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# Response of Medicinal and Aromatic Plants under Prevailing Air Quality in Subhumid Mid Hills Zone of Himachal Pradesh, India

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***Abstract***: The increasing atmospheric pollution have become a global problem threatening both human and ecosystems health. Therefore, the air pollution tolerance index (APTI) and the anticipated performance index (API) are evaluated in order to determine both the degree of tolerance or sensitivity of medicinal and aromatic plants to pollutants in mid hill subhumid zone of Himachal Pradesh. The commonly occurring thirty medicinal and aromatic plants comprised of seventeen herbs, six shrubs, three climbers and four trees were selected for the study. All the herbs, shrubs and trees under study behaved similar, whereas significant variation was observed in climbers for the APTI. The highest APTI was in *Spilanthes acmella* (10.40), *Murraya koenigii* (7.735), *Tinospora cordifolia* (8.530) and *Terminalia arjuna* (5.770) with respect to herbs, shrubs, climbers and trees. The anticipated performance index of the selected medicinal and aromatic plants ranged from very poor to very good. Among the herbs, *Spilanthes acmella* with the highest tolerance index and *Cymbopogon citratus* with very good and *Acorus calamus* and *Valeriana jatamansi* with good performance score and among the shrubs, *Murraya koenigii* with the highest tolerance index and *Vitex negundo* with a moderate performance score and among the climbers, *Tinospora cordifolia* with the highest tolerance index and moderate performance score and among the trees, *Terminalia arjuna* with the highest tolerance index and moderate performance score can be suggested for plantations to manage the harmful effect of air pollution in the mid hill sub humid zone in particular and in Himachal Pradesh in general.

***Keywords***: Air pollution, APTI, API, Tolerance, Performance, Plants

Himachal Pradesh is a state in the northern part of India, situated in the Western Himalayas. According to Census Population Estimate report & UIAI for 2021 estimates, Himachal Pradesh has a population growth rate of 8.56% during 2011-2021. Its estimated population in 2021 is 74.81 Lakh an increase of around 6.36 lakhs from 2011. The population density rose to 133/km$^2$ from 109/km$^2$ in 2001. This shows a clearcut population pressure over fragile economy of the state this implies rapid urbanization processes, which is a key factor in the alteration and degradation of states' spatial structure, environment, and ecology (Kumara 2018), because of the growing demand for food, fuel, energy, water, and industrial raw materials, among others. Presence of forests and trees, however, has been recognized as beneficial since their presence has been correlated with atmospheric pollutant sinks and removal and climate change mitigation (Nowak et al., 2014, FAO 2018). Due to air quality problems, anatomical, morphological, physiological, and biochemical disturbances have been observed in different plants (Gulia et al., 2015, Uka et al., 2017). Particulate matter (PM) and other gases can cause negative effects and have a high potential of affecting forests and trees (Kumar 2012 and Rai 2016). These effects depend on PM concentrations and vegetation characteristics, due to the deposition of particles on leaves, results in reduction of incident light, stomatal closure, interference with gaseous exchange, thus altering the thermal balance of the plant (Singh and Verma 2007). The deposition of pollutant on leaves transform the nitrates and sulphates into acid and increased the level of trace and heavy metals such as lead (Grantz et al., 2003). So, it is fundamental to evaluate the tolerance and sensitivity of different plants to estimate atmospheric pollutants stress on vegetation by exposure to atmospheric pollutants (Lodenius 2013).

Among the different methodologies used to evaluate the tolerance and sensitivity of plant species to atmospheric pollutants is the air pollution tolerance index (Singh et al., 1991), which incorporates the biochemical parameters of a tree to determine the degree of impact to its organism (Kaur and Nagpal 2017). Additionally, the anticipated performance index supplements the APTI with biological and socioeconomic parameters of the species in order to determine its performance (Govindaraju et al., 2012). Both indexes have been widely used to characterize different plant species according to their tolerance and performance (Skrynetska et al., 2018, Qiu et al., 2019, Alotaibi et al., 2020, Javanmard et al., 2020, Banerjee et al., 2021 and Watson et al., 2021). In India these indexes have been successfully used to report plant that are key in the development and management of the ecosystem due to their tolerance and performance as well as their high capacity to filtrate and retain PM in the atmosphere (Achakzai et al., 2017 and Skrynetska et al., 2018). These mentioned reports have shown consensus regarding the classification of the trees using the APTI and API indexes, without a finding in conflicting reports between the studies consulted.

Because of the consistently rising levels of air pollutants (mostly PM) that have been observed, the mid-hill subhumid zone of Himachal Pradesh has drawn attention from locals, visitors, public administration, and other segments of society in recent years. In view of this context, the current study assessed the APTI and API indices of thirty species of medicinal and aromatic plants that are found in mid hill subhumid zone of Himachal Pradesh to determine the species' susceptibility or tolerance to air pollution.

## MATERIAL AND METHODS

**Study area:** The present study was carried out at Dr. YS Parmar University of Horticulture and Forestry, Nauni in Solan district located in mid hill region of Himachal Pradesh. The Nauni area is at the geometrical centre (30˚52'0" N, 77˚11'30" E with 1275 m amsl. Himachal Pradesh lies in the Indian Himalayan Region (IHR), one of the richest reservoirs of biological diversity in the world. The state is endowed with a high diversity of flora around 3500 plant species including more than 1000 species of medicinal and aromatic plants (Chauhan 2003). Because of increasing productivity, innovation, and the attraction of human capital to establish various educational institutions, this region has witnessed better economic growth.

Its climate is characterized by a bimodal rainfall pattern: western disturbances during winter and south west monsoon during summer season. This rainfall pattern is associated with the dynamics of the Intertropical Convergence Zone (ITCZ), which determines two seasons (dry and humid). The area receives the mean annual rainfall of 1450 mm with average of 64 rainy days with a mean annual temperature of 18.4°C, fluctuates from 2.1°C to 40°C for winter season to summer season.

**Selection of species and sample analysis:** Preliminary identification of different medicinal and aromatic plant species present in the campus was done, out of which 17 herbs, 6 shrubs, 3 climbers and 4 trees were selected randomly for the study (Table 1).

Leaf samples from the selected plant species were collected in accordance with a standard procedure in order to analyze a number of anatomical and biochemical parameters. The leaf samples were brought in an ice box to the lab, where they were first cleaned with regular water, then with 0.1 N HCL, and lastly with distilled water.

**Physiological and biological parameters determination:** The physiological and biochemical parameters of the selected plants were determined by using triplicates to ensure quality control of the data.

**Relative water content (R):** Thirty sample of leaves were selected. After taking the fresh weight of leaves, the leaves were immersed in water over night, blotted dried and then weighted to obtain turgid weight. The leaves were dried overnight at 70 ºC in oven and reweighed for dry weight. Relative water content (RWC) of the samples was estimated by using the method proposed by Singh (1977).

$$\text{RWC (\%)} = \frac{(\text{FW} - \text{DW})}{(\text{TW} - \text{DW})} \times 100$$

Where

FW = Fresh weight, DW = Dry weight, TW = Turgid weight

**pH of leaf extract (P):** The fresh leaves (5g) were homogenized in 10 ml deionized water and supernatant obtained after centrifugation and collected for determination of pH and leaf pH was measured ( Prasad and Rao 1982). Determination of pH was done by using pH meter (Model – ESICO 1013) with buffer solution of pH 4 and 9 (Barrs and Weatherly 1962).

**Total chlorophyll content (T):** The leaf chlorophyll content was estimated by using Hiscox and Israeistam, (1979) method. The fresh leaves were chopped to fine pieces under subdued light and 100 mg of chopped leaf sample was placed in vial containing 7 ml of Dimethyl sulphoxide. Then vials were incubated at 65º C for 30 minutes. The extract was then transferred to graduate test tube and the final volume was made to 10 ml with Dimethyl sulphoxide. The optical density values of the above extract were recorded on spectrophotometer (Model- spectronic-20) at 645 and 663nm wavelength against dimethyl sulphoxide blank.

$$\text{Total chlorophyll (mg g}^{-1}\text{)} = \frac{20.2\text{A}645 + 8.02\text{A}663}{a \times 100 \times w} \times v$$

Where, v = volume of extract made, a = length of light path in a cell (usually 1cm)

w = weight of the sample taken, A645 = absorbance at 645 nm

A663 = absorbance at 663 nm

**Ascorbic acid content (A):** The ascorbic acid content was estimated by AOAC (1980) method. Fresh leaves (10 g) were homogenized in metaphosphoric acid solution and volume was made up to 100 ml. This solution was titrated against indophenols dye. Appearance of rosy pink colour was taken as the end point. The amount of ascorbic acid in milligrams per grams was calculated.

$$\text{Amount of ascorbic acid (mg g}^{-1}\text{)} = \frac{\text{Dye factor} \times \text{Titre reading} \times \text{Volume made}}{\text{Weight of leaves taken} \times \text{Volume taken for estimation}}$$

**Air pollution tolerance index (APTI) and anticipated performance index (API)**

**Air pollution tolerance index (APTI):** The four biochemical parameters of the plant species; ascorbic acid, total chlorophyll content, pH of the leaf extract, and relative water content were used to determine the APTI score in order to

**Table 1.** Description of selected medicinal and aromatic plants

| Plant species | Common name | Family | Habit | Leaf shape |
|---|---|---|---|---|
| Herbs | | | | |
| *Acorus calamus* | Sweet flag | Acoraceae | Perennial herb | Sword-shaped |
| *Bryophyllum pinnatum* | Patharchatta | Crassulaceae | Perennial herb | Broad and flattened |
| *Cymbopogon citratus* | Lemon grass | Poaceae | Perennial herb | Linear in shape |
| *Lavandula angustifolia* | Lavender | Lamiaceae | Perennial herb | Erect |
| *Matricaria chamomilla* | Babuna | Asteraceae | Annual herb | Long and narrow |
| *Melissa officinalis* | Balm | Lamiaceae | Perennial herb | Ovate |
| *Mentha piperita* | Peppermint | Lamiaceae | Perennial herb | Ovate |
| *Ocimum basilicum* | Bhavri | Lamiaceae | Perennial herb | Oval |
| *Ocimum sanctum* | Holy basil | Lamiaceae | Perennial herb | Oval |
| *Origanum vulgare* | Oregano | Lamiaceae | Perennial herb | Oval or round |
| *Pelargonium graveolens* | Scented geranium | Geraniaceae | Annual herb | Lobed or toothed |
| *Rosemarinus officinalis* | Rosemary | Lamiaceae | Perennial herb | Needle-shaped |
| *Silybum marianum* | Milk thistle | Asteraceae | Annual herb | Oblong to lanceolate |
| *Spilanthes acmella* | Akarkara | Asteraceae | Perennial herb | Ovate |
| *Tagetes minuta* | Wild marigold | Asteraceae | Annual herb | Linear to narrowly lanceolate |
| *Thymus vulgaris* | Thyme | Lamiaceae | Perennial herb | Linear or diamond shaped |
| *Valeriana jatamansi* | Muskwala | Valerianaceae | Perennial herb | Cordate-ovate |
| Shrubs | | | | |
| *Asparagus racemosus* | Satavari | Asparagaceae | Perennial shrub | Pine needle like leaves |
| *Justicia adhatoda* | Basuti | Acanthaceae | Perennial shrub | Lance-shaped |
| *Murraya koenigii* | Curry leaf | Rutaceae | Perennial shrub | Lance-shaped |
| *Vitex negundo* | Banna | Lamiaceae | Perennial shrub | Toothed or serrated |
| *Withania somnifera* | Ashwagandha | Solanaceae | Annual shrub | Ovate |
| *Zanthoxylum armatum* | Timar | Rutaceae | Perennial shrub | Lanceolate, obovate or elliptic |
| Climbers | | | | |
| *Celastrus paniculatus* | Mal-kangni | Celastraceae | Perennial climber | Ovate or elliptic |
| *Tinospora cordifolia* | Giloy | Menispermaceae | Perennial climber | Heart shaped |
| *Tylophora indica* | Damabuti | Apocynaceae | Perennial, climber | Obviate-oblong to elliptic-oblong |
| Trees | | | | |
| *Phyllanthus emblica* | Amla | Phyllanthaceae | Deciduous tree | Oblong |
| *Terminalia arjuna* | Arjun | Combretaceae | Deciduous tree | Oblong, conical |
| *Terminalia bellirica* | Bahera | Combretaceae | Deciduous tree | Simple, alternate, clustered at the tip |
| *Terminalia chebula* | Harad | Combretaceae | Deciduous tree | Ovate or elliptic obovate |

classify the species as either tolerant (when the APTI score is high) or sensitive (when the APTI score is low). These parameters together provide a basis for classifying species as tolerant or sensitive. These biochemical parameters were estimated by using experimental design CRD with 3, 4, 5 and 4 replications for herbs, shrubs, climbers and trees.

The deterioration of chlorophyll in leaves was correlated with pH values because of stress brought on by air pollution. The ascorbic acid content plays a crucial function in protecting chlorophyll against hydrogen peroxide ($H_2O_2$) damage, which starts at pH>3 when superoxide dismutase (SOD) dismutates superoxide radicals ($H_2O_2$). Ascorbic acid levels in plant organisms promote the integration of chlorophyll (a and b), which helps in the development of resistance to air pollution The relative water content in the equation taken into consideration the ability of cells to remain intact when exposed to air contaminants. The whole term of the equation, comprising the four biochemical parameters, is divided into 10 in order to obtain a manageable value (Singh et al., 1991; Uka et al., 2017) as:

$$APTI = \frac{A\,(T+P)+R}{10}$$

Where,

A = Ascorbic acid content (mg $mg^{-1}$)

T = Total chlorophyll content (mg $mg^{-1}$)

R = Relative water content (%)

P = pH of leaf

**Anticipated performance index (API):** As per the process described by Mondal et al. (2011), the resulting APTI values were combined with biological and socioeconomic parameters such as plant height, canopy structure, plant size, texture, hardness, and economic value (Anonymous 2008). Different grades (+ or -) were assigned to the plants and plants that scored differently according to their grades were categorized (Table 2). Based on the plant species ability to thrive under stressful conditions, such as air pollution, the API was determined (Table 3).

## RESULTS AND DISCUSSION

### Biochemical Characteristics

**Ascorbic acid (A):** There was a significant variation in ascorbic acid content (mg $g^{-1}$) among 30 individual plant species under analysis ranged from 0.220 to 2.040 mg $g^{-1}$ (Table 4).

Among the 17 herbs, significantly higher content of ascorbic acid (2.040 mg $g^{-1}$) was in *Valeriana jatamansi* followed by *Tagetes minuta* which was statistically at par with *Spilanthes acmella* and *Acorus calamus* and minimum (0.220 mg $g^{-1}$) was in *Lavandula angustifolia*, which was statistically at par with Ocimum basilicum. In shrubs ranged between 0.60-1.34 with maximum content in *Vitex negundo* preceded by *Murraya koenigii* whereas minimum was in *Asparagus racemosus*, which was statistically at par with *Withania somnifera* Similarly in climbers the maximum amount of ascorbic acid was observed in *Tylophora indica* (1.23 mg $g^{-1}$) followed by *Celastrus paniculatus* and minimum in *Tinospora cordifolia* (0.61 mg $g^{-1}$). The descending order of four selected trees in term of ascorbic acid was *Terminalia chebula* > *Phyllanthus emblica* >*Terminalia bellirica* >*Terminalia arjuna*, however, it was statistically at par in *Terminalia arjuna* and *Terminalia bellirica* (Table 4). There

**Table 2.** Plant classification based on APTI, biological parameters and socio-economic parameters

| Grading character | Pattern of assessment | Grade allotted * |
|---|---|---|
| a) Tolerance | | |
| APTI | 3.1-4.5 | + |
| | 4.6-6.0 | ++ |
| | 6.1-7.5 | +++ |
| | 7.6-9.0 | ++++ |
| | 9.1-10.5 | +++++ |
| b) Biological and socioeconomic | | |
| Plant habit (Ph) | Small | - |
| | Medium | + |
| | Large | ++ |
| Canopy structure (Cs) | Sparse/irregular/globular | - |
| | Spreading crown/open/semi-dense | + |
| | Spreading dense | ++ |
| Type of plant (Tp) | Deciduous | - |
| | Evergreen | + |
| c) Laminar structure | | |
| Size (Ls) | Small | - |
| | Medium | + |
| | Large | ++ |
| Texture (Tx) | Smooth | - |
| | Coriaceous | + |
| Hardiness (H) | Delineate | - |
| | Hardy | + |
| Economic value (Ev) | Less than three uses | - |
| | Three or four uses | + |
| | Five or more uses | ++ |

* Maximum score that can be attained is 16, which corresponds to 100%

**Table 3.** Anticipated performance index (API) of plant species

| Grade | Score (%) | Assessment category |
|---|---|---|
| 0 | Up to 30 | Not recommended |
| 1 | 31–40 | Very poor |
| 2 | 41–50 | Poor |
| 3 | 51–60 | Moderate |
| 4 | 61–70 | Good |
| 5 | 71–80 | Very good |
| 6 | 81–90 | Excellent |
| 7 | 91-100 | Best |

was a significant variation of ascorbic acid content in different plant species, which might be due to their different genetic makeup. Being an antioxidant higher the ascorbic acid content in plant species more will be its pollution tolerance ability (Tambussi et al., 2000) and vice-versa which was observed in *Valeriana jatamansi* and *Lavandula angustifolia,* respectively.

**Total chlorophyll content (T):** Plant species that are

**Table 4.** Air pollution tolerance index (APTI)

| Plant species | A (mg $g^{-1}$) | T (mg $g^{-1}$) | P | R (%) | APTI |
|---|---|---|---|---|---|
| Herbs | | | | | |
| *Acorus calamus (AC)* | 1.61 | 0.79 | 7.51 | 73.39 | 8.67 |
| *Bryophyllum pinnatum (BP)* | 0.31 | 0.47 | 4.67 | 80.15 | 8.17 |
| *Cymbopogon citrates (CC)* | 0.67 | 0.35 | 6.77 | 83.12 | 8.79 |
| *Lavandula angustifolia (LA)* | 0.22 | 0.47 | 7.48 | 66.43 | 6.82 |
| *Matricaria chamomilla (MC)* | 0.31 | 0.65 | 7.03 | 50.75 | 5.31 |
| *Melissa officinalis (MO)* | 0.96 | 1.08 | 7.42 | 45.88 | 5.41 |
| *Mentha piperita (MP)* | 1.22 | 0.93 | 7.19 | 39.02 | 4.89 |
| *Ocimum basilicum (OB)* | 0.29 | 0.71 | 5.03 | 78.13 | 7.98 |
| *Ocimum sanctum (OS)* | 0.47 | 0.52 | 7.63 | 59.37 | 6.32 |
| *Origanum vulgare (OV)* | 0.38 | 0.89 | 7.78 | 77.86 | 8.12 |
| *Pelargonium graveolens (PG)* | 1.20 | 0.47 | 4.45 | 78.96 | 8.49 |
| *Rosemarinus officinalis (RO)* | 0.63 | 0.59 | 7.47 | 85.21 | 9.02 |
| *Silybum marianum (SM)* | 0.38 | 0.34 | 4.31 | 65.57 | 6.73 |
| *Spilanthes acmella (SA)* | 1.64 | 1.15 | 7.32 | 90.12 | 10.41 |
| *Tagetes minuta (TM)* | 1.64 | 0.51 | 6.61 | 42.16 | 5.38 |
| *Thymus vulgaris (TV)* | 0.98 | 0.43 | 7.59 | 91.22 | 9.91 |
| *Valeriana jatamansi (VJ)* | 2.04 | 0.86 | 6.97 | 68.65 | 8.46 |
| Mean | 0.88 | 0.66 | 6.66 | 69.18 | 7.58 |
| Shrubs | | | | | |
| *Asparagus racemosus (AR)* | 0.60 | 0.19 | 8.07 | 59.36 | 6.43 |
| *Justicia adhatoda (JA)* | 0.81 | 0.75 | 8.61 | 57.41 | 6.49 |
| *Murraya koenigii (MK)* | 1.20 | 0.63 | 5.63 | 69.84 | 7.73 |
| *Vitex negundo (VN)* | 1.34 | 0.75 | 6.97 | 57.35 | 6.77 |
| *Withania somnifera (WS)* | 0.64 | 0.62 | 7.42 | 57.16 | 6.23 |
| *Zanthoxylum armatum (ZA)* | 1.21 | 0.60 | 7.23 | 47.69 | 5.71 |
| Mean | 0.97 | 0.59 | 7.32 | 58.14 | 6.56 |
| Climbers | | | | | |
| *Celastrus paniculatus (CP)* | 1.22 | 1.17 | 7.12 | 43.86 | 5.45 |
| *Tinospora cordifolia (TC)* | 0.61 | 1.26 | 7.64 | 79.84 | 8.53 |
| *Tylophora indica (TI)* | 1.23 | 0.21 | 7.42 | 57.94 | 6.74 |
| Mean | 1.02 | 0.88 | 7.39 | 60.55 | 6.91 |
| Trees | | | | | |
| *Phyllanthus emblica (PE)* | 0.77 | 0.31 | 4.36 | 36.41 | 3.99 |
| *Terminalia arjuna (TA)* | 0.41 | 1.77 | 7.30 | 54.07 | 5.77 |
| *Terminalia bellirica (TB)* | 0.44 | 0.42 | 5.64 | 41.72 | 4.44 |
| *Terminalia chebula (TC)* | 1.22 | 0.63 | 5.74 | 36.38 | 4.42 |
| Mean | 0.71 | 0.78 | 5.76 | 42.15 | 4.66 |

APTI ≤ 11, sensitive species; 11–16, intermediate species; ≥ 16, tolerant species (Singh and Verma 2007) susceptible to air pollution may exhibit reduced photosynthetic activity, which causes their leaves to lose chlorophyll and carotenoids. (Rai 2016, Uka et al., 2017). There was a significant variation in the total chlorophyll content of selected herbs, shrubs, climbers and trees individually. The T values for the 30 plant species ranged

**Table 5.** Anticipated performance index (API) score of 30 plant species

| Plant species | APTI | Ph | Cs | Tp | Ls | Tx | H | Ev | Total | Score (%) | API Category |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Herbs | | | | | | | | | | | |
| *Acorus calamus* | ++++ | - | - | + | ++ | - | + | ++ | 10 | 62.5 | Good |
| *Bryophyllum pinnatum* | ++++ | - | - | + | + | - | + | - | 7 | 43.7 | Poor |
| *Cymbopogon citratus* | ++++ | + | - | + | ++ | + | + | ++ | 12 | 75.0 | Very good |
| *Lavandula angustifolia* | +++ | - | - | + | - | + | + | + | 7 | 43.7 | Poor |
| *Matricaria chamomilla* | ++ | - | - | - | - | + | + | ++ | 6 | 37.5 | Very poor |
| *Melissa officinalis* | ++ | - | - | + | - | + | + | + | 6 | 37.5 | Very poor |
| *Mentha piperita* | ++ | - | - | + | - | + | + | + | 6 | 37.5 | Very poor |
| *Ocimum basilicum* | ++++ | - | - | + | - | - | + | ++ | 8 | 50.0 | Poor |
| *Ocimum sanctum* | +++ | - | - | + | - | - | - | ++ | 6 | 37.5 | Very poor |
| *Origanum vulgare* | ++++ | - | - | + | - | + | + | - | 7 | 43.7 | Poor |
| *Pelargonium graveolens* | ++++ | - | - | - | - | + | + | - | 6 | 37.5 | Very poor |
| *Rosemarinus officinalis* | ++++ | - | - | + | - | - | + | + | 7 | 43.7 | Poor |
| *Silybum marianum* | +++ | - | - | - | + | + | + | - | 6 | 37.5 | Very poor |
| *Spilanthes acmella* | +++++ | - | - | + | - | + | + | - | 8 | 50.0 | Poor |
| *Tagetes minuta* | ++ | - | - | - | - | + | + | + | 5 | 31.2 | Very poor |
| *Thymus vulgaris* | +++++ | - | - | + | - | + | - | ++ | 9 | 56.2 | Moderate |
| *Valeriana jatamansi* | ++++ | - | - | + | + | + | + | ++ | 10 | 62.5 | Good |
| Mean | 7.4 | 46.3 | Poor | | | | | | | | |
| Shrubs | | | | | | | | | | | |
| *Asparagus racemosus* | +++ | + | - | + | - | + | + | - | 7 | 43.7 | Poor |
| *Justicia adhatoda* | +++ | + | - | + | + | - | + | - | 7 | 43.7 | Poor |
| *Murraya koenigii* | ++++ | - | + | + | - | - | + | + | 8 | 50.0 | Poor |
| *Vitex negundo* | +++ | ++ | ++ | + | - | + | - | - | 9 | 56.2 | Moderate |
| *Withania somnifera* | +++ | + | + | - | + | + | + | - | 8 | 50.0 | Poor |
| *Zanthoxylum armatum* | ++ | + | - | + | - | - | + | - | 5 | 31.2 | Very poor |
| *Asparagus racemosus* | +++ | + | - | + | - | + | + | - | 7 | 43.7 | Poor |
| Mean | 7.3 | 45.5 | Poor | | | | | | | | |
| Climbers | | | | | | | | | | | |
| *Celastrus paniculatus* | ++ | ++ | - | + | + | + | + | - | 8 | 50.0 | Poor |
| *Tinospora cordifolia* | ++++ | ++ | - | + | + | - | + | - | 9 | 56.2 | Moderate |
| *Tylophora indica* | +++ | ++ | - | + | + | - | + | - | 8 | 50.0 | Poor |
| Mean | 8.3 | 52.1 | Moderate | | | | | | | | |
| Trees | | | | | | | | | | | |
| *Phyllanthus emblica* | + | ++ | ++ | - | - | + | + | - | 7 | 43.7 | Poor |
| *Terminalia arjuna* | ++ | ++ | ++ | - | + | + | + | - | 9 | 56.2 | Moderate |
| *Terminalia bellirica* | + | ++ | ++ | - | + | + | + | - | 8 | 50.0 | Poor |
| *Terminalia chebula* | + | ++ | ++ | - | + | + | + | - | 8 | 50.0 | Poor |
| Mean | 8.1 | 50.1 | Moderate | | | | | | | | |

between 0.19 to 1.77 mg g (Table 4).. Chlorophyll content in leaves of different herbs ranged from 0.34 to 1.15 mg $g^{-1}$, in shrubs from 0.19 to 0.75 mg g, in climbers from 0.21 to 1.26 mg g and in trees from 0.31 to 1.77 mg g (Table 4). Begum and Harikrishna (2010) reported that chlorophyll content varied from species to species. Tripathi and Gautam (2007) explained that a decrease in the total chlorophyll content in plant leaves subjected to air pollution stress may be the result of air pollutants like SPM attacking the chloroplast.

**Leaf extracts pH (P):** There was a significant variation in leaf extract pH ranged between 4.31 and 8.61 (Table 4). For herbs 4.31 to 7.78, shrubs 5.63 to 8.61, climbers 7.12 to 7.64 and trees 4.36 to 5.76. The highest (most basic) value of was observed in climbers and the lowest (most acidic) in trees (see the order: climbers > shrubs > herbs > trees). The pH of approximately 7 is essential as it creates optimal conditions for photosynthesis in tolerant tree species, while less tolerant plants usually have lower stomatal sensitivity and photosynthetic activity (Rai 2016).

**Relative water content (R):** *R* values for the 30 plants range between 36.38 and 91.22 % (Table 4). In herbs ranged between 39.02 and 91.22%, shrubs 47.69 and 69.84 %, climbers 43.86 and 79.84 % and in trees 36.38 and 54.07 %. The average relative water content was observed highest in shrub (69.18 %), followed by climbers (60.55%), shrubs (58.14 %) and Trees (42.15 %). The non-significant variation in *R* value was observed in herbs, shrubs, trees but, significant in climbers (Table 4). Nwadinigwe (2014) noted that the relative water content varied with different plant species. The ability of a plant species to withstand pollution may be the reason for its maximum relative water content. The relative water content was characterized by means of turgor, growth, stomatal conductance, transpiration, photosynthesis, and respiration; hence, higher the *R* more will be the tolerance to the stressful environmental conditions (Rai 2016).

**APTI:** The non-significant variation in APTI was recorded which varied from 3.99 to 10.4. As per the criteria of Singh and Verma (2007) out of 30 plants 26.8 % were observed as very poor, 50% as poor, 13.3% as moderate 6.6% as good and 3.3% as very good. No plant was observed under excellent and best category. The mean APTI value of observed highest for herbs (7.58) followed by climbers, shrubs and lowest for trees (4.66). Among the herbs highest APTI was in *Spilanthes acmella* (10.41) followed by *Thymus vulgaris* and lowest in *Mentha piperita* (4.892), in climbers highest in *Tinospora cordifolia* (8.53) and lowest in *Celastrus paniculatus* (5.45), in shrubs the highest was for *Murraya koenigii* (7.74) and lowest for *Zanthoxylum armatum* (5.71) similarly for tree it was highest for *Terminalia* arjuna (5.770) and lowest (3.99) was for *Phyllanthus emblica* (Table 4). Gholami et al. (2016) investigated that air pollution tolerance vary from species to species depending on the plant's ability to tolerate the impacts of air pollution.

**API:** Among the selected herbs *Cymbopogon citratus* stand under very good category, *Acorus calamus* and *Valeriana jatamansi* under good category and *Thymus vulgaris* under moderate category and remaining under poor and very poor categories (Table 5). Lowest API of *Bryophyllum pinnatum*, *Lavandula angustifolia*, Ocimum *basilicum*, *Origanum vulgare*, *Rosemarinus officinalis*, *Spilanthes acmella* was due to low APTI values, sparse canopy structure and low economic value.

Among the selected shrubs high API of *Vitex negundo* was attributed to large plant habit, spreading dense canopy structure along with better laminar characteristics. Low API of Asparagus *racemosus, Justicia adhatoda, Murraya koenigii* and *Withania somnifera* was probably due to their sparse canopy structure, laminar characteristics as well as low economic value. The climbers *Tinospora cordifolia* stand in moderate category, whereas *Celastrus paniculatus* and *Tylophora indica* fell under poor category respectively. The tree *Terminalia arjuna* fell under moderate category, whereas *Phyllanthus emblica*, *Terminalia bellirica* and *Terminalia chebula* fell under poor category, respectively (Table 5). Bahadoran et al. (2019) reported that a combination APTI and API indices could be quite useful for assessing plant responses to a variety of pollutants for green belt purposes. In addition, the plant's socio-economic relevance played a significant role in determining its API (Table 5).

## CONCLUSION

The study indicated that in the prevailing air conditions *Ocimum basilicum, Spilanthes acmella, Murraya koenigii, Withania somnifera, Celastrus paniculatus, Tylophora indica, Terminalia bellirica* and *Terminalia chebula* should be grown in mid hills zone of Himachal Pradesh which possessed good performance index. These species can also be included when the objective is to use them as bioindicators of air quality, due to their high susceptibility to atmospheric pollutants and poor performance in urban environments.

## AUTHOR'S CONTRIBUTIONS

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Shilpa Sharma, Mohinder Brahmi, Satish Bhardwaj, and Bhupender Dutt. The first draft of the manuscript was written by Shilpa Sharma and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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