ASSESSMENT OF AIR POLLUTION TOLERANCE INDEX OF PLANT SPECIES SURROUNDING CEMENT INDUSTRY AT BARMANA IN HIMACHAL PRADESH

Thesis

by

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(F-2021-19-M)

submitted to

Dr YASHWANT SINGH PARMAR UNIVERSITY
OF HORTICULTURE AND FORESTRY
SOLAN (NAUNI) HP -173 230 INDIA

in

Partial fulfilment of the requirements for the degree

of

MASTER OF SCIENCE
ENVIRONMENTAL SCIENCE

DEPARTMENT OF ENVIRONMENTAL SCIENCE
COLLEGE OF FORESTRY

2023

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CERTIFICATE-I

This is to certify that the thesis entitled**, "Assessment of Air Pollution Tolerance Index of plant Species surrounding Cement Industry at Barmana in Himachal Pradesh"** submitted in partial fulfillment of the requirements for the award of degree of **Master of Science** in the discipline of **Environmental Science** to Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan (HP)-173230 is a Bonafide research work carried out by **Mr Ajay (F-2021-19-M)** son of Shri Murari Lal under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of the investigation have been fully acknowledged.

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Dated:

(Dr PK Baweja)
Major Advisor

CERTIFICATE-II

This is to certify that the thesis entitled, **"Assessment of Air Pollution Tolerance Index of Plant Species surrounding Cement Industry at Barmana in Himachal Pradesh"** submitted by **Mr. Ajay (F-2021-19-M)** s/o Shri Murari Lal to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP) - 173 230, India in partial fulfilment of the requirements for the degree of Master of Science Environmental Science in the discipline of **Environmental Science** has been approved by the Advisory Committee after an oral examination of the student in collaboration with the External Examiner.

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ACKNOWLEDGEMENT

With limitless humility, I would like to thank God, the Almighty, who imparted me with good health, courage and strength to go through this crucial juncture.

*It is an honor for me to express my sincere gratitude and debt of gratitude to my major advisor**, Dr PK Baweja**, Principal Scientist (Agrometeorology), Directorate of Extension Education in Dr YSP UHF, Nauni, Solan (HP), for her never-ending inspiration, insightful advice, cordial demeanor, genial disposition, priceless guidance, ongoing and constructive criticism, consistent encouragement, and parental love that helped me to overcome every obstacle that stood in my way throughout the research.*

*I place my indebtedness to **Dr SK Bhardwaj,** Professor and Head, Department of Environmental Science and my heartiest thanks to my advisory members **Dr HC Sharma**, Assistant Professor, Department of Environmental Science and **Dr ML Verma,** Principal Scientist, Department of Soil Science and Water Management for their valuable guidance, help and support rendered during the investigation.*

I cordially acknowledge the assistance extended by Mrs Balbir Kaur, Mrs Anita, Mrs Monika, Mr Jitender, Mr Keshav and Mr Bansal for timely and sincere help while experimentation and administrative work.

*I owe this pride place and can never forget to express my respect and gratitude to my parents **Shri Murari Lal** and **Smt Shakuntla Devi** for their constant faith, selfless persuasion, sacrifice, heartful blessings and constant inspiration for my sucess.*

*I do not find words to express my sincere gratitude towards my friend **Priyanka Kumari** for her role in making my journey possible in every way she could. Language seems to be inadequate media to express my deepest feeling to **Aanchal Chaudhary, Akshay Chadda, Abhishek, Shalini, Shivansh Gautam, Rishav Kumar, Itika, Saurabh Saini, Dr. Anmol Negi** for their outstanding and valuable help, cooperation and encouragement.*

*Feelings from the core of my heart, molded into words could not convey what I truly wish to express to my friends who believed in me and motivated me. I will forever value the warmest presence of my friends **Ankita Kakkar, Tanvi Sharma, Kriti Thakur, Vasu, Meenakshi, Kirti, Dheeraj** and my seniors **Vijeta Thakur, Amita Sharma, Pooja, Neha Awasthi, Lekhika Parihar and Jyoti Joshi.***

Thanks, are also due to university staff for their valuable help and co-operation

Needless to say, omissions and errors are mine

Place: Nauni, Solan
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CONTENTS

ABBREVIATIONS USED

%	:	Per cent
API	:	Anticipated performance index
APTI	:	Air pollution tolerance index
CD	:	Critical difference
CO_2	:	Carbon Dioxide
CV	:	Coefficient of variance
df	:	Degree of freedom
et al.	:	And others
Fig.	:	Figure
g	:	Gram
km	:	Kilometer
m	:	Meters
mg	:	Milligram
NH	:	National Highway
No.	:	Number
NS	:	Non-significant
pH	:	Potential of Hydrogen
RBD	:	Randomized block design
RWC	:	Relative water content
SD	:	Standard deviation
Viz.	:	Videlicet

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Chapter-1

INTRODUCTION

Plants are an integral part of our ecosystem and most likely to affected by air borne pollutants. Biomonitoring of plants is basic tool to evaluate the impact of air pollution. Thus, the vegetation become increasingly important not only for social reasons but also for the local and regional air quality. Environment comprises a very large and intertwining complex of water, air, soil and biological life, which includes nature and all living beings affected by human activities and vice versa (Tabatabae *et al.* 2012).

Air quality in developing countries has been deteriorating severely in recent decades because of substantial increases in traffic, vehicle and industrial emissions. Decline in urban vegetation cover also leads to deteriorating the air quality. Air pollution is an inevitable harmful byproduct of rapid industrialization and urbanization, responsible for variety of deleterious effects on both human and plant communities (Kim *et al.* 2015). Plants are known to play an important role in reducing air pollution by trapping particulate matter and absorbing gaseous pollutants (Hamraz *et al.* 2014). Only plants are capable of cleaning the pollutants by absorbing and metabolising them. As a result, the significance of vegetation in air pollution abatement has become more recognised in recent years (Woo and Je 2006).

Being second largest manufacturing industry in India, cement industry is a potential anthropogenic source of air pollution in the form of Suspended Particulate Matter (SPM), SO_x, NO_x and carbon monoxide (CO) which causes harm to faunas as well as the biodiversity of the region (Radhapriya *et al.* 2012).

Among the damages caused by air pollutants, the most significant ones occur in the leaves of plants include chlorosis and necrosis of leaves. Plants exposed to pollutants showed a wide variety of stress responses (Deepalakshmi *et al.* 2013).

Emission from the cement industries can pollute the ambient air quality of the atmosphere. Particulate dust and greenhouse gases (GHG) such as oxides of nitrogen (NO_x), carbon dioxide (CO_2), oxides of sulphur (SO_x) and carbon monoxide (CO) are some of the basic components of air pollutants. These pollutants are emitted from operations such as grinding, quarrying, kiln operation, power generation, transportation and bagging. Cement industries account for around 5% of the total global CO_2 emissions, which contribute to global warming and climate change (Ian and David 2002).

The dust emitted by cement industry is frequently carried with by the flow of wind and deposited on places near and distant from the industry. Such depositions of particulate matter and other pollutants interfere with normal metabolic activities of plants, causing reduced photosynthesis activity which includes the physiological and other biochemical response results in direct injury which deteriorate the growth and quality of crop especially decline in yield (Ediagbonya *et al.*2013; Prajapati 2012).

Plant sensitivity and response to air pollution varies. The physiological and biochemical responses of plants to air pollution can be understood by examining the elements that govern resistance and susceptibility. Air pollution has also been demonstrated to have an effect on ascorbic acid levels (Conklin 2001). Ascorbic acid is an antioxidant that helps to protect plants from oxidative damage caused by aerobic metabolism, photosynthesis and a variety of other contaminants due to air pollution. When the plants exposed to air pollution, the water content in plant tissues helps to preserve the plant's physiological balance. Chlorophyll is involved in plant productivity and its amount is direct indicator of leaf damage caused by pollution. The estimation of chlorophyll in air polluted condition is an essential tool for analysing the effects of air pollution on plants since it plays an important role in plant metabolism and any decrease in chlorophyll concentration in leaves has been found to be correlated directly with plant development (Aji *et al.* 2015).

Biomonitoring of plants is an important tool to evaluate the impact of air pollution. Since last decade, urban vegetation became increasingly important not only for social reasons but mostly for affecting local and regional air quality besides other ecosystem services. Air Pollution Tolerance Index (APTI) is considered as a best tool to select bioindicator species. It can be evaluated through four biochemical parameters such as ascorbic acid (A), total chlorophyll content (T), leaf extract pH (pH) and relative water content (R). Species that score higher APTI values are considered as the most tolerant species against polluted environment and act as green belt. The species which scored low APTI value have been considered as the most sensitive species and act as bio-indicator species with respect to air pollution (Socha *et al.* 2017).

The ACC Limited Gagal cement plant Barmana in district Bilaspur, Himachal Pradesh is emitting a significant air pollution, smoke and dust from the cement plant which is harming the ecology. Leaves of plants and grass blades growing in vicinity of the cement industry can be seen covered with a thick layer of dust, which is affecting the local vegetation, its growth, quality and yield reduction of locally grown cereal, vegetable and fruit crops by number of ways such as reduced photosynthetic activity, reduced transpiration rate, reduced respiration rate, reduced chlorophyll content and other parameters. Therefore, keeping in view the above facts, the present investigation has been proposed to study the following objective: -

Objective

Assessment of Air pollution tolerance index of plant species around Barmana cement industry

Chapter-2

REVIEW OF LITERATURE

The information available in the literature pertaining to the present studies entitled, **"Assessment of Air Pollution Tolerance Index of Plant Species surrounding Cement Industry at Barmana in Himachal Pradesh"** have been reviewed by surfing various research papers published on the relevant topic throughout the world for thorough understanding and detailed investigations on air pollution and its components especially their affect on the plant species grown alongside of road surrounding the cement industry.

Thus, the relevant literature have been collected and discussed with the following objective:

Assessment of Air pollution tolerance index of plant species around Barmana cement industry

2.1. Leaf dust accumulation

2.2. Relationship of plant characteristics with air pollution

2.2.1. Physical and physiological characteristics

2.2.2. Biochemical characteristics

2.3. Air Pollution Tolerance Index (APTI)

2.4. Anticipated Performance Index (API)

2.1. Leaf dust accumulation

Ade-Ademilua *et al.* (2008) studied the effect of cement dust pollution on heavy metal uptake, growth, chlorophyll content, vitamin content and metal accumulation of *Celosia argentea* (Lagos spinach). The spinach plants were polluted with 10.2 g m^{-2} cement dust. The results demonstrated that cement dust had no effect on the germination of *C. argentea* seeds. Polluted plants had a considerable reduction in shoot length and total leaf area. Throughout the investigation, the dry weight of contaminated plants was considerably lower than that of control plants. The frequency and size of the polluted leaves' epidermal cells and stomata were drastically altered. Vitamin A levels were dropped by 62%, vitamin B levels by 55% and vitamin C levels by 24%. Despite an increase in iron and calcium concentrations of 78% and 26%, respectively, there was a substantial buildup of heavy metals such as aluminum (Al), copper (Cu) and zinc (Zn) in the polluted plants. These findings might inhibited the vegetable cultivation crops in places prone to cement dust contamination.

Rai *et al.* (2010) investigated ten annual plant species viz., *Abelmoschus esculentus, Celosia cristata, Coleus blumei, Cyamopsis tetragonolobus, Gomphrena globosa, Impatiens balsamina, Ocimum sanctum, Phaseolus vulgaris, Solanum melongena and Zinnia elegans* their growth parameters and leaf morphological features. They were exposed to dust for 60 days in an experiment. Micro-morphological characteristics such as wax, cuticle, epidermis, stomata and trichomes were studied using light and scanning electron microscopes. When the dust-treated plants were compared to the relevant controls, significant variations in growth indices and micro-morphological traits were observed. Growth metrics, epidermal cell size and stomata were all reduced and cuticle damage was also detected. They concluded that the relative fraction of fine particles played significant role in limiting the plant growth than ultra-fine and coarse particles.

Chukwu (2012) studied the impact of cement dust on *Chromolaena odorata* and *Manihot esculenta* around cement industry in Nigeria. The results attained that cement dust had direct impact on photosynthesis rate of plants especially affected the chlorophyll amount and number of stomata. Chlorophyll synthesis was impaired by high accumulation of dust accumulation on leaf surfaces.

Younis *et al.* (2013) assessed the dust accumulation capacity of *Ficus carica* at eight different locations in and around Multan. *Ficus carica* exhibited the highest dust-gathering capacity along roadsides due to its long petioles and widely ovate leaves. Furthermore, the species' degree of pubescence and vast surface area enable it to trap more dust particles, which is a major manifestation of particulate pollution. As a result, *Ficus carica* played key contribution in removing dust pollution from the environment. They proposed that planting *Ficus carica* in dusty places might helped to minimize particle pollution for protection to human health.

Dwivedi and Dubey (2017) studied the effect of cement industrial dust on various parts of *Mangifera indica* trees growing at different distances from the cement industrial belt at Maihar, Satna (M.P.). Sampling was done at different distances ranging from 0.5-2.0 kms from the point source. The site was compared with controlled site of Uchehra (15 km away from the cement industry). Increased concentration of cement dust pollutants caused invisible injuries such as declined photosynthetic ability and closure of leaf stomata and thus affected the growth and productivity of Mango. Besides the deleterious effects of the dust were expressed by the reduction in size of the leaf, damaged leaf margin and changed the colour. Overall study showed that Mango trees grown near cement industries were physiologically affected adversely as far as commercially growing for fruit production.

Alhesnawi *et al.* (2018) evaluated the dust accumulation capabilities of seven different plant species. The highest capacity for retaining dust was observed in *C. lancifolius* attained 6.45 mg cm^{-2}, while the lowest capacity was seen in *F. nitida* with 0.99 mg cm^{-2}. The sequence of dust deposition on leaf surfaces followed this order: *C. lancifolius* > *Z. spina christi* > *O. europaea* > *N. oleander* > *D. iscosa* > *E. camaldulensis* > *F. nitida*. The study highlighted specific morphological attributes that significantly influenced the interception of dust from the environment. These attributes included the orientation of leaves on the main stem, the size and shape of leaves, the surface texture (smooth or ridged), the presence or absence of trichomes (hair-like structures) and the presence of wax on leaf surfaces. These characteristics, either individually or in combination, played crucial role in determining the plant's ability to capture and retain dust particles.

Chaudhary and Rathore (2018) evaluated dust removal efficiency of urban trees. The study was conducted at Gandhinagar town and found that the highest level of dust was deposited during winter season followed by summer and lowest in monsoon season. Dust deposition had a detrimental impact on leaf dry weight, photosynthetic pigments, membrane permeability, stomatal index and the development of oxidative stress as evaluated by ascorbic acid in all experimental trees. Their study concluded that the *Ficus religiosa* was superior air pollution tolerant plant species with moderate dust removal capacity while *Dalbergia sissoo* was moderately air pollution tolerant species with highest dust removal capacity.

Meerabai and Subbalakshmi (2022) studied the influence of quarry dust and cement dust on selected trees growing around the quarries and around Panyam cements & mineral industries Ltd. at Bethamcherla in Andhra Pradesh. They recommended that the plant species viz; Azadirachta *indica, Ficus benghalensis L., Holoptelea integrifolia Roxb.* and *Terminalia catappa L.* attained considerably increased APTI percentage at both the study sites. They further recommended that species grown in polluted areas surrounded the cement industry acted as green belt for protection of atmosphere against dust pollutants.

2.2. Relationship of plant characteristics with air pollution

2.2.1. Physical characteristics

Beckett *et al.* (2000) found that leaf orientation, age, roughness and wettability of the leaf surface all influenced the dust interception and retention. They attained that several characteristics of the surfaces of various types of leaves differed. Some leaves have a higher surface stiffness or roughness, which might affected the stickiness of particle solubility. Stickier leaves were better at collecting particles because more particles stick to their surface. As a result, certain plant leaves were found to be more effective for capturing the dust than others.

Rai *et al.* (2010) investigated the sticky particulate matter released by automotive exhausts was the primary ingredient of particulate pollution that was deposited on the leaf surfaces of common roadside plants. *T. arjuna* (2.31 mg/cm^2) > *C. fistula* (1.47 mg/cm^2) > *B. mahara* (1.33 mg/cm^2) > *P. longifolia* (0.97 mg/cm^2). They also found that these plants had increased cuticle injury or epidermal cells with distorted stomata cell.

Assadi *et al.* (2011) studied the effects of air pollution on several physiological and morphological features of *Eucalyptus camaldulensis* in southwest Iran from Gamboeh Park in southwest Ahvaz (a clean zone) and Foolad Industrial Company in southwest Ahvaz (a polluted location). Leaf area, stomata count, leaf and petiole length and leaf width were all investigated. The results revealed that the leaves of *Eucalypus camaldulensis* were reduced in polluted areas compared to clean areas.

Kumar *et al.* (2013) reviewed the utility of the plant species in controlling the environmental pollution. They hypothesized that evergreen plants, large leaved, rough bark, ecologically compatible, low water requirement, high absorption of air pollutants, agroclimatic had the pollution tolerance & dust scavenging capacity. They further suggested that fast-growing species may be planted with high carbon sequestration to neutralize the carbon production in various industries.

Rai and Panda (2014) reported that foliar surface of plants were constantly exposed to the surrounding atmosphere and thus the primary receptor of dust and physical traits may be used to determine the level of dust in the surroundings as well as the ability of individual plant species to intercept and mitigate it. They also reported that plants with waxy coating, rough surface and folded margins acquired more dust than plants with smooth, flat surface and without folded margins.

Kushwaha *et al.* (2018) revealed that reduction in length and width of epidermal and stomatal guard cells on dorsal and ventral sections of the leaves of plant species under consideration grown on various polluted sites as compared to university campus of Rewa city. The reduction in stomatal size could be considered as an adaptive response to avoid entry of harmful constituents of vehicular exhaust. Distorted shapes of stomata were also due to lowered pH in cytoplasm of guard cell.

2.2.2. Biochemical characteristics

Tripathi and Gautam (2007) studied the variation in biochemical parameters like chlorophyll, protein, soluble sugar, free amino acid, ascorbic acid, nitrate reductase, superoxide dismutase and peroxidase in the leaves were found to be pollution load dependent. These variations may be used as indicators of air pollution for early diagnosis of stress or as a marker for physiological damage to trees prior to the onset of visible injury symptoms.

Rai (2016) revealed that air pollution stand as a significant global challenge during the current Anthropocene period, characterized by rapid industrialization and urban expansion. More specifically, the pollution resulted from particulate matter (PM) posed danger to both the natural environment as well as human well-being. He considered the attributes of vegetation, such as its widespread presence and extensive surface interaction became crucial. It became evident that vegetation served as valuable gauge of the comprehensive repercussions of PM pollution and its detrimental effects on plants. The current analysis critically examined how PM pollution and its elements affected various biochemical parameters such as pigment levels, enzymes, ascorbic acid, protein and sugar content, along with physiological aspects like pH and relative water content in plants. He investigated resilient plants with capacity to endure PM pollution and possessed high Air Pollution Tolerance Index (APTI) and Air Pollution Index (API) values may be identified. The robust plants could be identified as effective biomonitoring agents and potentially recommended for the purpose of establishing green areas.

2.2.2.1. Ascorbic acid content

Prajapati and Tripathi (2008) studied the dust interception efficiency of some selected tree species and impact of dust deposition on ascorbic acid content of leaves. The plant species selected for the study were *Ficus religiosa, Ficus benghalensis, Mangifera indica, Dalbergia sissoo, Psidium guajava* and *Dendrocalamus strictus.* It was found that ascorbic acid content increased with the increment in dust deposition. Maximum dust interception was attained by *Dalbergia sisso* and least by *Dendrocalamus strictus*. They concluded that trees act as sink of air pollutants and reduced the concentration in the air.

Jyothi and Jaya (2010) evaluated Air Pollution Tolerance Index (APTI) of selected tree species along roadsides in Thiruvananthapuram, Kerala. The study revealed higher baseline levels of ascorbic acid content in the leaves of *Polyalthia longifolia* (Sonner) among the evergreen trees studied and *Clerodendrum infortunatum* L., among the shrubs studied, indicated tolerance to pollutants that normally affected the roadside vegetation. Which exhibited higher APTI value of 7.43. Lower ascorbic acid levels in the leaves of other plant species tested support the plants sensitivity to contaminants, particularly vehicular exhausts.

Chandawat *et al.* (2011) studied the Air Pollution Tolerance Index (APTI) of the tree species at cross roads of Ahmedabad city in Gujarat. The ascorbic acid content of all plant species increased as the pollution load increased, which could be owing to increased rate of generation of reactive oxygen species during the photo-oxidation process of SO_2 to SO_3, where sulphites are produced from SO_2 absorbed. SO_2 exposure increases the free radical scavenger ascorbic acid, which protects plants from oxidative stress damage. Thus, higher ascorbic acid content of the plant is a sign of its tolerance against sulphur dioxide pollution. Similar, reports were published by Chaudhary and Rao (1977) and Varshney and Varshney (1984) revealed lower ascorbic acid content in leaves of *A. indica* and *P. logifolia* supported sensitive nature of these plants against automobile exhausts.

Raina and Bala (2011) studied the effect of vehicular pollution on *Duranta repens* L. in Jammu city. They found that gaseous pollutants entered the leaves through stomata by the mechanism of diffusion pathway as SO_2. Thus, plants increase the area for proper gaseous exchange as an adaptation. Ascorbic acid concentration also increased significantly in *Duranta repens* L. at polluted sites as compared to reference. The Air Pollution Tolerance Index (APTI) was also calculated and found to have increased significantly in plants at polluted locations. This indicated that *Duranta repens* L. acted as a sink for air pollutants and could be effectively employed for phyto-monitoring auto exhaust pollution along the roadside of busy traffic ways.

Manjunath and Reddy (2019) assessed the air pollution tolerance index (APTI) of six plant species that were commonly grown in the polluted regions of Bengaluru, Karnataka.

Statistically significant difference was obtained between polluted and non-polluted for ascorbic acid content. The average ascorbic acid content of plants in polluted areas had experienced a significant increase by 304.52 ± 7.04 µg g^{-1} compared to 239.42 ± 23.69 µg g^{-1} in non-polluted areas. The highest influence of air pollution on the total ascorbic acid content had been recorded in *B. spectabilis* (351.75 µg g^{-1} in polluted areas; 226.97 µg g^{-1} in non-polluted areas) and *V. rosea* (487.65 µg g^{-1} in polluted areas; 328.67 µg g^{-1} in non-polluted areas). Among the evaluated parameters ascorbic acid content regressed with the APTI scores attained significant variability (R^2 0.88). APTI of >23 was recorded in *B. spectabilis* and *V. rosea*, indicated the tolerance to air pollution. However, *O. sanctum* recorded lowest APTI thus acted as biomonitoring of the air pollution. *L. aspera*, *V. rosea*, and *B. spectabilis* with APTI score >16 may be acted as green belt in the polluted areas.

2.2.2.2 Total chlorophyll content

Chlorophyll is an important tool for assessing the impact of air pollution on plants because it is involved in plant metabolism. Reduced chlorophyll concentrations equate directly with the decreased plant growth (Marinari *et al.* 2007).

Jyothi and Jaya (2010) studied the seasonal chlorophyll content of selected plant species under the summer, monsoon and winter seasons. Regardless of season, all plant species at station-10 (control condition) had the highest chlorophyll contents. During the study period, all other sites showed substantial reduction in chlorophyll content with the biggest drop at station-6, which was the urban centre (Thampanoor of district Thiruvananthapuram, Kerala) with the highest traffic intensity among the study stations.

Chauhan (2010) estimated reduction in chlorophyll a, chlorophyll b and total chlorophyll content. When leaf samples of *Ficus religiosa*, *Mangifera indica, Polyalthia longifolia and Delonix regia* from polluted sites (exposed to automobile exhaust) were compared to samples from control areas in Dehradun-Uttarakhand, India. Maximum reduction in chlorophyll a content (43.36%) was observed in *Ficus religiosa* leaves and minimum (26.57%) reduction was attained in *Mangifera indica*, while maximum (30.99%) carotenoid depletion was observed in *Polyalthia longifolia* and minimum (18.42%) was observed in *Mangifera indica* with at the polluted site.

Chandawat *et al.* (2011) studied Air Pollution Tolerance Index (APTI) of the tree species at cross roads of Ahmedabad city in Gujarat. The study revealed that the chlorophyll content of all plants showed fluctuated values with the level of pollution in the area, with higher levels of pollution through automobile exhausts resulted in lower chlorophyll content. They also revealed that the declined chlorophyll content was observed in sensitive plant species.

Chaurasia *et al.* (2013) studied the effects of cement industrial pollution on chlorophyll content of some crops in Kodinar, Gujarat. The chlorophyll content of plant species *Arachis hypogaea*, *Sesamum indicum* and *Triticum species* exposed to cement industry revealed that the amount of chlorophyll in plants located away from the cement industry had more chlorophyll content in compression to nearby the plant species. The results revealed 74.69% reduction caused adverse effects on photosynthetic pigments.

Geeta and Namrata (2014) studied the effect of air pollution on the photosynthetic pigments of selected plant species along roadsides in Jamshedpur, Jharkhand. The effects of air pollution on the chlorophyll content of three plant species *Polyalthia longifolia*, *Thevetia nerifolia and Alstonia scholaris* in the tree leaves collected from industrial, commercial and residential areas. The *Alstonia scholaris* chlorophyll a and chlorophyll b content revealed modest reduction in the industrial area whereas large reduction in *Polyalthia longifolia* was attained. In addition, increased total chlorophyll content in the *Thevetia nerifolia* was also found.

2.2.2.3 Leaf extract pH

Govindaraju *et al.* (2011) studied the identification and evaluation of air pollution tolerant plants around lignite-based thermal power station for green belt development. The study evaluated different plants species around Negveli thermal power plant by APTI based on significant biochemical parameters. API was also calculated by combined APTI values with other socio-economic and biological parameters. Among 30 different plant species evaluated *Mangifera indica* was identified as keystone species which was accessed as excellent. They found that the leaf extract pH of selected plants species was ranged from 3.10 ± 0.0 (in *Tamarindus indica*) to 7.70 ± 0.0 (in *Ficus benghalensis*) at three of the experimental and control sites. The polluted areas, plants exhibited greater levels of leaf extract pH, which was responsible as the tolerance factor to air pollution.

Zhang *et al.* (2016) observed that the loss of average leaf extract pH of plant species at the Bai-ZhiFang site with higher SO_2 than the other two sites in Beijing, China indicated the role of pH in determining plant resistance (61.1%) to pollutant concentrations. The average pH of ornamental plant species in the downtown site exceeded that of the peripheral site by 38.9%. As a result, the pH of leaf extract may be proposed as an indicator of local air pollution. Amini *et al.* (2009) discovered that mulberry had the highest leaf extract pH (7.15) and *Laurus nobilis* had the lowest pH (5.09) which indicated the stress level of plants with respect to pollution.

Javanmard *et al.* (2019) investigated the dust collection efficiency and APTI of many plant species typically employed in urban green spaces in Iran's major cities. The pH of the leaf extract was reduced, most likely due to the entry of acidic dust particles (pH 6.65) into the leaf tissues thus increased the accumulated dust on the leaf.

Yadav *et al.* (2020) evaluated the pH values of leaf extract of selected plant species *A. indica*, *F. benghalensis*, *M. azedarach* and *P. longifolia* collected from different sites of Bathinda city, Punjab. The pH ranged between 4.56-6.06, 4.63-6.04, 7.03-8.33, 7.09-8.66, 3.90-6.73, 4.24-6.73, 5.82-6.51 and 6.16-6.85. Except for *F. benghalensis*, the pH value of plant species was lower than 7 in both the seasons. The acidic nature of plant leaves caused by the presence of gaseous air pollutants in the urban environment, such as SO_2, NO_x and CO_2, which were diffused in the cell and transformed into acidic radicals.

Shrestha *et al.* (2021) assessed the air pollution tolerance of plants species in vegetation traffic barriers in Kathmandu, Nepal. They attained the leaf extract pH of selected plant species ranging from 5.13 to 8.44. The results showed that *F. benjamina* had the highest pH (8.44), followed by *C. camphora* (7.71), *Thuja sp.* (7.69), *S. pueckleri* (7.66), *P. guajava* (7.58), *Ficus sp.* (7.29), *N. oleander* (5.94), *D. lutescens* (5.48) and *A. juliusbrissin* (5.13). The pH of the majority of the plant species chosen for the study was higher than 7. Plants exposed to acidic pollutants such as SO_x, NO_x and CO_2 have lower leaf extract pH (Karmakar *et al.* 2021).

2.2.2.4 Relative water content

Singh and Verma (2007) evaluated the RWC (Relative Water Content) at three of the experimental sites and they observed that RWC ranged in between 37.70 ± 2.46% in *Annona squamosa* to 94.40 ± 2.95% in *Alstonia schlolaris* than control site.

The presence of high-water content in plants ensurse the mainatenance of the physiological balance under stress such as air pollution and the relative water content which is usually associated with the protoplasmic permeability of cells and is also involved in the loss of water and dissolved nutrients in plants, resulting in senescence of leaves (Tsega and Deviprasad 2014; Ogunkunle *et al.* 2015).

Lohe *et al.* (2015) evaluated the water content of leaf relative to its full turgidity referred to as its relative water content. The presence of high-water content within the plant body physiological balance in stressful conditions of high transpiration rate. Air pollution reduced transpiration rates and damaged the leaf engine, which pushed water up from the roots. Pollutants impacted on leaf transpiration rate caused reduced relative water content in plant species.

Karmakar *et al.* (2016) evaluated the effects of industrial air pollution on biochemical parameters of *Shorea robusta* and *Acacia auriculiformis*. The study revealed that increasing and decreasing levels of several plant characteristics at specific places might be interpreted as plant adaptation to environmental conditions in order to protect plants from air pollution stress. The biochemical and physiological parameters of plants in tropical forest located at the polluted site. The species with highest MAI and APTI values could be used in green space management foe reduction in air pollution.

2.3 Air pollution Tolerance Index (APTI)

Radhapriya *et al.* (2012) evaluated Air pollution tolerance index (APTI) of all plants surrounding the cement industry was indicative of high pollution exposure. The results revealed that the APTI rating, around 37% of the plant species were tolerant. *Mangifera indica*, *Bougainvillaea species* and *Psidum quajava* all had significant APTI values. Three-thirds of the species were susceptible to the negative impacts of suspended particulate matter, *Thevetia neriifolia*, *Saraca indica*, *Phyllanthus emblica* and *Cercocarpus ledifolius* had low APTI values. Each species had 15% at the intermediate and moderate tolerance levels.

Rai *et al.* (2013) evaluated air pollution tolerance indices (APTI) from six common roadside plant species grown along industrial (Rourkela) and non-industrial area at Aizawl Orissa, India. The plant species selected for the study were *Ficus bengalensis, Mangifera indica, Bougainvillea spectabilis, Psidium guajava, Hibiscus rosa-sinensis* and *Lantana camara.* Reduction in total chlorophyll content and pH was found in the leaf samples of all selected plants collected from industrial site (Rourkela) when compared with samples from non-industrial site (Aizawl). Whereas APTI, ascorbic acid and RWC were found to be higher in the plant samples of Industrial site (Rourkela) as compared to non-industrial site (Aizawl). On the basis of APTI, *F. bengalensis* was found to be tolerant (8.64) in industrial site (Rourkela) and *M. indica* (7.95) in non-industrial site (Aizawl). Plant species such as *M. indica and B. spectabilis* indicated least differences in their APTI values may be considered as tolerant for both (industrial and non-industrial) sites.

Chaturvedi *et al.* (2013) studied the impact of dust load (DL) on the leaf characteristics of four tree species planted along roadside at low pollution Banaras Hindu University (BHU) campus and highly polluted industrial district Varanasi, Uttar Pradesh. The results revealed substantial effect of site and species on dust load and leaf characteristics. The average dust load for the four tree species was higher at Chunar, but the average values of leaf characteristics were higher at the BHU campus. *Tectona grandis* had the highest dust load at the Chunar site, while *Syzygium cumini* had the lowest on the BHU campus. *S. cumini* had the highest values of specific leaf area, chlorophyll content and Gsmax across both sites, whereas *Anthocephalus cadamba* had the highest values of relative water content (RWC), leaf nitrogen content (LNC), leaf phosphorus content (LPC), maximum photosynthetic rate (Amax) and intrinsic water-use efficiency (WUEi). *A. cadamba* and *S. cumini* accumulated 28 and 27 times more dust, at the most polluted Chunar site than at the BHU campus, respectively.

Bharti *et al.* (2018) evaluated the Air Pollution Tolerance Index (APTI) of 25 plant species growing at Talkatora industrial area, Lucknow Uttar Pradesh, India. An APTI score of ≤11, 12-16 and ≥17 classified the tree species as sensitive, intermediate and tolerant towards air pollution, respectively. The biochemical properties of plant species ranged from 0.6-19.6 mg/g (ascorbic acid), 41.34%-98.62% (RWC), 4.5-8.2 (pH) and 0.59-1.49 mg/g (chlorophyll content). Findings revealed that among 25 plant species, *Ficus bengalensis* > *Ficus religiosa* > *Eucalyptus globus* > *Azadirachta indica juss* > *Heveabra brasiliensis* are tolerant towards air pollution, whereas *Polythalia longifolia* was found to be most sensitive. Pearson correlation of biochemical parameters revealed that ascorbic acid showed significant correlation ($R^2 = 0.897$) with APTI. The species having < 11 APTI values used as a bio-indicator of air quality, whereas those having APTI ≥17 may be designed for green belt.

Kaur *et al.* (2019) evaluated Air Pollution Tolerance Index (APTI) of plants in the vicinity of the cement factory in Bhagwanpur, Haridwar, Uttrakhand. Twenty-four plant species were collected and evaluated for APTI near the cement industry, point source of air pollution. The APTI was determined to be between 10.68 to 43.50. High APTI was found in *Cyperus rotendusand* and *Cynodon dactylon*. The results highlighted the importance of regular monitoring of APTI values during the growing season.

Elawa *et al.* (2022) evaluated the potential use of four tree species (*Eucalyptus camaldulensis*, *Casaurina equisetifolia*, *Conocarpus lancifolius* and *Ficus benjamina*) grown as green belt of 21 cement factories in Egypt to mitigate air pollution by compared their air pollution tolerance index (APTI) and anticipated performance index (API) to two reference sites. The results showed that *E. camaldulensis* was predicted to be an excellent performer, *C. equisetifolia* and *C. lancifolius* were predicted to be very good performers and *F. benjamina* was predicted to be good performer.

Correa-Ochoa *et al.* (2022) evaluated the Air Pollution Tolerance Index (APTI) and the anticipated performance index (API) in order to determine both the degree of tolerance or sensitivity of trees to pollutants in the air and their performance in urban areas. Six tree species were selected *Mangifera indica, Tabebuia chrysantha-rosea, Erythrina fusca, Jacaranda mimosifolia, Fraxinus uhdei* and *sapthosea campanulate* found in four biomonitoring zones in the city of Medellin, Colombia. A total of 54 individual trees were evaluated by means of the APTI and API and it was determined that the species with the highest tolerance (APTI≥16) and the best performance (81<API<90) was *Mangifera indica*, which highlighted the importance of species in urban areas with air quality problems. On the other hand, it was determined that the most sensitive species (APTI≤11) were *Tabebuia chrysantha-rosea, Erythrina fusca* and *Spathodea campanulata*, while the species with poor performance (41<API<50) were *Tabebuia chrysantha-rosea*, *Erythrina fusca* and *Jacaranda mimosifolia.* These values, could be utilized for plantations as planted as pollutant sinks and bioindicators and thus highlighted the importance of urban forest and trees for environmental management and planning with respect to air quality assessment.

Sarkar *et al.* (2021) studied the Durgapur industrial belt in West Bengal from August 2019 to February 2020. Based on their seasonal APTI values, eighteen plant species (herbs) were gathered, evaluated and classified as sensitive, moderate, or tolerant. In all three seasons, the results showed that *Solanum sisymbriifolium* was placed in the middle range. *Persicaria sp.* was identified as a tolerant plant throughout the study and might be used to create a green belt. *Persicaria orientalis* was a sensitive species that can be used as an indicator of pollution.

2.4 Anticipated Performance Index (API)

The anticipated performance index is significant improvement over the APTI because it uses biological and socio-economic characteristics of plants, such as plant height, canopy structure, plant size, texture, hardness and economic value of the plant, as well as biochemical parameters, to evaluate the overall performance of the species.

Mondal *et al.* (2011) assessed the air pollution tolerance index of ten plant species gathered from an urban area. The assessment was based on the analysis of key biochemical parameters. The sequence of plant tolerance was as followed as: *Psidium guajava* (31.75%) > *Swietenia mahagonii* (28.08%) > *Mangifera indica* (27.97%) > *Polyanthia longifolia* (25.58%) > *Ficus benghalensis* (25.02%). The anticipated performance index (API) for these plant species was also computed, incorporating their APTI values along with additional socio-economic and biological parameters. Based on the API calculations, the most resilient plant species for green belt development were *Ficus benghalensis* (87%), *Mangifera indica (87%)*, *Swietenia mahagonii* (87%) and *Saraca indica* (81%).

Kaur and Nagpal (2017) evaluated the Air Pollution Tolerance Index (APTI) and anticipated performance index (API) of four roadside plants from the Apocynaceae family: *Alstonia scholaris*, *Nerium oleander*, *Tabernaemontana coronaria* and *Thevetia peruviana*. On the basis of API score, *A. scholaris* was anticipated to be an excellent performer during the pre-monsoon and post-monsoon seasons followed by *N. oleander*, *T. coronaria* and *T. peruviana*.

Bui *et al.* (2021) conducted their investigation on assessment of air pollution tolerance and particulate matter accumulation of 11 woody plants. The biochemical features of leaves (ascorbic acid, chlorophyll concentration, leaf pH and relative water content) were analyzed to assess air pollution tolerance. Plant species anticipated were chosen based on air pollution tolerance index (APTI) and expected performance index (API). The accumulation of sPM and wPM, as well as the plant species, revealed a substantial variation in the results. PM accumulation and APTI were found to be positively related. The highest PM accumulation and APTI values were found in *Pinus strobus*, while the lowest was found in *Cercis chinensis*. API was classified into five groups with. *Pinus densiflora* was deemed the best group, whereas *Cornus officinalis* and *Ligustrum obtusifolium* were graded as zero. The study focused on leaf surface and in wax PM (sPM and wPM) accumulation were compared for 11 plants species widely used for land spacing in South Korea.

Banerjee *et al.* (2021) studied the pollution responsive variables such as ascorbic acid, pH, total chlorophyll, relative water content, total soluble sugar, amino acid and protein in four different plant species, namely *Ficus religiosa*, *Anthocephalus cadamba*, *Lagerstroemia speciosa* and *Cassia siamea* at nine different sites in Durgapur, West Bengal, India. The regional variability studies of the Air Pollution Tolerance Index (APTI) and the Anticipated Performance Index (API) were performed for all the plant species. The API grading revealed that *L. speciosa* was the top performer, followed by *A. cadamba and F. religiosa* in contrast, *C. siamea* performed poorly across all sites.

Sabitha and Thambavani (2011) assessed the Air Pollution Tolerance Index (APTI) and Anticipated Performance Index (API) of five tree species grown near a sugar mill, a source of air pollution, over a six-month period from October 2010 to March 2011. The most tolerant plant species were *Ficus religiosa* and *Ficus benghalensis,* whereas the least tolerant were *Delonix regia* and *Azadirachta indica.*

Chapter-3

MATERIAL AND METHODS

The present studies entitled "**Assessment of Air Pollution Tolerance Index of Plant Species surrounding Cement Industry at Barmana in Himachal Pradesh"** was conducted under the Department of Environmental Science, College of Forestry, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan HP during 2022-2023. To undertake the present investigations materials used and methodology adopted has been described below:

3.1 Description of the study area

3.1.1 Location

The investigation has been carried out for APTI of plant species grown over the surrounding of industry namely M/S ACC Limited Gagal cement works of ACC Pvt. Ltd. lies in 31°21'54.10" North and 76°50'04.62" East with 552 m evaluation at Barmana village of district Bilaspur, Himachal Pradesh. The industry operating captive limestone mine since 1984. The total mining area of 231.25 ha. coverage has been utilized for various cement works including mining, cement plant, workshops and offices. The industry is situated in the Barmana village quite close to Bilaspur city. Thus, the area is subjected to dust pollution due to industry as well as vehicles utilized for various activities of cement industry.

Bilaspur district occupies an area of 1,167 km^2. According to the 2011 population census, Bilaspur district has a population of 381,956. It is the third-least populated district of Himachal Pradesh behind Kinnaur and Lahul and Spiti. The density of Bilaspur district in 2011 was 327 people per sq. km. The study site, i.e., the ACC cement plant in Barmana and surrounding area, is subjected to dust pollution and increasing vehicular density due to the various activities of the cement industry.

3.1.2 Climate and weather conditions

Bilaspur experiences warm summers and cool winters in general but is protected from the temperature extremes of the surrounding mountains by its situation in a valley. The monsoon season from July to September, is a period of high rainfall. The highest temperature months are May and June when the temperature is typically around 37 °C and 38 °C, sometimes exceeding 40 °C. The annual rainfall is 1067.9 mm. The driest month is November with 1mm Rainfall. In July precipitation reaches its peak with an average of 300.2 mm. However, during the year 2023, the summer season experienced 374.5mm, which was the highest since the last 10 years.

3.2 Experimental details

In order to conduct the present investigation a preliminary survey of the Cement industry was before the start of experiment done during the year 2022-2023. In the selected area around the cement industry vegetation distribution was studied. The commonly occurring plant species namely *Ricinus communis*, *Murraya koenigii*, *Toona ciliata*, *Cassia fistula* and *Mangifera indica* were selected for the study. In order to study the impact of cement industry on the vegetation, plants were selected from 0-150 m, 150-300 m around the cement industry. Thus, accordingly 20 treatment combinations were considered which were replicated four times for the study.

Factors:

1. Distance : 2 (0-150 m, 150-300 m)
2. Season : 2 (winter and summer)
3. Plant Species : 5

Total number of treatments : 2×2×5=20

Number of replications : 4

Total number of observations : 20×4= 80

Design : RBD factorial

Table 3.1 Morphological characters of selected plant species

Plant species	Common Name	Family	Nature	Leaf Shape
Ricinus communis	Castor	Euphorbiaceae	Evergreen	Star-shaped leaf
Murraya koenigii	Kadipatta	Rutaceae	Evergreen	Oval-pinnate
Toona ciliata	Indian mahogany	Meliaceae	Deciduous	Ovate-lanceolate
Cassia fistula	Amaltas	Fabaceae	Deciduous	Ovate-lanceolate
Mangifera indica	Mango	Anacardiaceae	Evergreen	Lanceolate leaf

Shrub species

Ricinus communis

Ricinus communis can vary greatly in its growth habit and appearance. It is a fast-growing, suckering shrub that can reach the size of a small tree, around 12 m (39 feet), but it

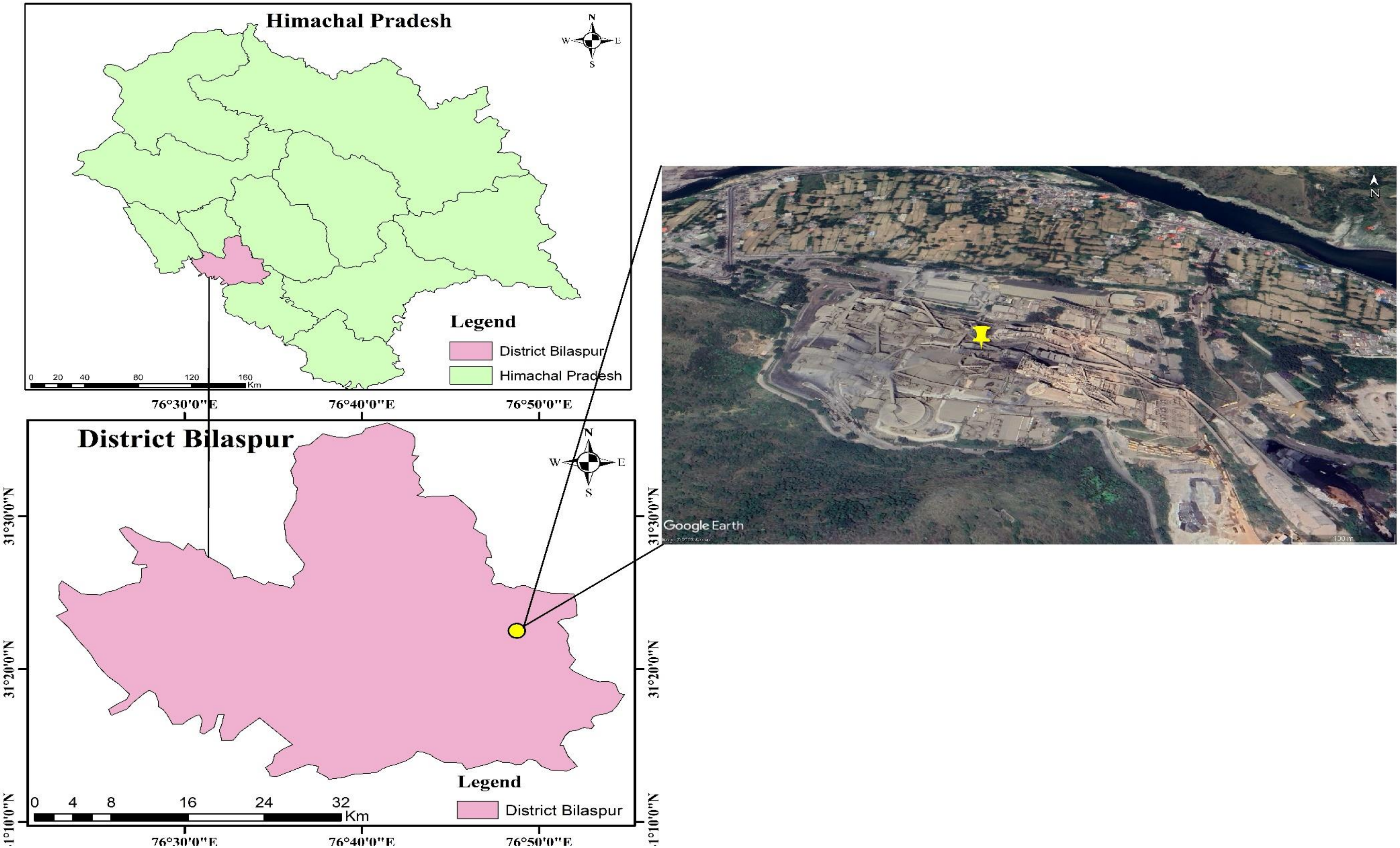

Fig 3.1: Map showing study area

is not cold hardy. *Ricinus communis* is indigenous to the southeastern Mediterranean Basin, Eastern Africa, and India, today it is widespread throughout tropical regions.

Murraya koenigii

Murraya koenigii is a small, tropical to sub-tropical tree or shrub that typically grows to 6 to 15 feet tall with a trunk up to 40 cm (16 in) in diameter. The shrub is native to the Indian subcontinent. Commercial plantations have been established in India.

Tree species

Toona ciliate

Toona ciliata is a medium to large sized deciduous tree native to much of the Indian subcontinent, East Asia, Southeast Asia and Australia. It is primarily found growing in wooded thickets, hillsides, riparian areas, and disturbed habitats. The species can grow to around 60 m (200 ft) in height and its trunk can reach 3 m (10 ft) in girth with large branches that create a spreading crown.

Cassia fistula

Cassia fistula is a small to medium-sized tree that typically grows to 30-40 feet tall in an upright form often open at the top and 3-4 feet in diameter It is native to India, Malaysia and Southeast Asia.

Mangifera indica

Mangifera indica is a large fruit tree, it can grow up to 15–30 m (50–100 feet) tall with a similar crown width and a trunk circumference of more than 3.7 m (12 ft). Mango trees typically branch 0.6–2 m (2–6.5 ft) above the ground and develop an evergreen, dome-shaped canopy.

3.3 Collection of samples

In order to investigate the horizontal distribution of the dust contents, distance like 0-150 m and 150-300 m were considered and four samples of each species were collated from each section. The data were collected form five plant species viz. *Ricinus communis*, *Murraya koenigii*, *Toona ciliata*, *Cassia fistula* and *Mangifera indica* as selected through preliminary survey of the selected site. Utmost care was taken that the samples from each study site were collected from plants growing in isoecological conditions. Fully mature leaves in the quadruplicate were collected in morning hours from the selected plant species of almost same diameters at breast height (DBH) and from the shrubs of almost same height.The randomly selected plant species were utilized for the collection of data during two seasons of winter and summer of 2022-23. Leaf dust load and leaf samples collected as per the standard procedure. The leaf samples were brought to the laboratory in an ice box and washed with ordinary water, first with 0.1 N HCL and finally with distilled water. The following physiological and biochemical characteristics of leaf samples were analyzed.

3.3.1 Leaf dust accumulation

Fully matured leaves of the selected tree species were collected form the experimental area. The upper surface of the leaves was cleaned with a fine brush and an identification mark was marked on them. These sampled leaves were kept for 24 hours to allow dust stabilization before being collected in pre-weighed butter paper bags with the help of a fine brush. After collecting dust accumulation data, the leaves were cut from the petiole, stored in an ice box and utilized for analysis. The amount of dust deposited on leaves was weighed on a top-pan electronic balance and calculated by the following equation:

$$W = \frac{W_2 - W_1}{A}$$

Where

W	=	Dust content (mg m^{-2})
W_1	=	Initial weight of butter paper bag (mg)
W_2	=	Final weight of butter paper bag with dust (mg)
A	=	Total area of leaf (m^2)

3.3.2 Leaf area

Selected plant species were subjected to further investigation with collection of leaves from the random selected plants and six leaves were cut and placed in sampling bag for selected from each plant and the leaf area was measured using a leaf area meter (MODEL-LI-COR-3100). The average leaf area was attained after averaging their area through simply adding all the leaves area and divided by six. Leaf area was measured in meter squares.

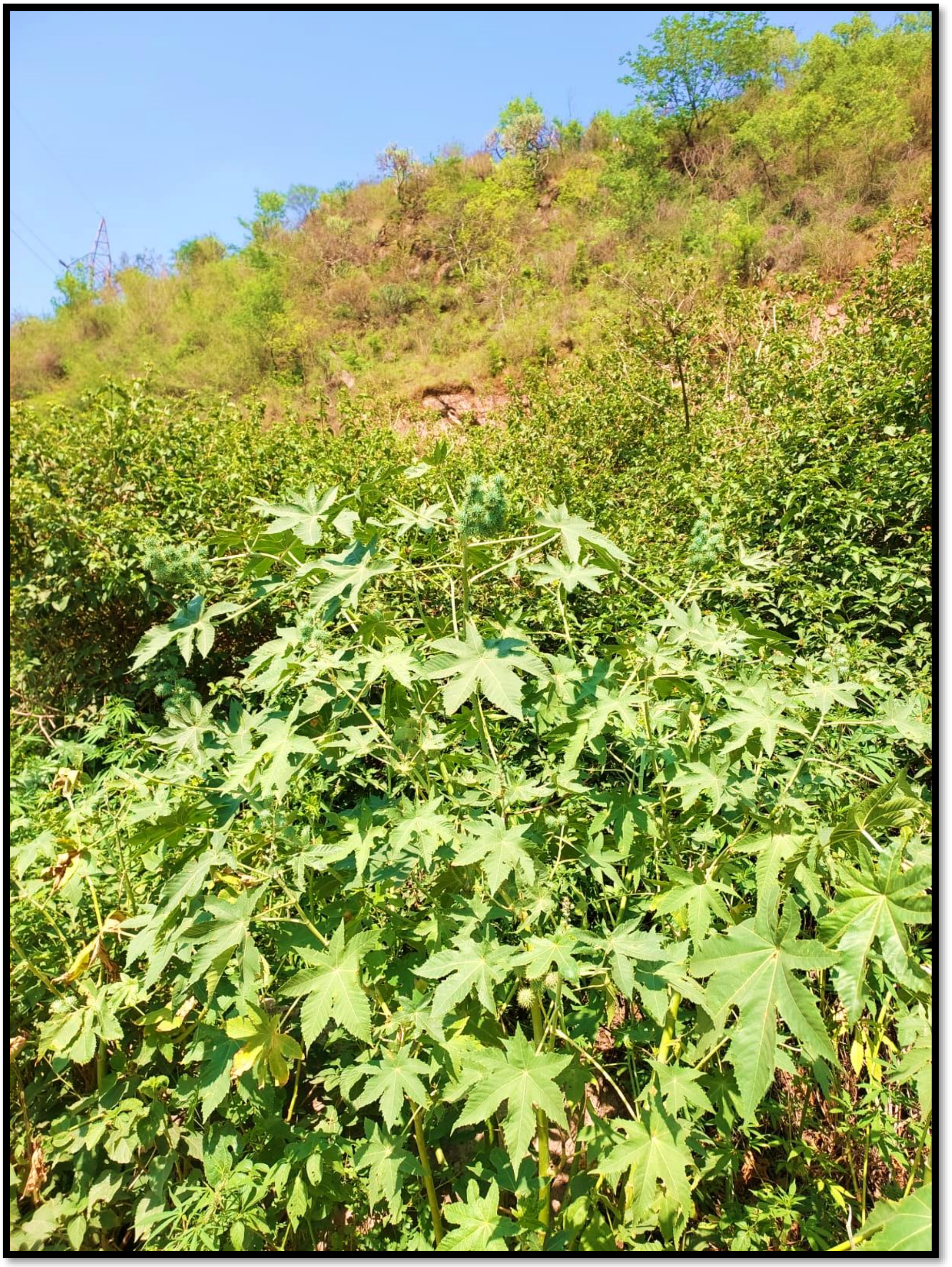

Plate 1. ***Ricinus communis***

Plate 2. ***Murraya koenigii***

Plate 3. ***Toona ciliata***

Plate 4. ***Cassia fistula***

Plate 5. ***Mangifera indica***

3.3.3 Biochemical analysis

Sampling was done in the early morning hours. After completion of harvest process freshly matured leaves were harvested and samples were collected from plants growing in iso-ecological conditions. Fresh leaves were brought to the lab in an ice box and tested for ascorbic acid content, total chlorophyll content, leaf extract pH and relative water content.

3.3.3.1 Ascorbic acid content

The A. O. A. C. (1980) method was caried out for calculating the ascorbic acid content. In a metaphosphoric acid solution, fresh leaves (10 g) were homogenised. The volume was made to 100 ml and titrated against indophenol dye. The appearance of rose pink colour indicated final point. Ascorbic acid content (mg g^{-1}) in milligrams per gram was calculated as:

$$\text{Ascorbic acid (mg/g)} = \frac{\text{Dye factor} \times \text{Titre reading} \times \text{Volume made}}{\text{Weight of leaves taken} \times \text{Volume taken for estimation}}$$

3.3.3.2 Chlorophyll content

Under low light, fresh leaves were chopped into fine pieces and 100 mg of chopped leaf samples were placed in vials containing 7 ml of dimethyl sulphoxide. After incubating the vials for half an hour at 65°C, the extract was transferred to a graduated test tube and the final volume was adjusted to 10 ml with dimethyl sulphoxide. The extract O.D. was measured using a Spectrophotometer (Model-Spectronic-20) at 645 and 663 nm against a dimethyl sulphoxide blank. The total chlorophyll content was determined by using Hiscox and Israelstam (1979) method, as shown below:

$$\text{Total chlorophyll (mg g}^{-1}\text{)} = \frac{20.2\ \text{A645} + 8.02\ \text{A663} \times \text{V}}{\text{a} \times 1000 \times \text{W}}$$

Where

V	=	volume of the extract made (ml)
W	=	weight of sample (mg)
A	=	length of light path in cell (using 1cm)
A645	=	Absorbance at 645nm
A663	=	Absorbance at 663nm

3.3.3.3 Leaf extract pH

Fresh leave sample (5 g) were homogenized in 10 ml deionized water and the supernatant obtained after centrifugation. The sample was collected for pH determination using a pH meter.

3.3.3.4 Relative water content (RWC)

The fresh leaf weight was determined by weighing the fresh leaves. Leaves were submerged in water overnight, blotted dry and weighed the turgidly. The leaves were then dried overnight in an oven at 65°C to obtain their dry weight. The relative water content of leaves was calculated by Turner (1981) method using equation:

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

Here

RWC	=	Relative water content (%)
FW	=	Fresh weight of leaf samples (g)
DW	=	Dry weight of leaf samples (g)
TW	=	Turgid weight of leaf samples (g)

3.3.3.5 Air pollution tolerance index (APTI)

From all the above parameters finally, APTI was calculated using the equation proposed by Singh and Rao (1983) by the following equation:

$$\mathrm{APTI} = \frac{[\mathrm{A}\ (\mathrm{T} + \mathrm{P})] + \mathrm{R}}{10}$$

Where

A	=	Ascorbic acid content (mg g^{-1}) of leaf sample
T	=	Total chlorophyll content (mg g^{-1}) of leaf sample
P	=	pH of leaf extract
R	=	Relative water content (%) of leaf sample

3.3.3.6 Anticipated performance index (API)

The resultant APTI values were then subject to combined with some relevant biological and socioeconomic character like plant height, canopy structure, plant size texture, hardness and economic value, the API was estimated for different plant species. Based on these characters, different grades (+ or -) were allotted to plants. Different plants were scored based on their grades as per the procedure outlined by Mondal *et al.* (2011) and presented in Table 3.2(a) and 3.2(b).

Table 3.2 (a) Gradation of plant species based on Air Pollution Tolerance Index (APTI) as well as biological parameters and socio- economic importance

Grading character	Pattern of assessment	Grade allotted
(a) Air Pollution Tolerance Index (APTI)	8.5-9.0 9.1-9.5 9.6-10 10.1-10.5 10.6-11	+ ++ +++ ++++ +++++
(b) Plant habit	Small Medium Large	- + ++
(c) Canopy structure	Sparse/irregular/globular Spreading Crown/open/semi-dense Spreading dense	- + ++
(d) Type of plant	Deciduous Evergreen	- +
(e) Laminar characteristics **(i) Size** **(ii) Texture**	Small Medium Large Smooth Coriaceous	- + ++ - +
(f) Hardiness	Delineate Hardy	- +
(g) Economic value	Less than three uses Three or four uses Five or more uses	- + ++

Note: Maximum score a plant can attained = 16

Table 3.2 (b) Anticipated Performance Index 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

3.4 Statistical Analysis

The data recorded for various parameters were subjected to a Randomized Block Design. The analysis of variance approach was used for RBD statistical analysis based on mean values per treatment.

Table 3.3 The following calculations will be made to the analysis of variance (ANOVA) table

Source of variation	**Degree of freedom**	**Sum of squares**	**Mean sum of squares**	**F_{cal}**
Treatments	(t-1)	S_t	$M_t = S_t/ (t-1)$	M_t/ M_e
Replications	(r-1)	S_r	$M_r = S_r/ (r-1)$	M_r /M_e
Error	(r-1) x (t-1)	S_e	$M_e = S_e/ (r-1) \times (t-1)$	
Total	(r) x (t) -1	S_T		

Where,

r = Number of replications

t = Number of treatments

S_r = Sum of squares due to replications

S_t = Sum of squares due to treatments

S_e = Sum of squares due to error

S_T = Total sum of squares

M_r = Mean sum of squares due to replications

M_t = Mean sum of squares due to treatments

M_e = Mean sum of squares due to error

The replication and treatment mean sum of squares shall be tested against the mean sum of squares due to error by the 'F' test at (r-1), (r-1) x (t-1) and (t-1), (r-1) x (t-1) degree of freedom for RBD at 5% level of significance.

The calculated F-values shall be compared with tabulated F- value. When F- test shall be found significant, critical difference shall be calculated to find out the superiority of one treatment over the others.

Critical difference (CD) for RBD shall be calculated as follows:

$CD_{0.05}$	=	S.E. (d) x $t_{(0.05)}$ (r-1) (t-1) df
SE (d) ±		$\sqrt{2Me/r}$
SE (m) ±	=	$\sqrt{Me/r}$

where,

SE (m) ±	=	Standard error of mean
SE (d) ±	=	Standard error of difference of mean
$CD_{0.05}$	=	Critical difference at 5% level of significance

Correlation Coefficient (r)

Seasonal variation of different dust accumulation pattern, biochemical parameters and their significant level were computed using analysis of variance technique. In order to study the relationships of leaf dust accumulation with physiological and biochemical parameters (ascorbic acid content, chlorophyll content, leaf extract pH and relative water content) of leaves of selected plants. Karl Pearson's Correlation Coefficient was calculated using SPSS version 21. The significance of the Correlation was tested at 1% and 5% level of significance.

The Pearson Correlation Coefficient formula is as follows:

$$\mathbf{r} = \frac{\mathbf{n}(\sum \mathbf{xy}) - (\sum \mathbf{x})(\sum \mathbf{y})}{\sqrt{[\mathbf{n}\sum \mathbf{x}^2 - (\sum \mathbf{x})^2][\mathbf{n}\sum \mathbf{y}^2 - (\sum \mathbf{y})^2]}}$$

Chapter-4

RESULTS AND DISCUSSION

The results obtained from the present investigation entitled **"Assessment of Air Pollution Tolerance Index of Plant Species surrounding Cement Industry at Barmana in Himachal Pradesh"** have been described in this chapter under the following headings.

4.1 Leaf dust accumulation

4.2 Leaf physiological and bio chemical parameters

4.2.1 Ascorbic acid content

4.2.2 Total chlorophyll content

4.2.3 Leaf extract pH

4.2.4 Relative water content

4.3 Air Pollution Tolerance Index (APTI)

4.4 Anticipated Performance Index (API)

4.5 Relationship of leaf dust accumulation with biochemical parameters species wise

4.6 Relationship of leaf biochemical parameters and APTI of selected plant species

4.1 Leaf dust accumulation

Significant variation in dust load accumulation of the selected plant species was attained with respect to species, horizontal distance and seasons of the year (Table 4.1a). In shrub species, higher dust accumulation was observed in *Ricinus communis* (30.69 mg m^{-2}) and lower in *Murraya koenigii* (6.57 mg m^{-2}). Whereas, in tree species, dust load accumulation was observed in the descending order of *Cassia fistula* (20.95 mg m^{-2}) > *Toona ciliata* (19.35 mg m^{-2}) > *Mangifera indica* (19.26 mg m^{-2}). The highest dust accumulated on the leaves of *Ricinus communis* may be attributed to its coriaceous leaf texture preventing dust fall from leaf surface and leaf size, which have accumulated more dust in leaves. These results are in line with the findings of Chaturvedi *et al.* (2013) they reported that rough textured leaf had greater dust accumulation as compared to the other plant species which have comparatively smoother leaf texture. Whereas, relatively less dust accumulation on the leaves of *Cassia fistula*, *Toona ciliata* and *Mangifera indica* may be attributed to their smoother leaf surface texture and the presence of a waxy coating. These characteristics likely contributed to reducing the adherence of dust particles, leading to less dust accumulation on the leaf surfaces. These findings are in conformity with findings of Alhesnawi *et al.* (2018) who reported that the interception of dust load from the environment is influenced by specific morphological characteristics, whether acting independently or in combination. These include the leaf's orientation on the main axis, its size (leaf area) and shape, as well as the type of surface, which can be either smooth or striate. Additionally, the presence or absence of trichomes and wax deposition on the leaf surface also play a significant role in determining the plant's ability to capture and retain dust particles from the surrounding ambience.

The leaf dust accumulation on the leaves of the selected plant species surrounding the cement industry showed seasonal variations, which ranged from 16.98 to 21.78 mg m^{-2}. The highest dust accumulation was observed during the winter season (21.78 mg m^{-2}) as compared to summer season (16.95 mg m^{-2}). The lower dust accumulation on leaves during the summer season as compared to the winter season may be attributed due to rainfall during the season which might have washed the dust particles from leaves. Higher rainfall during the summer season may wash the dust resulting in lower dust accumulation compared to the winter season. These results are in line with the findings of Rai *et al.* (2014) who reported that during winter season the maximum dust deposition was attributed to wet surfaces of leaves that aid in capturing dust and prevent its dispersion. In contrast, the washing of leaves by rain leads to the least dust accumulation.

The dust accumulation on the leaves of the selected plant species exhibited variations at different horizontal distances from the cement factory. The highest dust load of (20.61 mg m^{-2}) was recorded on the leaves of plant species growing at the distance 0-150 m from the cement industry and lowest dust load of (18.12 mg m^{-2}) was recorded on the leaves of plant species growing at the distance of 150-300 m from the cement industry (Table 4.1 a). This may be due to plants growing closer to the cement industry experienced the highest dust load on their leaves. This is likely because they are situated in the immediate vicinity of the emission sources, such as dust and particulate matter released during cement manufacturing processes. These results are in conformity with the findings of Shukla *et al*. (2008) they also reported that dust load was found maximum on plants species growing near the cement industry and followed the decreasing trend with increasing distance from the source of the dust.

Interaction between species and seasons resulted in significant variation on the dust accumulation in the surrounding of the cement industry for the selected plant species (Fig 4.1). The highest dust accumulation of 34.68 mg m^{-2} was observed in *Ricinus communis* during the

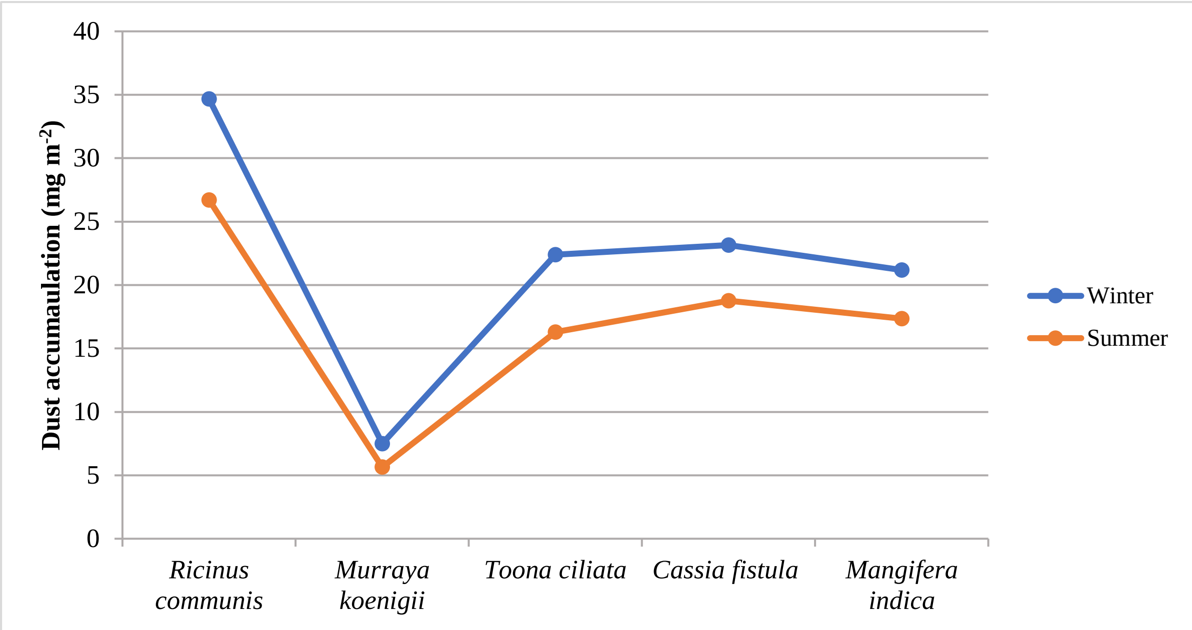

Fig 4.1 Seasonal dust accumulation pattern of selected plant species growing surrounding cement industry

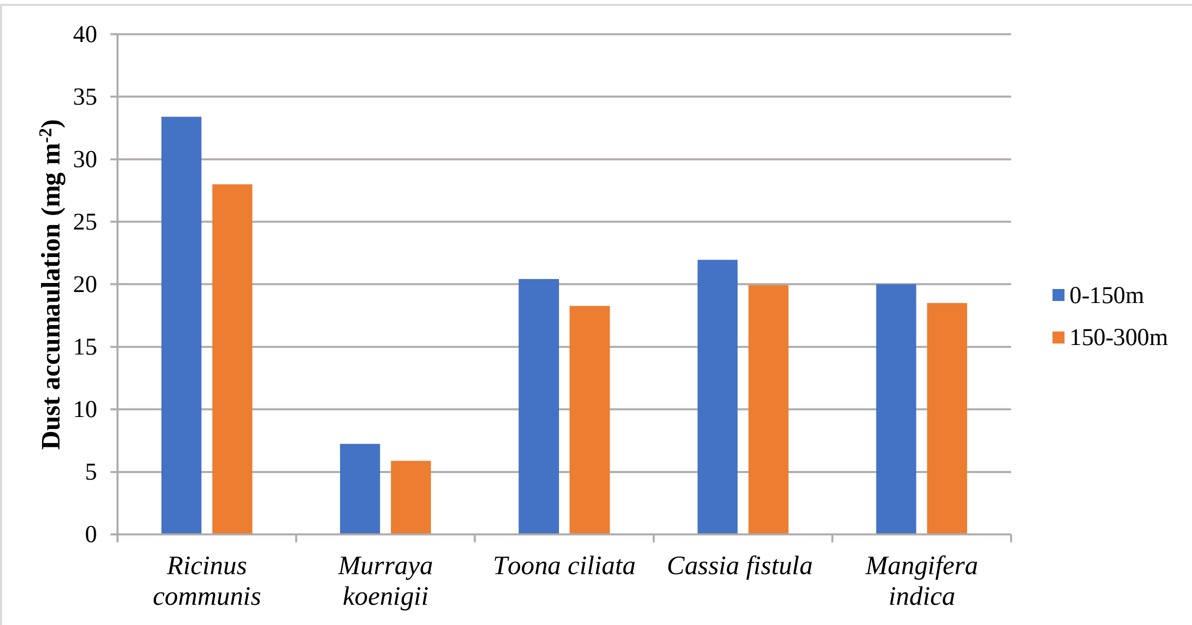

Fig 4.2 Variation in dust accumulation pattern of selected plant species growing surrounding cement industry

winter season, whereas the lowest dust accumulation of 5.64 mg m^{-2} was recorded in *Murraya koenigii* during the summer season.

The two-way interaction of species and distance was noticed to be significantly influenced the dust accumulation of the selected plant species surrounding the cement industry significantly (Fig 4.2). Highest dust load was recorded in *Ricinus communis* (33.40 mg m^{-2}) at a horizontal distance of 0-150 m from the cement industry, which was found significantly higher than all the dust accumulated values over leaf surfaces of other plant species under consideration. Whereas, lowest dust accumulation was recorded in *Murraya koenigii* (5.89 mg m^{-2}) at a distance of 150-200 m away from the cement industry.

The three-way interaction between selected plant species, seasons and distance from the cement industry was observed to be statistically non-significant with respect to dust accumulation on leaf surface of various plant species (Table 4.1b).

Table 4.1 (a) Seasonal dust load accumulation (mg m^{-2}) on different plant species surrounding cement industry

Plant Species	Horizontal distance			Seasons	
	0-150m	150-300m	Mean	Winter	Summer
Ricinus communis	33.40	27.99	30.69	34.68	26.71
Murraya koenigii	7.25	5.89	6.57	7.50	5.64
Toona ciliata	20.42	18.27	19.35	22.39	16.30
Cassia fistula	21.96	19.95	20.95	23.15	18.76
Mangifera indica	20.02	18.50	19.26	21.17	17.35
Mean (Distance)	20.61	18.12	**Mean (Season)**	21.78	16.95
Winter	23.13	20.43	21.78		
Summer	18.09	15.81	16.95		

CD (0.05)

Species	0.48	**Species × Season**	0.67
Seasons	0.30	**Species × Distance**	0.67
Distance	0.30	**Season × Distance**	NS

Table 4.1 (b) Conjoint effect of species, season and distance on dust accumulation (mg m^{-2}) of the selected plant species

Plant Species	Winter		Summer	
	0-150m	150-300m	0-150m	150-300m
Ricinus communis	37.87	31.48	28.93	24.50
Murraya koenigii	8.11	6.89	6.40	4.89
Toona ciliata	23.38	21.41	17.46	15.14
Cassia fistula	24.27	22.04	19.66	17.86
Mangifera indica	22.02	20.33	18.02	16.68

CD (0.05)

Species × Season × Distance NS

4.2 Leaf physiological and bio chemical parameters

4.2.1 Ascorbic acid content

Ascorbic acid is an antioxidant within plants that plays an important role in maintaining cell division and the stability of cell membranes when plants are exposed to stressful conditions, as suggested by Bandara *et* al. (2021). The leaf ascorbic acid content among selected plant species surrounding the cement industry varied significantly, which ranged from 2.54 to 4.10 mg g^{-1} (Table 4.2.1a). In shrub species, *Ricinus communis* recorded the higher value of ascorbic acid content (3.71 mg g^{-1}), while *Murraya koenigii* showed the lower value (2.54 mg g^{-1}). In tree species, the highest ascorbic acid content was found in *Toona ciliata* (4.10 mg g^{-1}), which is at par with *Cassia fistula* (4.05 mg g^{-1}) and the minimum was observed in *Mangifera indica* (3.31 mg g^{-1}). The order of ascorbic acid content in the leaves of selected plant species was *Toona ciliata* (4.10 mg g^{-1}) > *Cassia fistula* (4.05 mg g^{-1}) > *Ricinus communis* (3.71 mg g^{-1}) > *Mangifera indica* (3.31 mg g^{-1}) > *Murraya koenigii* (2.54 mg g^{-1}). The variation in ascorbic acid content is attributed to the natural ability of the species to withstand and endure stressful environmental conditions. The results are in line with the findings of Kaur *et al*. (2017) who reported that the high ascorbic acid content was observed in plant species which can indicate more air pollution tolerance in plants.

The leaf ascorbic acids content of selected plant species surrounding cement industry varied significantly with seasons which ranged from 3.35 to 3.73 mg g^{-1}. Highest ascorbic acid content was observed during winter season (3.73 mg g^{-1}), while the lowest amount of ascorbic acid content was attained during summer season (3.35mg g^{-1}). Both the values were found significantly different from each other. Higher ascorbic acid content during winter season may be due to higher production of antioxidants under stressed conditions. The results are in line with the findings Karmakar and Padhy (2019) who reported that during the winter season, plants exhibited higher ascorbic acid content compared to the summer season. This was attributed to higher pollution levels in the study area during winter, causing plants to develop more resistance and enhanced tolerance during winter season. The results are also similar to those reported Yadav *et al*. (2020) who observed decrease in ascorbic acid content in the selected plant species during the summer season in comparison to the winter season.

The significant variation was observed in the leaf ascorbic acid content of selected plant species growing at different horizontal distance from the cement industry

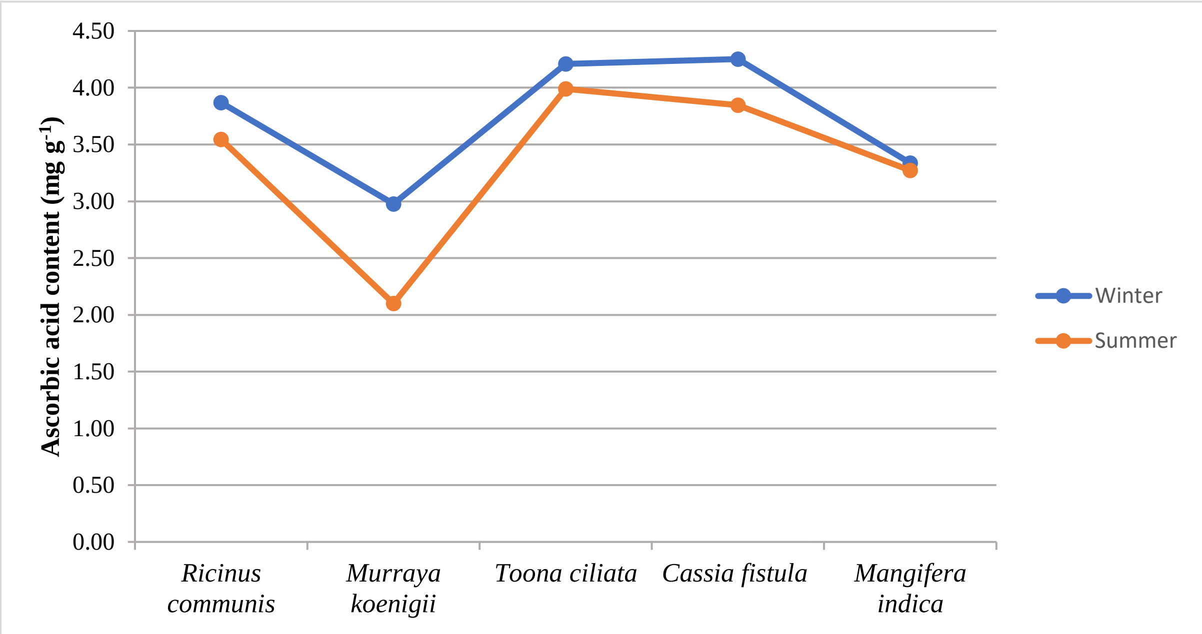

Fig 4.3 Seasonal variation in the leaf ascorbic acid content (mg g^{-1}) of selected plant species growing surrounding cement industry

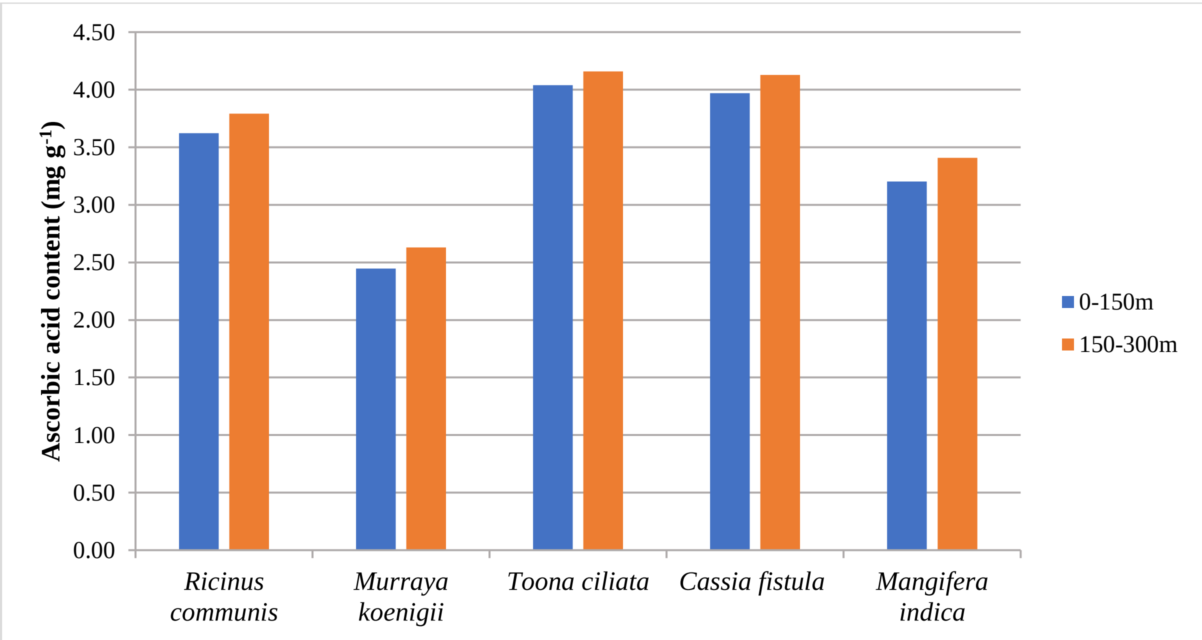

Fig 4.4 Variation in ascorbic acid content (mg g^{-1}) of selected plant species growing at different horizontal distances surrounding cement industry

(Table 4.2.1a). Highest amount of ascorbic acid of 3.62 mg g^{-1} were found at a horizontal distance of 150-300 m from the cement industry, while lowest amount (3.46 mg g^{-1}) was observed in plant species growing at horizontal distance of 0-150 m from the cement industry. The results are in line with the findings of Sharma *et al*. (2019) who reported that the maximum ascorbic acid content in the leaves of the selected plant species was attributed to more production of antioxidants (ascorbic acid), in response to conditions of stress.

Interaction between species and seasons showed significant variation in the leaf ascorbic acid content of the selected plant species (Fig 4.4). Among the selected plant species, *Cassia fistula* (4.25 mg g^{-1}) showed the highest level of leaf ascorbic acid content during the winter season, at par value with *Toona ciliata* (4.21 mg g^{-1}) during the winter season, while the lowest value was found in *Murraya koenigii* (2.10 mg g^{-1}) during the summer season. The higher levels of leaf ascorbic acid in *Cassia fistula* and *Toona ciliata* may be attributed to stress response mechanism and also their higher tolerance potential toward pollution.

The data presented in (Table 4.2.1a) indicated that three-way interaction between species, distance and season were found to be statistically non-significant with respect to leaf ascorbic acid content of selected plant species.

Table 4.2.1 (a) Seasonal variation in leaf ascorbic acid content (mg g^{-1}) of selected plant species growing at different distances surrounding cement industry

Plant Species	Horizontal distance			Seasons	
	0-150m	150-300m	Mean	Winter	Summer
Ricinus communis	3.62	3.79	3.71	3.87	3.55
Murraya koenigii	2.45	2.63	2.54	2.98	2.10
Toona ciliata	4.04	4.16	4.10	4.21	3.99
Cassia fistula	3.97	4.13	4.05	4.25	3.85
Mangifera indica	3.20	3.41	3.31	3.34	3.27
Mean (Distance)	3.46	3.62	**Mean (Season)**	3.73	3.35
Winter	3.65	3.81	3.73		
Summer	3.27	3.43	3.35		

CD (0.05)

Species	0.09	**Species × Season**	0.13
Seasons	0.06	**Species × Distance**	NS
Distance	0.06	**Season × Distance**	NS

Table 4.2.1 (b) Conjoint effect of species, season and distance on ascorbic acid content ($mg\ g^{-1}$) of the selected plant species

Plant Species	Winter		Summer	
	0-150m	150-300m	0-150m	150-300m
Ricinus communis	3.73	4.02	3.52	3.57
Murraya koenigii	2.95	3.01	1.95	2.25
Toona ciliata	4.16	4.27	3.93	4.06
Cassia fistula	4.18	4.33	3.76	3.93
Mangifera indica	3.23	3.45	3.18	3.37

CD $_{(0.05)}$

Species × Season × Distance NS

4.2.2 Total chlorophyll content

Chlorophyll content of the plant signifies its photosynthesis activity as well as the growth and development of biomass. The selected plant species growing in vicinity of cement industry were found to exhibit significant variation in their leaf chlorophyll content. The leaf chlorophyll content of the selected plant species varied from 0.77-2.44 mg g^{-1} (Table 4.2.2a). In shrub species, higher leaf chlorophyll content was observed in *Ricinus communis* (0.85 mg g^{-1}), while lower was observed in *Murraya koenigii* (0.77 mg g^{-1}) which was found at par with tree species *Toona ciliata* (0.82 mg g^{-1}). Among the tree species *Cassia fistula* showed the maximum leaf chlorophyll content of 2.44 mg g^{-1}, which This was followed by *Mangifera indica* and *Toona ciliata* with respective values of 1.96 and 0.82 mg g^{-1}. The variation in leaf chlorophyll content among the selected plant species may be associated with genetic diversity, pollution levels, varying degrees of tolerance and sensitivity. These results are in line with Dhankhar *et al*. (2015) who reported that the variation in chlorophyll content among plant species is influenced by factors such as species-specific characteristics, leaf age, pollution levels and various biotic and abiotic conditions. The present results are also supported by the findings of Achakzai *et al*. (2017) who observed that the total chlorophyll content of plant species decreased when the source of pollution increased.

The total leaf chlorophyll content of selected plant species surrounding the cement industry showed seasonal significant variation, which ranged from 1.21 to 1.53 mg g^{-1}. The highest leaf chlorophyll content was recorded in the winter season with a value of 1.53 mg g^{-1} as compared to the summer season with a value of 1.21 mg g^{-1}. The increase in leaf chlorophyll content during the winter season is linked to reduced stress levels for plants adapted to colder climates. This natural response aligns with the plant strategies to optimize their photosynthetic

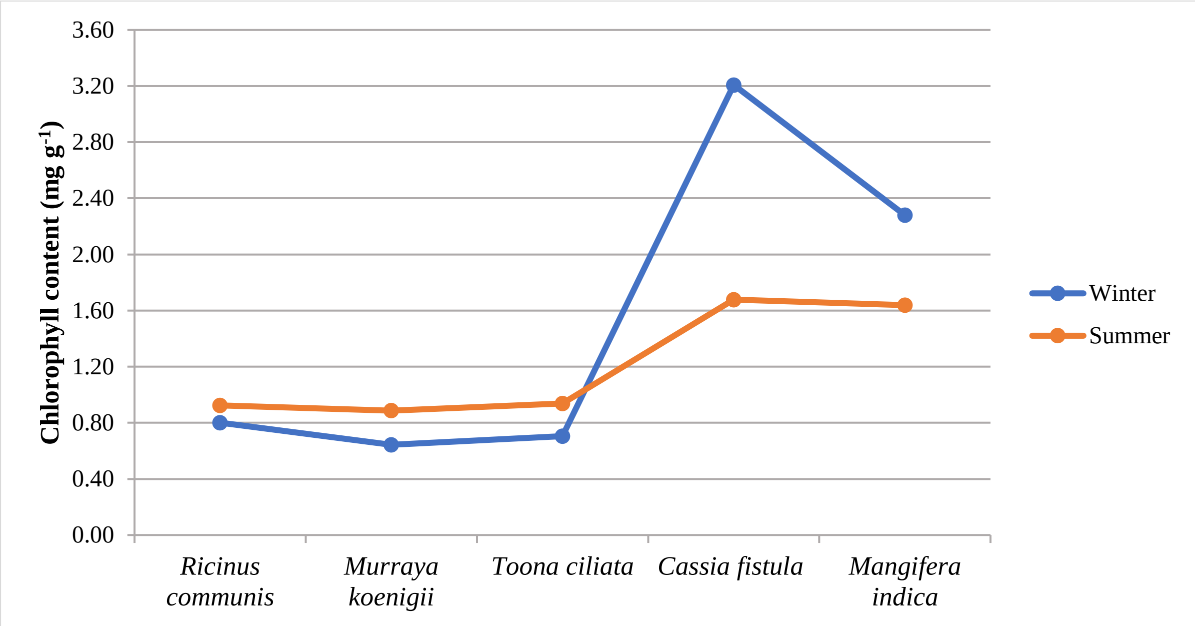

Fig 4.5 **Seasonal variation in leaf chlorophyll content (mg g^{-1}) of selected plant species growing surrounding cement industry**

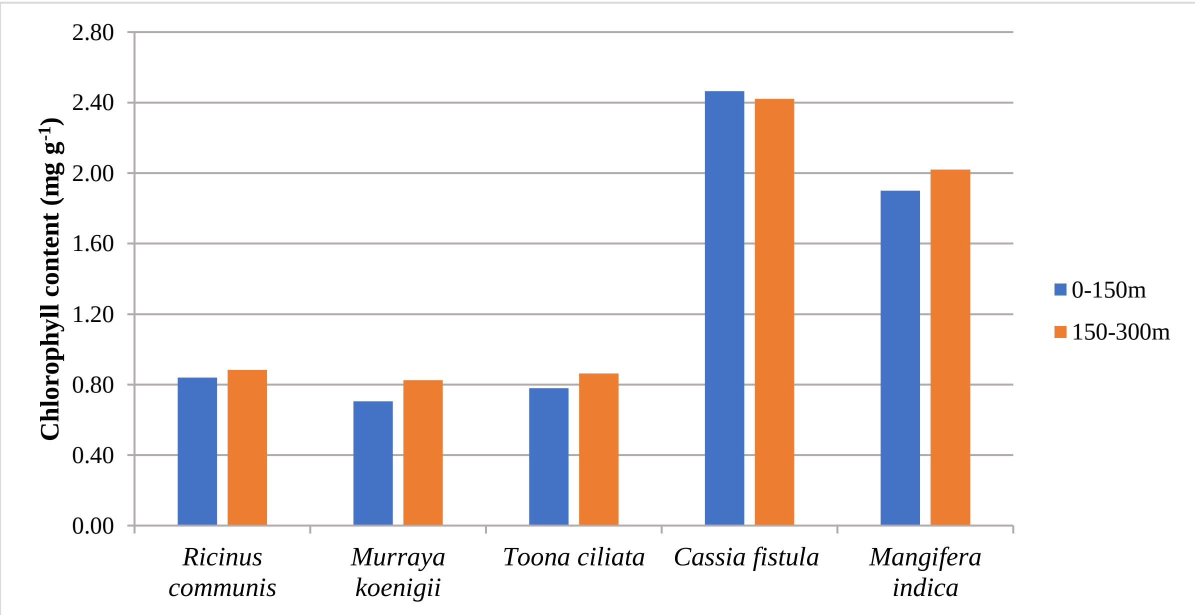

Fig 4.6 **Variation in leaf chlorophyll content (mg g^{-1}) of selected plant species growing at different horizontal distances surrounding cement industry**

capabilities under favorable conditions. However, variations in chlorophyll content can also arise due to species-specific differences and the age of the leaves. The results are in line with Sharma *et al*. (2019) who reported that the low leaf chlorophyll of the selected plant species during the summer season was attributed to the fact that there was a high pollution level in this season and temperature stress in this season.

The total leaf chlorophyll of the selected plant species growing surrounding the cement industry varied significantly with horizontal distance which ranged from 1.34-1.40 mg g^{-1}. The highest leaf chlorophyll content of 1.40 mg g^{-1} was observed in the leaves of plant species growing at the distance of 150-300 m from the cement industry and lowest leaf chlorophyll content of 1.34 mg g^{-1} was observed in the leaves of plant species growing at the distance of 0-150 m from the cement industry. The reduction in the leaf chlorophyll content at 0-150 m may be due to the fact that as distance from the cement industry increases, the dispersion and dilution of pollutants emitted by the industry may lead to lower pollutant concentrations around plants. Reduced pollutant exposure could promote healthier chlorophyll synthesis. These results are also in conformity with the findings of Noor *et al*. (2015) who noticed that the polluted area has a lower leaf chlorophyll content as compared to the non-polluted area.

The two-way interaction between the species and season showed the significant variation in the total leaf chlorophyll content of the selected plant species (Fig 4.6). Maximum amount of chlorophyll content was recorded in *Cassia fistula* (3.21 mg g^{-1}) during the winter season, while the minimum chlorophyll content was recorded in *Murraya koenigii* (0.64 mg g^{-1}) during the winter season, which showed at par value with *Toona ciliata* (0.71 mg g^{-1}) during the winter season. The variation in chlorophyll content among different plant species was found to be influenced by factors such as species-specific characteristics, leaf age and various biotic and abiotic conditions.

The interaction between species, seasons and distance exhibited significant influence on total leaf chlorophyll content of the selected plant species. The highest leaf chlorophyll content of 3.30 mg g^{-1} was recorded in *Cassia fistula* at a distance of 0-150 m during winter season (Table 4.2.2 b) and the lowest leaf chlorophyll content of 0.51 mg g^{-1} in *Murraya koenigii* at a distance of 0-150 m during winter season. The higher value of chlorophyll content in *Cassia fistula* may be due to variations of chlorophyll content within species to species.

Table 4.2.2 (a) Seasonal variation in leaf chlorophyll content (mg g^{-1}) of selected plant species growing at different distances surrounding cement industry

Plant Species	Horizontal distance			Seasons	
	0-150m	150-300m	Mean	Winter	Summer
Ricinus communis	0.84	0.88	0.86	0.80	0.92
Murraya koenigii	0.71	0.82	0.77	0.64	0.89
Toona ciliata	0.78	0.86	0.82	0.71	0.94
Cassia fistula	2.47	2.42	2.44	3.21	1.68
Mangifera indica	1.90	2.02	1.96	2.28	1.64
Mean (Distance)	1.34	1.40	**Mean (Season)**	1.53	1.21
Winter	1.51	1.55	1.53		
Summer	1.17	1.26	1.21		

CD (0.05)

Species	0.06	**Species × Season**	0.09
Season	0.04	**Species × Distance**	NS
Distance	0.04	**Season × Distance**	NS

Table 4.2.2 (b) Conjoint effect of species, season and distance on leaf chlorophyll content (mg g^{-1}) of the selected plant species

Plant Species	Winter		Summer	
	0-150m	150-300m	0-150m	150-300m
Ricinus communis	0.81	0.79	0.87	0.97
Murraya koenigii	0.51	0.77	0.90	0.88
Toona ciliata	0.66	0.75	0.90	0.98
Cassia fistula	3.30	3.11	1.63	1.73
Mangifera indica	2.26	2.30	1.54	1.74

CD (0.05)

Species × Seasons × Distance 0.13

4.2.3 Leaf extract pH

pH is a biochemical parameter that serves as a sensitivity indicator of air pollutant. pH of the leaf extract signifies the tolerant capacity of the plant species against climatic stress condition in its growing environment. Higher level of pH in leaf extract indicates that the plants are tolerant under the polluted conditions. Among the selected plant species growing surrounding the cement industry, the leaf extract pH ranged from 5.93-6.27 (Table 4.2.3a). In shrub species, higher leaf extract pH was observed in *Murraya koenigii* (6.23), whereas the lowest was observed in *Ricinus communis* (5.99). Among the tree species, the maximum leaf extract pH was observed in *Mangifera indicia* (6.27) which was found at par

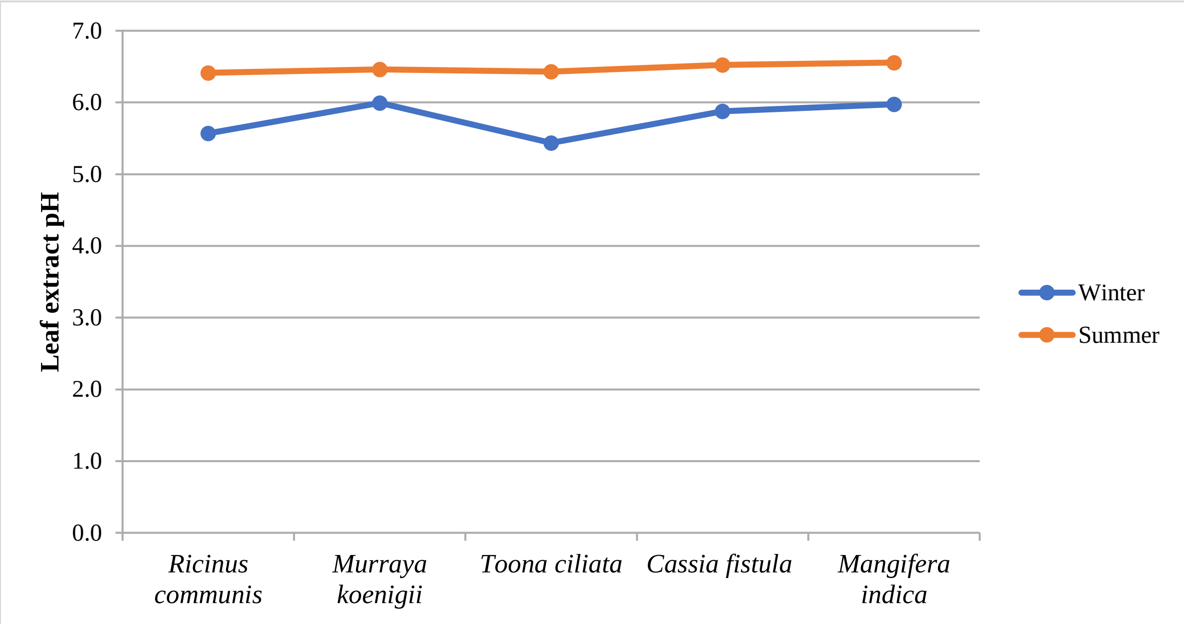

Fig 4.7 Seasonal variation in leaf extract pH of selected plant species growing surrounding cement industry

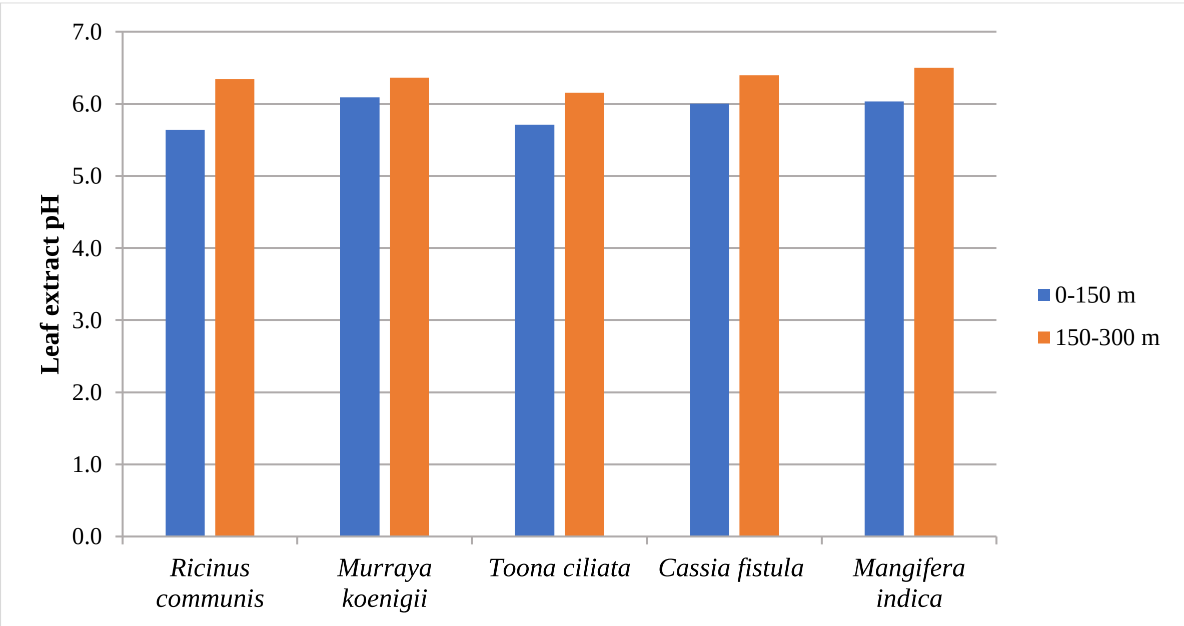

Fig 4.8 Variation in leaf extract pH of selected plant species growing at different horizontal distances surrounding cement industry

with *Cassia fistula* (6.20), whereas the minimum leaf extract pH was observed in *Toona ciliata* (5.93). These results are in line with Joshi *et al*. (2015) and Gholami *et al*. (2016) who observed that an elevated pH can provide resistance to plants against pollutants. When an acidic pollutant is present, it leads to a decrease in leaf pH and this reduction was observed more pronounced in sensitive plants when compared to plant species with higher tolerance levels.

The season were found to influence the leaf extract pH of selected plant species (Table 4.2.3a). Irrespective of species and horizontal distance from the cement industry highest leaf pH was observed during summer season (6.48), while the lowest pH (5.77) during winter season. The decrease in leaf extract pH observed during the winter season may be attributed to the relatively high dust accumulation as compared to the summer season. These results are in conformity with the findings of Javanmard *et al*. (2019) who reported that the decrease in leaf extract pH was potentially attributed to the infiltration of acidic dust particles into leaf tissues along with the accumulation of dust on the leaves.

The leaf extract pH of selected plant species growing at different horizontal distances from the cement industry ranged from 5.90-6.35. The leaf extract pH follows a similar trend to that of chlorophyll content concerning the horizontal distances of the plant species surrounding the cement industry. pH value of leaf extract was found to be increased with an increase in horizontal distance and it was recorded maximum 6.35 at a distance of 150-300 m from the cement industry. The minimum leaf extract pH of 5.90 was recorded at a distance of 0-150 m from the cement industry, indicating significant difference from each other. The lowest value of leaf extract pH near the cement industry may be attributed to high level of pollution. Thambavani *et al*. (2012) and Dash and Dash (2018) reported that the leaf extract pH decreases with the increase in the level of pollutants.

The two-way interaction between species × season and species × distance indicated non-significant variations with respect to the leaf extract pH of selected plant species growing in the surrounding cement industry.

A three-way interaction between species, seasons and distance was also found to be statistically non-significant (Table 4.2.3b)

Table 4.2.3 (a) Seasonal variation in leaf extract pH of selected plant species growing at different distances surrounding cement industry

Plant Species	Horizontal distance			Seasons	
	0-150m	150-300m	Mean	Winter	Summer
Ricinus communis	5.64	6.35	5.99	5.57	6.41
Murraya koenigii	6.09	6.36	6.23	5.99	6.46
Toona ciliata	5.71	6.16	5.93	5.44	6.43
Cassia fistula	6.00	6.40	6.20	5.88	6.52
Mangifera indica	6.03	6.50	6.27	5.98	6.56
Mean (Distance)	5.90	6.35	**Mean (Season)**	5.77	6.48
Winter	5.53	6.01	5.77		
Summer	6.26	6.69	6.48		

CD (0.05)

Species	0.20	**Species × Season**	NS
Season	0.12	**Species × Distance**	NS
Distance	0.12	**Seasons × Distance**	NS

Table 4.2.3 (b) Conjoint effect of species, season and distance on leaf extract pH of the selected plant species

Plant Species	Winter		Summer	
	0-150m	150-300m	0-150m	150-300m
Ricinus communis	5.21	5.93	6.07	6.76
Murraya koenigii	5.82	6.17	6.37	6.56
Toona ciliata	5.16	5.72	6.27	6.60
Cassia fistula	5.70	6.05	6.30	6.75
Mangifera indica	5.76	6.19	6.31	6.81

CD (0.05)

Species × Seasons × Distance NS

4.2.4 Relative water content

Relative water content is the most suitable indicator of a plant's condition concerning the physiological impacts of cellular water deficit. A high-water content within the plant structure contributes to upholding its physiological equilibrium, particularly when facing stressors like air pollution exposure, which often leads to elevated transpiration rates. Relative water content showed the significant variation among the selected plant species that varies from 76.46-81.06% (Table 4.2.4a). In shrub species, higher relative water content was recorded in *Ricinus communis* (79.63%) and lower relative water content in *Murraya koenigii* (76.65%). In tree species, maximum relative water content was observed in *Mangifera indica* (81.06%), while the minimum in *Toona ciliata*, which showed at par value with *Cassia fistula* (77.00%). The leaf relative water content was observed in the order of *Mangifera indica* (81.06%) > *Ricinus communis* (79.63%) > *Cassia fistula* (77.00%) > *Murraya koenigii* (76.65%) > *Toona* *ciliata* (76.46%) among the selected plant species. The variation in leaf relative water content may be attributed to variations in the inherent ability of plants to withstand stress conditions. These results are in conformity with the findings of Gholami *et al*. (2016) and Nayak *et al*. (2018) who revealed that in polluted conditions, plants often experience elevated transpiration rates, which can potentially result in desiccation. As a result, the plant's ability to uphold relative water content (RWC) plays an significant role in determining the level of tolerance to pollution.

The leaf relative water content of selected plant species growing in vicinity of the cement industry varied significantly with seasons, which ranged from 74.73% to 81.59%. Among the selected plant species, the leaves showed the highest relative water content of 81.59% in the winter season, whereas the lowest content of 74.73% during the summer season. Increased relative water content during the winter season may be attributed to reduced transpiration during the colder months due to the reason that transpiration rates in plants are generally lower due to lower temperatures and reduced atmospheric demand for water. These results are in line with the findings of Akande *et al*. (2021) who also reported that the maximum relative water content in plant leaves was recorded during the winter season and the minimum in the summer season.

The leaf relative water content of the selected plant species growing in vicinity of the cement industry also varied significantly with horizontal distance which ranged from 78.91 to 77.40%. The highest relative water content (78.91%) was recorded in the leaves of plant species growing at the distance of 0-150 m from the cement industry and lowest relative water content of 77.40% in the leaves of plant species growing at the distance of 150-300 m from the cement industry (Table 4.2.4a). The increased relative water content (RWC) observed in plant species growing at a distance of 0-150 m from the cement industry can be attributed to higher levels of pollutants. The higher RWC in plants situated near the cement industry might also be due to a comparatively reduced transpiration rate in areas with higher pollution levels. This could lead to changes in leaf behaviour in response to the presence of pollutants. The results are in congruence with Kapoor and Bhardwaj (2016) who reported increased relative water content in selected plants species at a distance of 15-30 m as compared to distance more than 30 m.

The two-way interaction between species and season was found to be non-significant with respect to the leaf relative water content of selected plant species growing in the surrounding cement industry.

The two-way interaction between species and distance showed a significant variation in the relative water content of the selected plant species. The highest relative water content was recorded in the leaves of *Mangifera indica* (84.42%) at a horizontal distance of 0-150 m from the cement industry, indicating a significant difference in comparison to other values. Whereas, the lowest relative water content was recorded in *Toona ciliata* (75.65%) at a horizontal distance of 0-150 m, which was found at par with *Ricinus communis* (78.67%), *Murraya koenigii* (76.08%), *Toona ciliata* (77.27%), *Cassia fistula* (77.31%) and *Mangifera indica* (77.69%) at a horizontal distance of 150-300 m from the cement industry.

Interaction between season and distance significantly influenced the relative water content of the selected plant species surrounding the cement industry significantly. Maximum relative water content (81.90%) was observed during the winter season at a horizontal distance of 150-300 m, which was found at par with relative water content (81.27%) at 0-150 m horizontal distance from the cement industry during the same season. Whereas, the minimum relative water content (72.90%) was observed during the summer season at a horizontal distance of 150-300 m. Higher relative water content during winter season can be attributed to the combined effects of pollution status and weather condition which prevailed during that season.

The three-way interaction between species, season and distance non-significantly influenced the relative water content of the selected plant species (Table 4.2.4b). The highest relative water content was recorded in *Mangifera indica* (84.72%) at a distance of 0-150 m during winter season which was at par with *Mangifera indica* (84.13%) at a distance of 0-150 m during summer season > *Cassia fistula* (83.73%) at a distance of 150-300 m during winter season > *Ricinus communis* (83.53%) at a distance of 0-150 m during winter season > *Ricinus communis* (82.12%) at a distance of 150-300 m during winter season > *Murraya koenigii* (81.49%) at a distance of 0-150 m during winter season > *Toona ciliata* (81.42%) at a distance of 150-300 m during winter season. The lowest relative water content was observed in *Cassia fistula* (70.88%) which was at par with *Mangifera india* (72.53%) at a distance of 150-300 m during summer season < *Murraya koenigii* (72.76%) at a distance of 150-300 m during summer season < *Murraya koenigii* (72.94%) at a distance of 0-150 m during summer season < *Toona ciliata* (73.10%) at a distance of 0-150 m during summer season < *Toona ciliata* (73.12%) at a distance of 150-300 m during summer season < *Cassia fistula* (74.94%) at a distance of 0-150 m during summer season < *Ricinus communis* (75.22%) at a distance of 150-300 m during winter season.

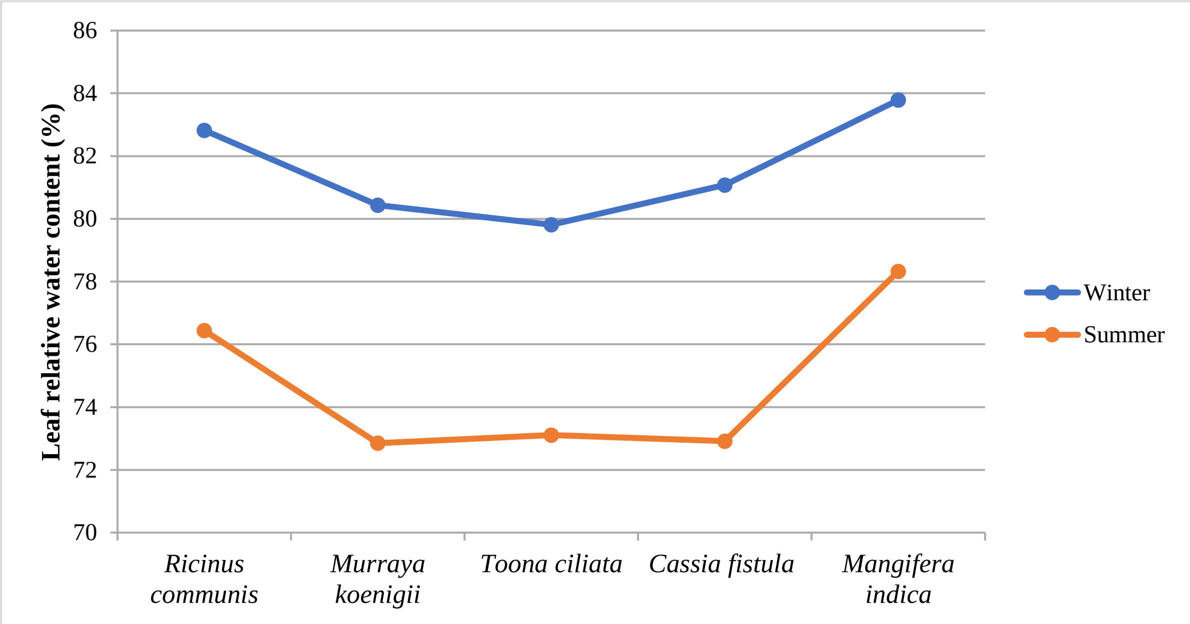

Fig 4.9 Seasonal variation in leaf relative water content of selected plant species growing surrounding cement industry

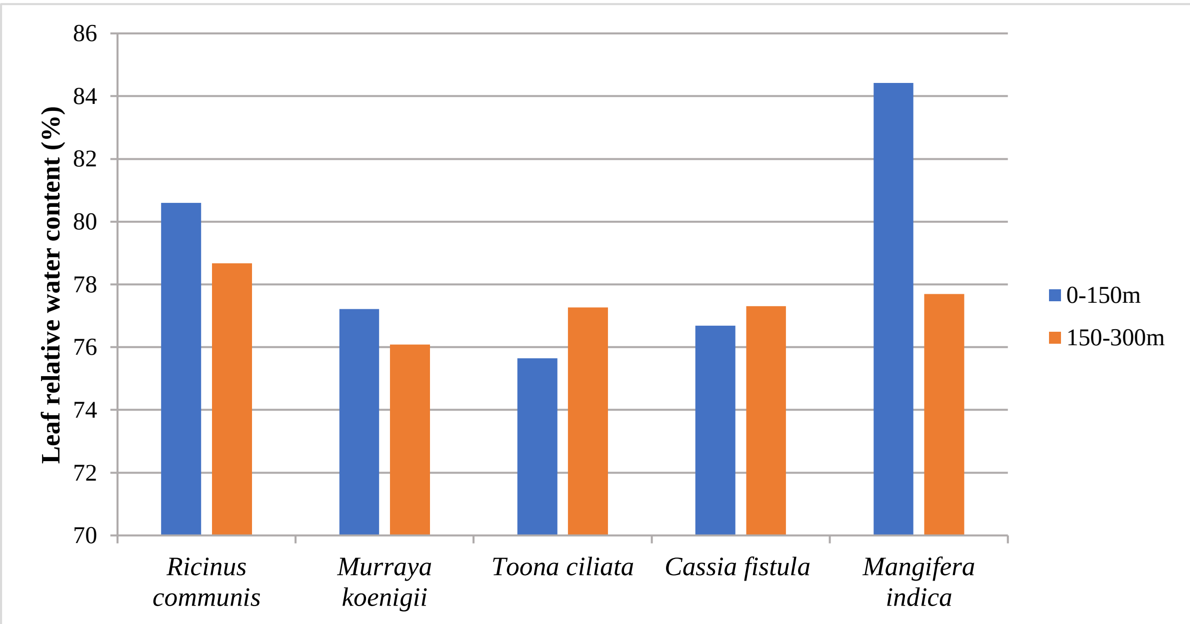

Fig 4.10 Variation in leaf relative water content of selected plant species growing at different horizontal distances surrounding cement industry

Table 4.2.4 (a) Seasonal variation in relative water content (%) of selected plant species growing at different distances surrounding cement industry

Plant Species	Horizontal distance			Seasons	
	0-150m	150-300m	Mean	Winter	Summer
Ricinus communis	80.60	78.67	79.63	82.83	76.44
Murraya koenigii	77.21	76.08	76.65	80.44	72.85
Toona ciliata	75.65	77.27	76.46	79.81	73.11
Cassia fistula	76.69	77.31	77.00	81.08	72.91
Mangifera indica	84.42	77.69	81.06	83.79	78.33
Mean (Distance)	78.91	77.40	**Mean (Season)**	81.59	74.73
Winter	81.27	81.90	81.59		
Summer	76.55	72.90	74.73		

CD (0.05)

Species	2.20	**Species × Season**	NS
Seasons	1.39	**Species × Distance**	3.12
Distance	1.39	**Season × Distance**	1.97

Table 4.2.4 (b) Conjoint effect of species, season and distance on leaf extract pH of the selected plant species

Plant Species	Winter		Summer	
	0-150m	150-300m	0-150m	150-300m
Ricinus communis	83.53	82.12	77.66	75.22
Murraya koenigii	81.49	79.40	72.94	72.76
Toona ciliata	78.20	81.42	73.10	73.12
Cassia fistula	78.43	83.73	74.94	70.88
Mangifera indica	84.72	82.85	84.13	72.53

CD (0.05)

Species × Season × Distance 4.41

4.3 Air Pollution Tolerance Index (APTI)

Plant response to quality of air can be determined by calculating an index known as the air pollution tolerance index. The air pollution tolerance index (APTI) plays a significant role in determining the resistivity and susceptibility of plant species to air pollution levels and in adapting to polluted air. During the investigation period, in the month of November, the cement industry was closed which staggered the movement of trucks to carry the cement.

Simultaneously, during the summer months, heavy rainfall of 374.5mm hindered the deposition of dustbin leaf surface, resulted in the low range of APTI. The detailed analysis has been discussed as follows:-

The APTI of the selected plant species growing around the cement industry exhibited significant variation (Table 4.3a). The APTI of the selected plant species varied from 9.43 to 11.21. In shrub species, a higher APTI of 10.50 was recorded in *Ricinus communis* and lower APTI of 9.43 was recorded in *Murraya koenigii*. In tree species, the maximum APTI was recorded in *Cassia fistula* (11.21), whereas the minimum APTI in *Toona ciliata* (10.41). The order of selected plant species in accordance with APTI was found in the order of *Cassia fistula* (11.21) > *Mangifera indica* (10.83) > *Ricinus communis* (10.50) > *Toona ciliata* (10.41) > *Murraya koenigii* (9.43). The higher APTI of *Cassia fistula* may be attributed to the capacity of plants to adapt to stress conditions due to pollution. The results are in line with the findings of Bharti *et al.* (2018) who reported that the plants vary in their responses to similar air pollutants, and variation in air pollution tolerance found to be due to variation in any of the four biochemical parameters (ascorbic acid content, total chlorophyll content, leaf extract pH and relative water content) used to calculate the APTI. Similar results were also reported by Gholami *et al*. (2016) who also reported that tolerance to air pollution varies among different plant species, depending on a plant's ability to withstand the impact of pollutants.

The APTI of selected plant species surrounding cement industry varied significantly with seasons which ranged from 10.6-10.89. The highest APTI value was observed during winter season with a value 10.89 as compared to summer season with value 10.6. These values were significantly different from each other. The higher value of APTI during winter season may be attributed to more dust accumulation and increased stress conditions which may enhanced the leaf biochemical parameters. The results are in line with Kapoor and Bhardwaj (2016) who reported that the seasons of the year have an influence on the Air Pollution Tolerance Index (APTI) values of plants. The results revealed that the plants displayed higher APTI values during the post-monsoon season in comparison to the pre-monsoon season.

The interaction between species and season were found to significantly influence APTI of the selected plant species growing surrounding the cement industry (Fig 4.11). The highest APTI of 11.98 was recorded in *Cassia fistula* during winter season, whereas the lowest APTI of 8.83 in *Murraya koenigii* during winter season. The highest value of *Cassia fistula* may be due to its genetic makeup.

The two-way interaction of season and distance were observed to significantly influence the APTI of the selected plant species surrounding cement industry. (Fig 4.12).

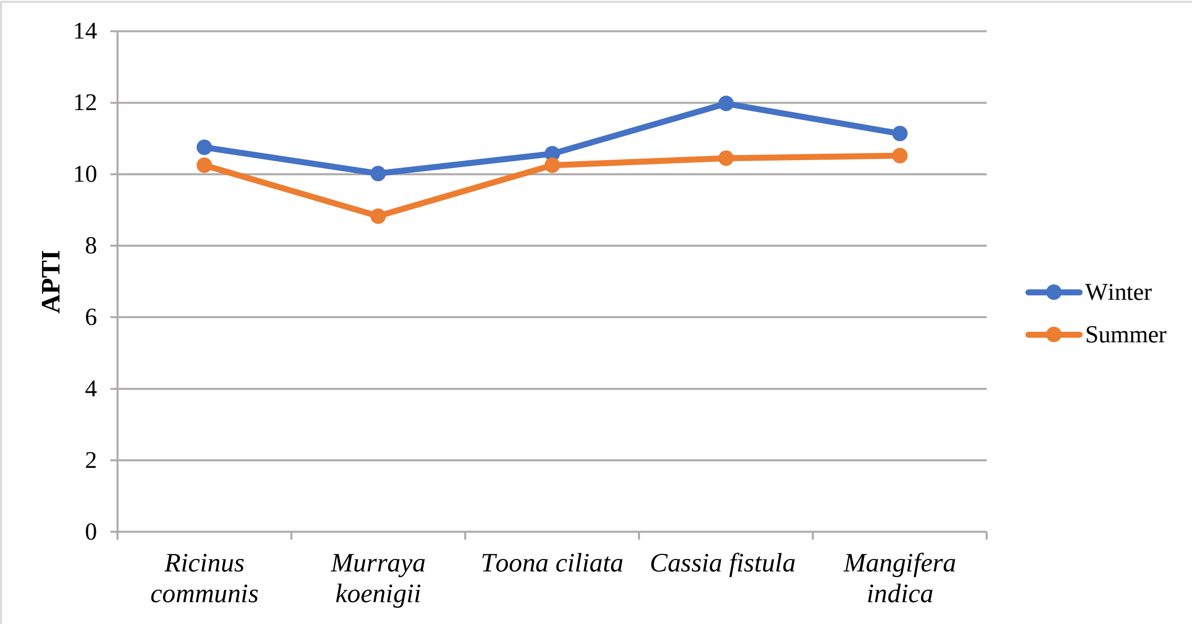

Fig 4.11 Seasonal variation in APTI of selected plant species growing surrounding cement industry

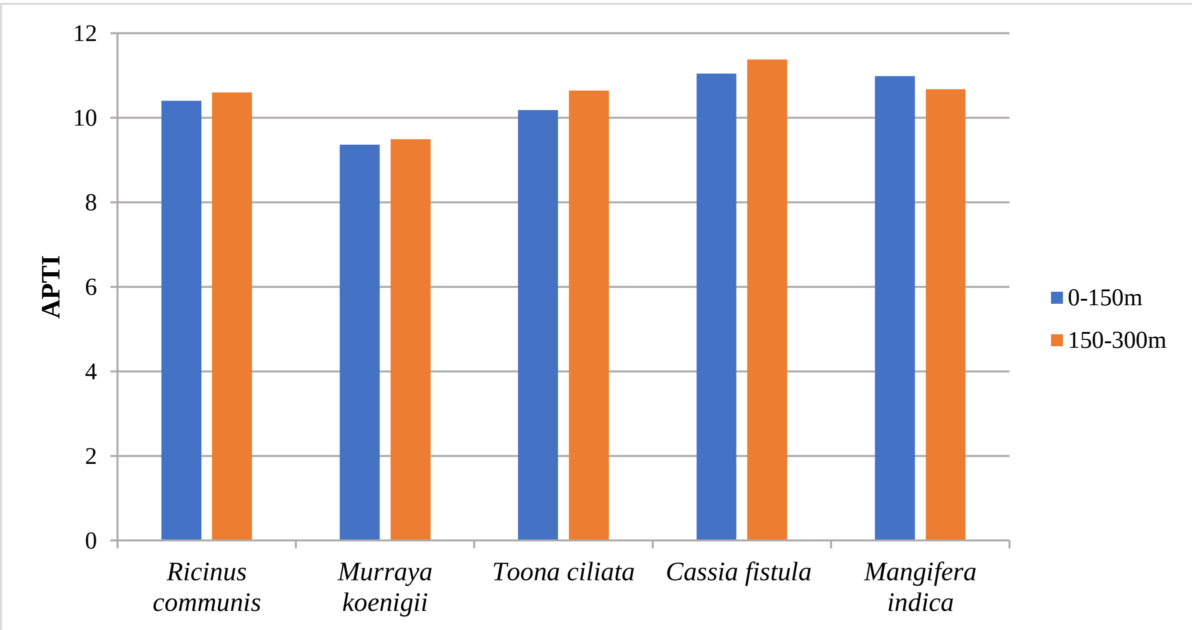

Fig 4.12 Variation in APTI of selected plant species growing at different horizontal distances surrounding cement industry

Highest APTI value of 11.08 was observed at a horizontal distance of 150-300 m during the winter season, whereas the lowest APTI value of 10.3 at a horizontal distance of 150-300 m during summer season, which was found to be at par with APTI value of 10.09 at a horizontal distance of 0-150 m during summer season.

Table 4.3 (a) Seasonal variation in APTI of selected plant species growing at different horizontal distances surrounding cement industry

Plant Species	Horizontal distance			Seasons	
	0-150m	150-300m	Mean	Winter	Summer
Ricinus communis	10.40	10.60	10.50	10.75	10.25
Murraya koenigii	9.36	9.49	9.43	10.02	8.83
Toona ciliata	10.18	10.64	10.41	10.57	10.25
Cassia fistula	11.04	11.38	11.21	11.98	10.45
Mangifera indica	10.98	10.67	10.83	11.14	10.52
Mean (Distance)	10.39	10.56	**Mean (Season)**	10.89	10.06
Winter	10.70	11.08	10.89		
Summer	10.09	10.03	10.06		

CD $_{(0.05)}$

Species	0.26	**Species × Season**	0.37
Season	0.17	**Species × Distance**	NS
Distance	NS	**Season × Distance**	0.24

Table 4.3 (b) Conjoint effects of species, season and horizonal distance on APTI of the selected plant species

Plant Species	Winter		Summer	
	0-150m	150-300m	0-150m	150-300m
Ricinus communis	10.59	10.92	10.21	10.28
Murraya koenigii	10.02	10.03	8.71	8.95
Toona ciliata	10.24	10.90	10.12	10.38
Cassia fistula	11.61	12.34	10.47	10.42
Mangifera indica	11.06	11.22	10.91	10.13

CD $_{(0.05)}$

Species × Season × Distance NS

4.4 Anticipated Performance Index (API)

API is used as an indicator to assess the capacity of the predominant species to clean up atmospheric pollutants. The assessment of the API with respect to the selected plant species growing surrounding the cement industry was found in the range of very poor to excellent (Table 4.4b). In the shrub species, *Ricinus communis* falls into the good category with an API grade of 4, whereas *Murraya koenigii* falls under the very poor category with an API grade of 1. Among tree species, *Mangifera indica* falls into the excellent category with the highest API grade (6), which was followed by *Toona ciliata* and

Cassia fistula, which falls into the good category with an API grade of 4. The highest value of API for *Mangifera indica* among the selected plant species is due to its high APTI. Further, the better laminar characteristics like leaf size, texture and canopy structure, along with the high economic values, might have enhanced its API value towards the excellent category. The results are in line with Kalaipriya *et al*. (2023) who reported that the Air Pollution Tolerance Index (APTI) is a useful tool in the selection of appropriate tree species, especially when combined with the anticipated performance index (API) value. Plants exhibiting elevated APTI and API values were suggested for the establishment of greenbelt development. These indices depend on biochemical parameters as well as biological and socioeconomic characteristics.

Table 4.4 (a) Evaluation of plant species on the basis of APTI value and some biological and socio-economic characteristics

Plant species	Assessment parameters				Laminar structure				Grade allotted		
	APTI	PLANT HABIT	CANOPY STRUCTURE	TYPE OF PLANT	LEAF SIZE	TEXTURE	HARDINESS	ECONOMIC VALUE	TOTAL PLUS	% SCORING	API GRADE
Ricinus communis	++++	-	-	+	++	+	+	++	11	69	4
Murraya koenigii	++	-	+	+	-	-	-	++	6	38	1
Toona ciliata	++++	++	+	-	++	+	-	+	10	63	4
Cassia fistula	+++++	+	+	-	+	-	+	+	10	63	4
Mangifera indica	+++++	+	++	+	+	+	+	++	14	88	6

Table 4.4 (b) Anticipated performance index (API) of plant species

Sr. No.	Plant species	Total Grade Allotted	%Score	API Grade	Assessment
1	*Ricinus communis*	11	69	4	Good
2	*Murraya koenigii*	6	38	1	Very Poor
3	*Toona ciliata*	10	63	4	Good
4	*Cassia fistula*	10	63	4	Good
5	*Mangifera indica*	14	88	6	Excellent

4.5 Relationship of leaf dust accumulation with biochemical parameters species wise

The significant negative correlation r = -0.99 was observed between leaf dust and chlorophyll content in *Toona ciliata* (Table 4.2). The correlation between leaf dust and leaf pH were found to be significant and negatively correlated (r = -0.99) in *Ricinus communis*, followed by *Toona ciliata* (r = -0.99), *Cassia fistula* (r = -0.99), *Murraya koenigii* (r = -0.97) and *Mangifera indica* (r = -0.95).

Table 4.5 Correlation between leaf dust and biochemical parameters of different plant species growing surrounding cement industry

Plant species	Ascorbic acid	Chlorophyll	Leaf pH	Relative Water Content
Ricinus communis	0.42	-0.82	-0.99**	0.94
Murraya koenigii	0.65	-0.84	-0.97*	0.87
Toona ciliata	0.67	-0.99**	-0.99*	0.82
Cassia fistula	0.70	0.92	-0.99*	0.74
Mangifera indica	-0.07	0.84	-0.95*	0.74

**** Significant at 0.01 level**

*** Significant at 0.05 level**

4.6 Relationship of leaf biochemical parameters and APTI of selected plant species

To investigate the impact of tolerance levels on different biochemical parameters of the selected plant species, a correlation analysis was conducted (as shown in Table 4.6). A strong positive correlation were found between the Air Pollution Tolerance Index (APTI) and the ascorbic acid content (r = 0.97). This correlation was particularly evident at a horizontal distance of 150-300 m from the cement industry during the summer season. The APTI and chlorophyll demonstrated a significant positive correlation (r = 0.97) within a horizontal distance of 0-150 m from the cement industry during the winter season. A significant positive correlation were found between APTI and relative water content (r = 0.94) at a horizontal distance of 150-300 m from the cement industry during winter season.

Table 4.6 Correlation between leaf biochemical parameter and APTI of selected plant species growing at different horizontal distance surrounding cement industry

Biochemical parameters	Air pollution tolerance index			
	Winter		Summer	
	0-150m	150-300m	0-150m	150-300m
Ascorbic acid	0.40	0.70	0.76	0.97**
chlorophyll	0.97**	0.86	0.64	0.44
pH	0.30	-0.04	-0.31	0.60
Relative water content	-0.04	0.94*	0.69	0.00

**** Significant at 0.01 level**

*** Significant at 0.05 level**

Chapter-5

SUMMARY AND CONCLUSION

In order to conduct the present investigation, a preliminary survey surrounding the cement industry was done during the year 2022-23. The commonly growing plant species *Cassia fistula*, *Toona ciliata* and *Mangifera indica* among tree species; Ricinus *communis*, and *Murraya koenigii* among shrub species, were selected for the study. To meet the objective of the study, horizontal distribution of the dust contents 300 m circumference was considered around the cement industry. Thus, two horizontal distances of 0-150 m and 150-300 m alongside of cement plant was selected for the experimentation during winter and summer seasons of 2022-2023. The morphological characters of the selected plant species were maintained through iso-ecological conditions to maintain uniformity. Several morphological characteristics of the plants, such as plant habit, canopy structure, plant type, leaf surface characteristics and leaf area were assessed. The Air Pollution Tolerance Index (APTI) was calculated using biochemical parameters, namely ascorbic acid content, total chlorophyll content, leaf extract pH and relative water content. The Anticipated Performance Index (API) of the plant species was also estimated by considering the APTI values in combination with biological and socio-economic parameters. The detailed summary of leaf dust load along with various bio- chemical parameters, APTI and API were given below:

Leaf dust accumulation

The leaf dust accumulation among the selected plant species varied within the range of 6.57 to 30.69 mg m^{-2}. In shrub species, the order was *Ricinus communis* > *Murraya koenigii*. Whereas, in tree species the order was Cassia *fistula* > *Toona ciliata* > *Mangifera indica*. The leaf dust accumulation decreases with increasing horizontal distance from the cement industry with its content ranging from 18.12 to 20.61 mg m^{-2}. Seasons of the year influenced the leaf dust accumulation on selected plant species with the highest dust accumulation (21.78 mg m^{-2}) in winter season and the lowest (16.95 mg m^{-2}) in summer season.

Biochemical parameters

The ascorbic acid content in the leaves of selected plant species ranged from 2.54 to 4.10 mg g^{-1}. In shrub species, the order was *Ricinus communis* > *Murraya koenigii*. Whereas, in tree species the order was *Toona ciliata* > *Cassia fistula* > *Mangifera indica*. The ascorbic acid content increased as the horizontal distance from the cement industry increased, ranging from 3.46 to 3.62 mg g^{-1}. The highest ascorbic acid content (3.73 mg g^{-1}) was recorded during the winter season, while the lowest (3.35 mg g^{-1}) was observed during the summer season.

The chlorophyll content in the leaves of the selected plant species ranged from 0.77 to 2.44 mg g^{-1}. In shrub species, the order was *Ricinus communis* > *Murraya koenigii*. Whereas, in tree species the order was *Cassia fistula* > *Mangifera indica* > *Toona ciliata*. The chlorophyll content increased as the horizontal distance from the cement industry increased and ranged from 1.34 to 1.40 mg g^{-1}. The highest chlorophyll content (1.53 mg g^{-1}) was recorded during winter season, while the lowest (1.21 mg g^{-1}) was observed during the summer season.

The leaf extract pH of the selected plant species exhibited a range from 5.93 to 6.27. In shrub species, the order was *Murraya koenigii* > *Ricinus communis*. Whereas, in tree species the order was *Mangifera indica* > *Cassia fistula* > *Toona ciliata*. As the horizontal distance from the cement industry increased, the pH value also increased and ranged from 5.90 to 6.35. The highest pH (6.48) was recorded during the summer season, while the lowest (5.77) was observed during the winter season.

The relative water content of the selected plant species ranged from 76.46 to 81.26%. In shrub species the order was *Ricinus communis* > *Murraya koenigii*. Whereas, in tree species the order was *Mangifera indica* > *Cassia fistula* > *Toona ciliata*. The relative water content decreased as the horizontal distance from the cement industry increased, ranging from 77.40 to 78.91%. The highest relative water content (81.59%) was recorded during the winter season, while the lowest (74.73%) was observed during the summer season.

Air Pollution Tolerance Index (APTI)

The air pollution tolerance index of the selected plant species ranged from 11.21 to 9.43. In shrub species the order was *Ricinus communis* > *Murraya koenigii*. Whereas, in tree species the order was *Cassia fistula* (11.21) > *Mangifera indica* (10.83) > *Toona ciliata* (10.41). The highest APTI (10.89) was recorded during the winter season, while the lowest (10.06) was observed during the summer season.

Anticipated Performance Index (API)

The anticipated performance index of the selected plant species varied from very poor to excellent category. Among the shrub plant species, the order of API was *Ricinus communis* > *Murraya koenigii*. Whereas, in tree species the order was *Mangifera indica* > *Cassia fistula* = *Toona ciliata*.

CONCLUSION

The study indicated that the plant growing surrounding the cement industry exhibited variations in the physiological and biochemical characteristics. Among the different plant species, *Mangifera indica* among the trees and *Ricinus communis* among the shrubs may be effectively grown for air pollution amelioration as green belt in the surroundings of cement plant industrial unit. Further, suggested that *Murraya koenigii* shrub may act as bio-indicator of air pollution being highly susceptible.

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APPENDIX-I

Analysis of variance table for leaf dust accumulation (mg m^{-2})

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated
Replication	3.00	1.13		
Species	4.00	4713.43	1178.36	2601.87
Season	1.00	465.99	465.99	1028.93
Species × Season	4.00	85.91	21.48	47.42
Distance	1.00	123.94	123.94	273.67
Species × Distance	4.00	44.41	11.10	24.51
Season × Distance	1.00	0.89	0.89	1.96
Species × Season × Distance	4.00	3.44	0.86	1.90
Error	57.00	25.82	0.45	
Total	79.00	5464.95		

APPENDIX-II

Analysis of variance table for ascorbic acid content (mg g^{-1})

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated
Replication	3	0.04		
Species	4	26.53	6.63	409.48
Season	1	2.87	2.87	177.35
Species × Season	4	1.50	0.38	23.22
Distance	1	0.56	0.56	34.44
Species × Distance	4	0.02	0.00	0.25
Season × Distance	1	0.00	0.00	0.00
Species × Season × Distance	4	0.12	0.03	1.78
Error	57	0.92	0.02	
Total	79	32.56		

APPENDIX-III

Analysis of variance table for chlorophyll content (mg g^{-1})

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated
Replication	3	0.16		
Species	4	38.80	9.70	1170.24
Season	1	1.98	1.98	238.44
Species × Season	4	9.54	2.39	287.82
Distance	1	0.08	0.08	9.87
Species × Distance	4	0.08	0.02	2.28
Season × Distance	1	0.01	0.01	1.71
Species × Season × Distance	4	0.19	0.05	5.80
Error	57	0.47	0.01	
Total	79	51.31		

APPENDIX-IV

Analysis of variance table for leaf extract pH

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated
Replication	3	2.75		
Species	4	1.44	0.36	4.75
Season	1	9.98	9.98	131.26
Species × Season	4	0.71	0.18	2.34
Distance	1	4.16	4.16	54.78
Species × Distance	4	0.40	0.10	1.32
Season × Distance	1	0.01	0.01	0.16
Species × Season × Distance	4	0.08	0.02	0.26
Error	57	4.33	0.08	
Total	79	23.86		

APPENDIX-V

Analysis of variance table for relative water content (%)

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated
Replication	3	34.10		
Species	4	273.79	68.45	7.07
Season	1	941.72	941.72	97.31
Species × Season	4	17.75	4.44	0.46
Distance	1	45.72	45.72	4.72
Species × Distance	4	167.58	41.89	4.33
Season × Distance	1	91.43	91.43	9.45
Species × Season × Distance	4	105.89	26.47	2.74
Error	57	551.63	9.68	
Total	79	2229.60		

APPENDIX-VI

Analysis of variance table for APTI

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated
Replication	3	1.63		
Species	4	28.35	7.09	51.52
Season	1	13.86	13.86	100.74
Species × Season	4	4.12	1.03	7.49
Distance	1	0.53	0.53	3.88
Species × Distance	4	1.38	0.34	2.50
Season × Distance	1	0.93	0.93	6.73
Species × Season × Distance	4	0.85	0.21	1.55
Error	57	7.84	0.14	
Total	79	59.50		

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Title of the thesis	**:**	**"Assessment of Air Pollution Tolerance Index of Plant Species surrounding Cement Industry at Barmana in Himachal Pradesh"**
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ABSTRACT

The present investigation entitled **"Assessment of Air Pollution Tolerance Index of Plant Species surrounding Cement Industry at Barmana in Himachal Pradesh"** was conducted during the year 2022-23 under the Department of Environmental Science, College of Forestry, Dr YS Parmar University of Horticulture and Forestry Nauni- Solan, Himachal Pradesh. The study was aimed at understanding the seasonal variation in biochemical parameters and determining the indices of the Air Pollution Tolerance and Anticipated Performance along with the dust accumulation capacity of plants growing around the cement industry. In the selected area around the cement industry vegetation distribution was studied. The commonly grown dominant species namely; *Cassia fistula, Mangifera indica, Toona ciliate, Ricinus communis* and *Murraya koenigii* were choosen for the study. Studied the seasonal impact of pollutants emitted from cement industry on the plants, horizontal distances of 0-150 m and 150-300 m during winter and summer seasons. Total 20 treatment combinations replicated four times were analysed through three way (factorial) randomized block design. The dust accumulation of selected plant species ranged from 6.57-30.69 mg m^{-2}. The leaf ascorbic acid content of the selected plant species varied from 2.54-4.10 mg g^{-1}. The leaf chlorophyll content of the selected plant species ranged from 0.77-2.44 mg g^{-1}. The leaf extract pH of selected species fluctuated from 5.93- 6.27. The relative water content of selected plant species ranged from 76.46-81.06%. The APTI was calculated on the basis of four bio-chemical parameters; ascorbic acid content, total chlorophyll content, leaf extract pH and relative water content. The APTI of selected plant species varied from 9.43-11.21. The order of selected plant species in accordance with APTI was *Cassia fistula* (11.21) > *Mangifera indica* (10.83) > *Toona ciliata* (10.41) among the tree species and *Ricinus communis* (10.50) > *Murraya koenigii* (9.43) in shrubs species. Anticipated Performance Index (API) was also calculated by combining APTI with some socio-economic characters. Among the selected plant species, the order of API was *Mangifera indica* > *Cassia fistula* = *Ricinus communis* = *Toona ciliate* > *Murraya koenigii*. Thus, the investigation suggested that *Mangifera indica* may be grown alongside of the cement industry as green belt. *Murraya koenigii* being the least tolerant plant species may act as bioindicator of pollutants in the area.

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Whether sponsored by some state/Central Govt./Univ./SAARC : No

Scholarship/ Stipend/ Fellowship, any other financial assistance received during the study period : University Stipend

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