhi and Lohidas 2020
Elaeocarpus munronii (Wl.) Masters; Elaeocarpaceae	Nari bikki	Tree; Native	Sep -April	KL, KA	Flavonoids, Phenols, Quinones, Triterpinoids; antidiabetic property	NT	Devi et al 2018
Embelia tsjeriam-cottam (Roem. & Schult.)A.DC.; Myrsinaceae	Malabar Embelia	Shrub; Native	Feb -Mar	KA	Embelin; antibacterial, antitubercular, antidiabetic and anti-inflammatory properties	VU	Bohara and Nagalakshmi 2021
Eugenia argentea Bedd.; Myrtaceae	-	Shrub; Native	Jan -March	KL	Essesntial oils, caryophyllanes	CE	Raj et al 2020
Eugenia indica (Wight) Chithra; Myrtaceae	Nara	Shrub; Native	March -May	KL	Folk medicine	EN	Remesh et al 2016
Euphorbia hirta L.; Euphorbiaceae	Spurge	Herb; Native	Throughout the year	TN, TS, AP	Beta carotene, vitamin; Asthma, hypertension, dengue and malaria	VU	Sasi et al 2011
Garcinia gummi-gutta (L.) Robs.; Clusiaceae	Malabar tamarind.	Tree; Native	Feb -Aug	KL, KA, TN	Tannin, pectin and fat; Rheumatism, obesity and ulcers	VU	Sathish et al 2017
Garcinia imberti Bourd.; Clusiaceae	Manjakanji	Tree; Native	Feb -Sep	KL	Alkaloids, flavanoids, glycosides, phenols, terpenoids; antioxidant	CE	Kandhasamy et al 2021
Garcinia indica (Thouars) Choisy.; Clusiaceae	Kokum butter	Tree; Native	Sep -May	KL, KA, TS	Benzophenones and garcinol; medicinal and nutraceutical	VU	Ananthakrishnan and Kumar 2016
Garcinia morella (Gaertn.) Desr.; Clusiaceae	Indian gamboge	Tree; Native	Nov -July	KL, KA	Benzophenones, triterpenoids; antimicrobial and anticancer	VU	Murthy et al 2020
Garcinia travancorica Bedd.; Clusiaceae	Mangosteen	Tree; Native	May -Sep	KL	Biflavonoid fukugiside, superoxide; Antitumor	VU	Aravind and Kumar 2016
Gymnema sylvestre (Retz.) Schult; Apocynaceae	Gymnema	Climber; Native	July -Jan	KA	Saponins; diuretic and antidiabetic	EN	Tejaswini and Jayashankar 2021
Hydnocarpus alpina Wight; Achariaceae	Attuchankala	Tree; Native	Feb -July	KL	Coumarins, quinones, alkaloids, and steroids; leprosy, cancer	VU	Ganesh et al, 2019
Hydnocarpus pentandra (Buch.-Ham.) Oken; Flacourtiaceae	Chaulmugra	Tree; Native	Dec -May	KL, KA	Hydnocarpin, flavonolignan, Fatty acids; antirheumatic, antidiabetic, anticancer	VU	Arun and Kiran 2014

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Kingiodendron pinnatum (DC.)Harms; Fabaceae	Chou Paini	Tree; Native	Feb -Dec	KA	Saponins, tannins,terpenoids, oleo-gum resin; Gonorrhoea	EN	Mepani and Cruz 2022
Litchi chinensis var. euspontanea; Sapindaceae	Litchi	Tree; Naturalized	April -June	KL	Flavonoids, phenols, anthocyanins; diabetes, obesity, hernia	VU	Singh 2017
Maba buxifolia (Rottb.) A.L. Juss.; Ebenaceae	Chinna-ullingi	Tree; Native	Jan -July	TS, AP	Protein, sugar; folk medicine	EN	Pullaiah 2015
Madhuca insignis (Radlk.) H. J. Lam.; Sapotaceae	Ibbe gida	Tree; Native	Dec -April	KL, KA	Terpenoids, hetrocyclics, phenolics; antidiabetic, antitumor	CE	Ravikumar et al 2004
Madhuca longifolia (Roxb.) A.Chev.; Sapotaceae	Mahua	Tree; Native	March -april	KL, TS	Alkaloid, glycoside, phenol; diarrhea, and antidote in snakebite	VU	Suryawanshi and Mokat 2019
Madhuca neriifolia (Moon) H.J.Lam; Sapotaceae	Ulinannil	Tree; Native	Nov -Mar	KA	Flavonoids and tannins; Kidney complaints, rheumatism, asthma	VU	Minu et al 2022
Mesua ferrea L.; Guttiferae	Iron wood	Tree; Native	Jan -Oct	KL	Xanthones, terpenoids; immunomodulatory	EN	Asif et al 2017
Momordica charantia ; Cucurbitaceae	Pakarkkai	Climber; Naturalized	June-Sep	TN	Vitamins and minerals; Diabetes	CE	Vizhi and Lohidas 2020
Morinda reticulata Benth.; Rubiaceae	Mapoon Bush	Climber; Native	March -Sep	KL	Flavonoids, anthraquinone glycosides; cancers, diabetes	EN	Singh et al 2022
Myristica fragrans Houtt.; Myristicaceae	Nutmeg	Tree; Native	Dec -June	KL	Terpenoids, anthraquinones; narcotic, antidiabetic	CE	Asgarpanah and Kazemivash 2012
Myristica malabarica Lam.; Myristicaceae	Malabar nutmeg	Tree; Native	Jan -Sep	KL, KA	Isoflavones, diarylnonanoids; anti-cancer, anti-diabetic	VU	Chelladurai and Ramalingam 2017
Olax psittacorum Roxb.; Olacaceae	Mekabanda	Tree; Native	Sep-oct	AP	Folk medicine	CE	Sathyavathi and janardhan 2014
Passiflora edulis ; Passifloraceae	Odey pannu	Climber; Naturalized	July-Oct	TN	Vitamins and minerals; Headache	EN	Sasi et al 2011; Sathyavathi and janardhan 2014
Phoenix acaulis Roxb. Ex Buch.-Ham.; Arecaceae	Stemless palm	Tree; Native	Feb -Sep	KA, TS, AP	Glycosides, phenols; diuretic, vertigo and unconsciousness.	NT	Charu et al 2021
Phyllanthus indofischeri ; Phyllantaceae	Nelli	Tree; Native	July-Feb	TN	Vitamins; Diabetes	VU	Rasingam 2012
Physalis peruviana ; Solanaceae	Pitlannu	Herb; Naturalized	July-Aug	TN, TS, AP	Thiamine, niacin, linoleic acid, oleic acid; Vomiting	CE	Sathyavathi and janardhan 2014; Sasi et al 2011
Psydrax dicoccos Gaertn.; Rubiaceae	Oppai	Shrub; Native	Oct-Nov	TN	flavanols, tannins; Antioxidant, antimicrobial, diarrhea	VU	Rasingam 2012
Santalum album L.; Santalaceae	Srigandha	Tree; Native	Mar -Oct	KA	omega-9 oils, fibre; folk medicine	VU	Swaminathan and Kennedy 2019
Syzygium arnottianum ; Myrtaceae	Nerli annu	Tree; Native	April-June	TN	Thiamine, riboflavin, vitamins; Toothache	VU	Sathyavathi and janardhan 2014
Syzygium calophyllifolium ; Myrtaceae	Kadu nerli	Tree; Native	Feb-May	TN	Rutin and ellagic acid; Toothache	EN	Sathyavathi and janardhan 2014

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Scientific name and family	Common name	L F and origin	Flowering - fruiting	State	Phytochemicals and utility	IUCN status	References
Syzygium caryophyllatum (L.) Alston; Myrtaceae	Kunta Nerale	Tree; Native	Feb -dec	KL, KA, TS, AP	Flavanoids, tannings, saponins; anti-inflammatory, anti-bacterial	EN	Heendeniya et al 2018
Syzygium densiflorum Wall. ex Wt. & Arn.; Myrtaceae	Ayuri (Mal)	Tree; Native	April -June	KL, KA	Flavonoids, sterols, terpenoids; antiulcerogenic, cardioprotective	VU	Shareef and Kumar 2020
Syzygium occidentale (Bourd.) Ghandhi; Myrtaceae	Karinjara	Tree; Native	Dec -June	KL	Total phenols, saponins; anti-oxidant, Antifungal	VU	Varghese and Sreekala 2017
Syzygium travancoricum Gamble; Myrtaceae	Poriyal	Tree; Native	April -July	KL	Essential oil, fibre, amino acids; arthritis, diabetes and hypoglycemic	CE	Rajalakshmi et al 2016
Syzygium zeylanicum (L.) DC.; Myrtaceae	Chaliyakkani	Tree; Native	Jan -April	KL	Phenolics, flavonoids, terpenoids; folk medicine,	EN	Anoop and Bindu 2015
Toddalia asiatica ; Rutaceae	Massikai	Shrub; Native	Sep-Jan	TN	Coumarins, alkaloids, triterpenes; skin allergy	VU	Sathyavathi and janardhan 2014
Trichosanthes cucumerina ; Cucurbitaceae	Kattu-padavalam	Climber; Native	July - Sep	TN	Cucurbitacin, sterols and stigmasterol; Headache, Diarrhea	NT	Kumar et al 2014
Vaccinium leschenaultii ; Ericaceae	Cranberry	Tree; Native	Feb - April	TN	Anthocyanins and Flavonoids; Antiulcer, antioxidant	EN	Sasi et al 2011

namely VU (31 species), EN (20 species) and CR (8 species). Further, our habit-wise analysis has revealed that around 53 species (76.8 %) were trees, 7 species (10.1 %) were shrubs, 2 species (2.9 %) were herbs and 7 species (10.1 %) were climbers (Fig. 4). Maximum number of species was recorded in Myrtaceae family (9 species), followed by Ebenaceae (7 species) and Clusiaceae (5 species) (Fig. 5, Table 2). Among these fruit species 63 species (91.3 %) were native and 6 species (8.7 %) were naturalized to SI. Maximum number of species was recorded in Kerala (37 species), followed by Karnataka (31 species) and minimum (13 species) in Andhra Pradesh (Table 2). Among 173 recorded documents, maximum were published in 2020-2021 followed by 2014-2015 (Fig. 6). Prior to 2000, there were only five publications regarding TNT-UEFS while these numbers were increased in the recent years. Many studies have provided a comprehensive review of UEFS in the context of World, Continent, India and portion of SI (Verheij et al 1991, Suresh et al 2014). Native and naturalized UEFS are primarily organic, nutritious and have substantial cultural, medicinal, regulatory and supporting values. Also constitute

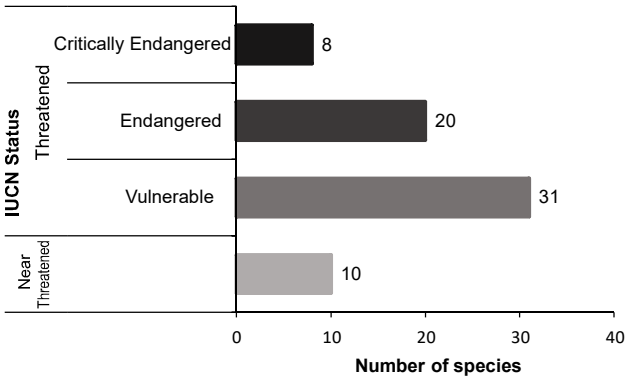

Fig. 3. Conservation status of UEFS of SI as per IUCN categories

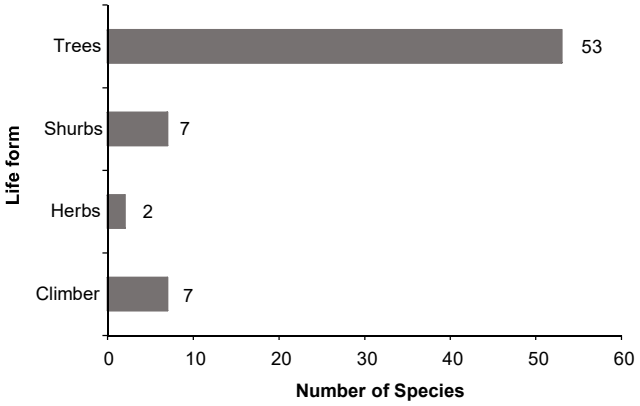

Fig. 4. Habit-wise species distribution

the major source of subsidiary nutrients to the tribal, forest dwellers and marginalized local communities. Studies suggested that integrating fruit trees are a key solution to address food and nutrition insufficiency while providing various ecosystem services (Tag et al 2012, Suresh et al 2014).

Collection calendar and documentation of TNT-UEFS: Collection calendar includes the flowering and fruiting period in the months for each species were recorded (Table 2). The most concentrated period of TNT-UEFS collection was April-August; some species were collected year-round. Round the year availability of TNT-UEFS of different species supplement diverse and nutrient-dense food and enhance the livelihood of the dependent communities. *Aporosa acuminata* was collected from January to June; *Aegle marmelos* from March to May, *Physalis peruviana* in the month of July to August, *Todalia asiatica* from September to January, *Artocarpus hirsutus* from December to March. The flowering and fruiting periods of these species are also important for developing appropriate conservation measures to save these species from extinction in the near future (Tag et al 2012). These UEFS were majorly collected from forests and other unmanaged landscapes. The extent of collection of UEFS depends on various factors such as agriculture failure, adverse climatic conditions and other lean times (Tag et al 2012, Suresh et al 2014). The cultivar fruits are less familiar and not accessible to tribal and local communities. The urban communities are unfamiliar with the UEFS that tribal and local communities utilize. Most of the forest dwellers and tribal populations are largely dependent on forest resources for their livelihood and sustenance. They collect a portion of the excessively available fruits from the forest for sustenance. Documentation of indigenous knowledge through ethnobotanical studies is significant for the sustainable bioprospecting, conservation and utilization of these natural fruit products (Tag et al 2012). UEFS like amla, bael, jamun, wood apple and many others find a place in various ancient literatures including Charaka Samhita and Vrikshayurveda since 4th century BC to date. Documentation helps in appraisal, cultivation, domestication, improvement, conservation and sustainable utilization which can diversify food and livelihood of rural poor and tribals. Hence, there is a need for scientific collating and validation of available traditional knowledge in Vedas, Grantas, Vrikshayurveda and many more. UEFS covers major portions of wild food plants and are eaten worldwide mostly in raw or unripe form as compared to cooked form (FAO 2011). The exploitation of UEFS in a particular area depends on availability in terms of duration and distance, demand, preferences, tastes and traditional knowledge (Tag et al 2012). UEFS have been playing dual role such as source of hidden harvest i.e. supplementing the community with food and income, and buffer food i.e. rescuing lives during food shortages and famines (Grivetti and Ogle 2000).

UEFS connection with culture, folklore and socio-economy: UEFS has been integrally associated with the culture, socio-economy and folklore of aboriginals (Grivetti and Ogle 2000, Tag et al 2012). UEFS are often the only fruits consumed by rural poor and tribals as they cannot afford cultivated commercial fruits in the many developing nations (Verheij et al 1991). Tribals of various ethnic groups like Savara, Khonds, Nayaka, Pulayans, Maratis, Irular, Uraly, Gonds, Koyas and others are predominant in the various parts of SI and follow traditional farming practices (Pullaiah and Rao 2002). Most of the UEFS are used in their diverse and seasonal diet and are often shared or sold in the local

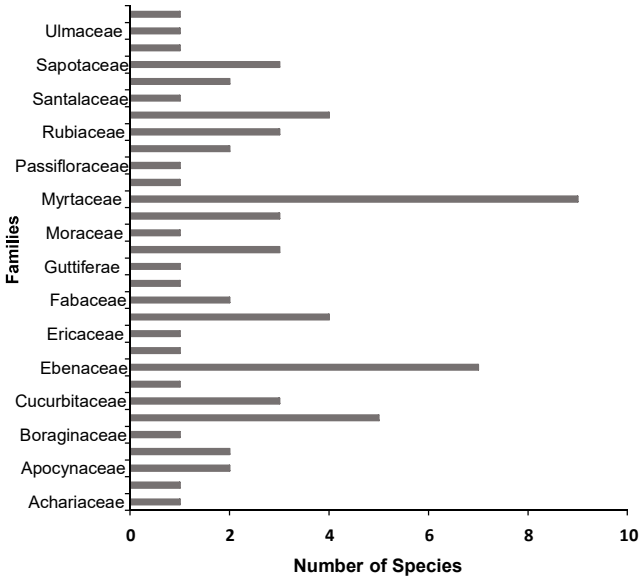

Fig. 5. Familywise dirstributionof TNT-UEFS recorded in SI

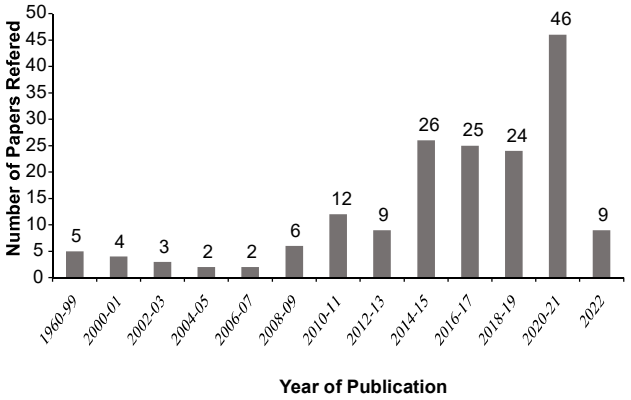

Fig. 6. Number of TNT-UEFS Paper refered

markets. They are consumed either raw or in the form of beverages, pickled or cooked with other dishes (Shankar et al 2020). The knowledge and utilization of UEFS depends on availability, habit, habitat, frequency of food shortages and people's way of life interms of their cultural, religious and socio economical domains (Grivetti and Ogle 2000, Tag et al 2012). Studies showed that different tribes had used a number of similar wild fruits with different uses which proving the diversification of knowledge in the region to region and nation to nation (Grivetti and Ogle 2000). In most parts of India, species such as *Aegle marmelos, Limonea acidissima,* Ficus species *etc.* have a strong connection with the culture, folklore and religious belief. Presently, this long-established culture and knowledge is loosing importance due to the western influence and intensive agriculture which result in the degradation of a harmonious relationship among biodiversity, farming and folklore (Pretty 2003). Hence, it is imperative to renew, document and utilize the traditional knowledge systems for sustainable development of the community.

Implications for food security: Contribution of UEFS to food security and livelihood of the dependent community is well documented even during erratic times such as agriculture failure, adverse climatic conditions and other lean times (Mahapatra et al 2012). Most of the UEFS are available round the year and they constantly supplement diverse and nutrient dense food to the dependent rural and tribal communities in many regions of the world. Ensuring food security of the dependent community further strengthens the education, employment, health and many other sectors. These UEFS can be processed into various products such as dry fruits, jam, jelly, juice, pickle, wine etc., by amalgamation of traditional knowledge and advanced techniques. The quality and shelf life of the products could be improved and reduce post-harvest losses with the application of modern techniques and scientific interventions (Meghwal and Singh 2016) Promoting UEFS-based small food and agro-based industries will contribute to sustainable rural development by providing many fold employment opportunities round the year. It can fulfil the growing need of alternative bio-nutritional sources and also used as a dietary supplement since it has valuable ingredients such as Fe, Na, K, Ca and many more (Tag et al 2012). Many studies showed its significance in meeting the nutrient demand of rural poor and tribal population (Grivetti and Ogle 2000, Tag et al 2012). The nutritional values of many TUEFS were found to be at par with the popular domesticated fruits such as banana, mango, papaya and many more (Mahapatra et al 2012). It improves household food and nutritional security under normal circumstances and food scarcity. Many studies have shown that good quality dry fruits, jams, juices and other drinks can be produced using simple procedures suitable for small-scale commercial production (Mahapatra et al 2012). Apart from the edibility, most of these UEFS are multiuse biological resources that are potential for cosmetic, medicinal, nutraceutical, ornamental, religious, therapeutic, wood, non-wood and other ancillary purposes. Most of these species are used for the preparation of medicinal Ayurvedic formulations like *Triphala*, *Chavanprash*, etc. UEFS are used in the treatment of a wide range of ailments as they are rich sources of antioxidants, minerals, and vitamins. Some UEFS have great antioxidant properties thus, they can be used to cure insomnia, constipation, rejuvenate skin cells and hair growth. Phytochemicals of some UEFS such as *Atalantia monophylla, Diploknema butyracea, Protium serratum, Sterculia foetida* and *Terminalia bellirica* are used in numerous therapeutic advantages (Mahapatra et al 2012).

Implications for diversifying agroecology: In the ancient Indian times, natural resource-based traditional subsistence farming was practiced with the indigenous knowledge and experience. The people worshipped some indigenous fruit species which became an integral part of their life. In recent times, rapid increase in population demanded intensive cultivation. Non-judicious use of chemical inputs in agriculture led India to sacrifice its ecological balance. Many indigenous traditional landraces have been forced to extinct because of the introduction of hybrids. Nowadays, people are realizing the potential of UEFS and hence demand for quality planting material is increasing. To meet this demand, vegetative propagation techniques such as cuttings, grafting, layering and stooling are adopted for commercial multiplication. Diverse, region specific, fruit crop-based models are adopted to diversify farm income, reduce the risk and enhance the productivity (Singh et al 2020). Most of the semi-arid region of SI is water deficient and suitable for the cultivation of horticulture crops, hence attention to be paid to develope region-specific fruit-based agroforestry (AF) models having high resource use efficiency. Plantation of UEFS should be done at proper spacing with locally available perennial organic mulches and proper canopy management (Singh et al 2020).

The Convention on Biological Diversity recognizes the sovereign right of each country over their biodiversity and assists in maintaining countries biological diversity (Prakash 2011). Many of the native species are severely TNT due to various natural and manmade factors. It is estimated that around 26,106 plant species are globally threatened whereas in India, 1700 angiospermic plants are categorized under the threatened list (Singh and Dash 2014). Prioritization of endemic and threatened plant species and their conservation

for sustainable utilization is a vital concern (Singh et al 2020). Genetic resources of some UEFS of SI are remained neglected or still available in outfields or forests. Apart from this, few are in the hands of local or tribal communities and they use mainly for their subsistence while protecting as part of their folkloric responsibilities. There is a great necessity for species-specific surveys and explorations in diverse areas of SI for systematic evaluation, characterization and conservation of indigenous UEFS germplasm.

The degradation and denudation of various land use systems (LUS) through various anthropogenic activities is a major driver to biodiversity loss, carbon (C) emission and uncertainty of food and livelihood for various dependent communities. Greenhouse gases are increasing the earth's temperature; among them, CO_2 is the key gas in global warming, leading to climate change. Additionally, human-induced intensive agriculture degrades productive soils (Rakesh et al 2022). Thus, sequestration of atmospheric C would be the possible solution for soil quality, yield sustainability, and environmental security (Rakesh et al 2022, Dinesha et al 2023). Planting fruit trees through various afforestation and reforestation programmes would help restore degraded lands. Plantation forestry helps improve the soil C sequestration and nutrient dynamics through continuous litter fall (Dinesha et al 2020). Earlier study showed successful integration of fruit species in various degraded and denuded ecosystems such as degraded forests, mined areas, marginal and wastelands (Ghosh et al 2021). Most of the farmers' surveys reported increased soil microbial status, earthworms and beneficial insects like pest antagonists', pollinators, etc. These LUS are explicitly focused on agro ecological balance and on-farm biodiversity. The most prominent effects on the success of restoration of the planted native and naturalized species depend on climate, existing natural vegetation, hydrological features, and soil quality. However, region-specific models of UEFS like bael, jamun, tamarind, chironji, khirni, custard apple, etc. are immensely constructive and climate-smart by surviving in harsh agroclimatic conditions and can be established on degraded lands (Singh et al 2020). These resilient fruit species also augment biodiversity, ecosystem and landscape. Most of these UEFS contribute to the region's diversity of flora and fauna and offer potential niches to various biotas. UEFS are being exploited continuously and unscientifically from the wild without any conservation efforts to propagate them. These UEFS have also been acknowledged as critical resources for long-term ecological security as they are providing multifarious ecosystem services, growing in varied climatic conditions and resistant to biotic and abiotic stresses (Suresh et al 2014).

Challenges and solutions of UEFS cultivation: Concerning UEFS cultivation, challenges and solutions were noted (Table 1). Farmers' awareness and attitude towards UEFS integration in farming are poor due to long gestation period of native and natural fruit species which require long-term investment. They are not aware about the various tangible and intangible benefits, and ecosystem services of UEFS. Many indigenous fruits such as *Adansonia digitata* and *Citrullus lanatus* in Africa and *Parkia timoriana* and *Pithocelobium dulce* in India have high nutraceuticals but very poorly organized production and marketing systems as well as research and policy support. Size of land, poor irrigation facility and lack of awareness induce negative perception and attitude among farmers towards fruit species adoption. Generally, the productivity of native UEFS are very low compared with other major fruit crops grown in India. Hence, there is a critical need of developing improved varieties, quality planting materials, the package of practices, transfer of technologies, post-harvest management, storage, marketing and transport to overcome these challenges and popularize the UEFS among growers. Many research organizations related to fruit crops are tremendously working under the GOI assistance to standardize cultivation practices and further improve UEFS. Developed varieties and standardized several production technologies like propagation methods, plant spacing, canopy management, crop compatibility, nutrient and water management, crop regulation, plant protection, post-harvest management and value addition (Singh et al 2020). In order to cope up with various abiotic stresses, UEFS like *Emblica officinalis*, *Aegle marmelos* and *Feronia limonia* are modified or improved to assure critical morpho-physiological functions i.e., strong deep root system, high root-to-shoot ratio, selective absorption, uptake and storage of more water and nutrients, reduced transpiration and heat shocks (Meena et al 2022). Additionally, synchronized flowering and fast fruiting, biosynthesis of antioxidants, proteins and drought-responsive genes, assist in growth and development under adverse conditions (Meena et al 2022). Generally, breeding and biotechnological interventions are hindered by major obstacles like genetic heterogeneity, long juvenile phase, self and cross incompatibility, sterility and many more (Gill et al 2022). Successful approaches to overcome these challenges are genetic diversity and phylogenetic studies, hybridization, omics-based interventions, linkage mapping, marker-assisted selection and mutation breeding (Gill et al 2022).

Outcome of the UEFS cultivation and farmers' messages: Recent studies reported the shifting of farmers from conventional farming to organic and natural farming

(NF), especially in the SI states namely Andhra Pradesh, Karnataka, Tamil Nadu and Telangana (Nayana and Veni 2020). Farmer's survey in these states reported better plant health, vigour and climate resilience in fruit crops integrated organic and NF system even under dry spells, flooding and cyclone situations (Bharucha et al 2020). Apart from increased incomes, farmers also experienced encouraging outcomes across a range of farm health indicators, agro biodiversity and sustaino-resilence of the agroecosystem (Bharucha et al 2020). Another study reported successful integration of UEFS like aonla (*Emblica officinalis*), bael (*Aegle marmelos*), ber (*Zizyphus* spp.) and jamun (*Syzigium* spp.) based cropping models to minimize the risk and enhance the yield and productivity in Arid and Semi-arid regions of India (Singh et al 2020). Furthermore, integration of leguminous crops under these UEFS models increased the income two to three-fold (Singh et al 2020).

Policy and institutional support: Government of India (GOI) is promoting fruit species incorporation through Mission for Integrated Development of Horticulture, Rashtriya Krishi Vikas Yojana, Sub-Mission on Agroforestry, National Mission for Sustainable Agriculture and National Food Security Mission. In addition, Ministry of Tribal Affairs in association with Ministry of Food Processing Industry and Tribal Cooperative Marketing Development Federation of India Limited (TRIFED) started a scheme called “Trifood” for value addition of forest produce including UEFS by establishing food processing centres in tribal areas. Therefore, the synergy among these missions encourages to improve farmers' income through improved cultivation practices, integrated farming practices, enhancing resource use efficiency, pest, disease and nutrient management, insurance, credit and market support. Some organizations like Food and Agriculture Organization (FAO), World Agroforestry Centre (ICRAF) etc., are fulfilling policy space, conducting scientific studies, providing best practices and publishing guidelines. Earlier studies reported that the growing support by the GOI for agriculture and horticulture over the past decade, including initiatives like the Mission for Integrated Development of Horticulture and the Crop Insurance Scheme (Khandelwal et al 2019). However, policies to support high-value fruit crops both economically and nutritionally are limited and few are embedded in broader agricultural policy initiatives. Furthermore, these policies mainly focus on exports, employment, livelihood and economic growth while lacking importance on its local consumption or inclusion in daily diets (Khandelwal et al 2019).

CONCLUSION

Studies suggested that integrating fruit species in various agroecosystems is a key solution to address food and nutrition insufficiency while providing various ecosystem services. Many of these enlisted TNT-UEFS were economically potential for edible, medicinal, ornamental, timber and many other uses. Hence, there is a need for coordinated research efforts for the survey, documentation, evaluation, cultivation and conservation (*ex-situ* and *in-situ*). Developing standard cultivation protocols, supply of quality planting materials, transfer of technology, processing and marketing through small-scale industries, self-help groups and farmer producer organizations are considered necessary. The government should also actively participate in this regard by providing necessary inputs and technical support. States of SI should come up with the clear-cut policy to encourage and promote UEFS cultivation, marketing and utilization. Furthermore, linking policy makers, researchers and practitioners may build a strong association between national policies and agroecosystem restoration initiatives. As these fruits are highly adaptable and show resistance for various insect-pest and diseases, hence pesticide and other chemical requirements are almost negligible. Thus, they can fit well into organic and natural farming, as they require less attention by the cultivars. On the other supporting hand, the government is emphasizing on promoting indigenous species through the slogan 'vocal for local' and 'local for global'.

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