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EFFECT OF ROADSIDE DUST ON LEAF ANATOMY OF SELECTED PLANTS

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ABSTRACT

Dust settling at roadsides has been shown to adversely affect plants in terms of biomass production, physiology and leaf anatomy. In this work, we aim to evaluate the effect of roadside dust fall on some common tree species growing around Sarangarh-Bilaigarh road, Chhattisgarh State, India. This will be carried out through an integrated field-work and lab-based protocol using 200 leaves collected from each of 5 species [Neem-Azadirachta indica; Peepal-Ficus religiosa; Mango-Mangifera indica; Banyan-Ficus benghalensis; Jamun-Syzygium cumini], distributed across sites of varying dust fall intensity. Dust load will be quantified gravimetrically and leaves subjected to detailed microscopical analysis to determine parameters including: number and size of stomata; thickness of upper and lower epidermis and cuticle; arrangement and thickness of mesophyll tissue; xylem and phloem diameter; and number of trichomes per unit area. Data will be analyzed using appropriate descriptive and inferential statistics, i.e. mean, t-test, ANOVA, correlation and regression. Preliminary findings suggest a decrease in the thickness of the leaf blade, number and size of stomata, and thickness of mesophyll, but concomitant increase in thickness of upper and lower epidermis and cuticle, with dust fall intensity. Banyan and Mango were predicted to show higher degrees of anatomical 'resistance' while Peepal was more 'susceptible'. Accordingly, certain leaf anatomical features may serve as useful bio-indicators of

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ambient air pollution. Results from the current project can subsequently aid selection of suitable species for afforestation along roadsides, establishment of green belts, augmentation of regional flora and improved environmental stewardship.

Keywords: Roadside Dust, Leaf Anatomy, Air Pollution, Stomatal Density, Epidermal Thickness, Dust Deposition, Plant Adaptation, Environmental Botany.

1. INTRODUCTION

1.1 Background of Roadside Dust Pollution

Roadside dust is generated as a consequence of transport, building and industrial activities and soil erosion. When dust settles on leaves, it has implications for the physiology, anatomy and vegetative growth of plants. If dust exposure continues over an extended period, it is possible that it will limit photosynthesis, transpiration and gas exchange at the level of the stoma. Leaves of plants situated along busy roads can show a range of anatomical differences to their epidermis, cuticle and mesophyle. Therefore, it is important to determine the effect of roadside dust on the anatomy of these plants so that more pollution-resistant candidates can be selected for use in green belts and other roadside plantings.

1.2 Sources and Characteristics of Roadside Dust

A number of processes contribute to the production of roadside dust. Vehicle movement (exhaust fumes, tyre and brake dust), building works, industry and soil dust raised by wind all generate roadside dust. This will comprise a mixture of inorganic, organic, metallic and carbonaceous components. Depending upon local circumstances such as volume of traffic, nature of the road, weather and adjacent land use, the composition and properties of roadside dust will vary. Smaller dust particles will tend to become firmly fixed on leaf surfaces, whereas coarser dust will fall due to gravity. As described above, continued dust loading will likely impact on leaf anatomy, function and yield.

1.3 Impact of Air Pollution on Plant Growth and Development

It is well established that atmospheric pollutants will negatively affect the physiology, biochemistry and anatomy of plants. A wide variety of air pollutants, ranging from suspended particulates to SO_2, NOx and toxic metal ions, will cause varying levels of harm. Where dust coats the leaves of a plant, this will limit incident radiation, gas exchange and hence may reduce the rate of photosynthesis. With sufficient time, leaf colour, mass and longevity will be impacted, and anatomical features modified. All plants will display some degree of response and acclimation to external stimuli, although the magnitude of this will depend on the attributes of the particular taxa, level and length of exposure to the relevant stressor(s).

1.4 Leaf Anatomy and Its Environmental Significance

The leaf anatomy of a plant is intimately linked to its ability to complete key life functions and accommodate external conditions. Key features of the leaf anatomy

include the cuticle, epidermis, stomata, mesophyle and veins. It would therefore stand to reason that if a plant was subjected to a form of air pollution, one or more of these structures might be affected. Dust can give rise to a variety of changes in leaf anatomy; for example, the thickness of the cuticle and epidermis, stomatal frequency, and arrangement and proportions of the mesophyle. By examining these features, a better understanding can be gained of the relative sensitivity of different taxa to dust.

1.5 Mechanism of Dust Deposition on Leaf Surfaces

There are four principal processes by which dust becomes deposited on the surface of a leaf: gravity, interception, impaction and Brownian motion. As noted previously, the rate and extent of dust fixation will be dependent on many variables including dust grain size, wind speed, relative humidity, traffic flow and leaf surface morphology. In particular, leaves with high densities of trichomes and/or a thick, raised cuticle will trap higher amounts of dust. Once fixed, the presence of dust can prevent the stoma from functioning, decrease incident light and inhibit transpiration. As dust continues to accumulate, further anatomical and functional effects may occur. Finally, the action of rain and wind will mobilise some of the dust particles.

1.6 Anatomical Adaptations of Plants under Dust Pollution Stress

Under the pressure of roadside dust, plants may adopt a range of anatomical traits to enable them to survive in the hostile environment. Examples of these can include development of a thicker cuticle, epidermis, variation in stomatal frequency and modifications to the mesophyle. Increased cuticular and epidermal dimensions can act to impede uptake of dust and minimize evaporative water loss. Similarly, the stoma and associated features can be modified to suit prevailing circumstances. The presence and prominence of trichomes on the leaf surface will also be influenced. Of course, these traits will vary according to the properties of the plant taxon under consideration

1.7 Statement of the Research Problem

With the increasing number of vehicles and construction projects taking place around Sarangarh-Bilaigarh district, Chhattisgarh state, India, there is likely to be a build-up of roadside dust that could impact on the resident flora. Over time, this would be expected to lead to a series of modifications in key leaf anatomical features such as the stoma, epidermis, cuticle and mesophyle. To what extent will these structures be changed and how will different taxa respond? These questions have yet to be fully addressed, and the current research aims to compare the dust-induced anatomical features of several taxa from roadside and non-roadside sites, and highlight any taxa showing relatively higher resistance to dust.

1.8 Significance and Rationale of the Study

This line of enquiry will therefore be beneficial to the fields of environmental botany, plant anatomy and pollution abatement. By establishing a link between roadside dust fixation and corresponding changes in the leaf anatomy, further progress can be made towards determining candidate taxa as bioindicators and those tolerant of high levels of dust. Consequently,

appropriate species can be recommended for planting along roadsides and within green belts, aiding the preservation of local biodiversity. Moreover, this work can form the basis of subsequent studies looking at other aspects of plant-air pollution relationships.

2. REVIEW OF LITERATURE

2.1 Roadside Dust Pollution and Its Impact on Vegetation

In a review of the impacts of dust on plants in various biomes**, Farmer (1993)** highlighted several anthropogenic contributors to airborne dust including: transport, quarries, mines and industry. Deposition of dust resulted in disruption to key processes such as photosynthesis, transpiration and overall plant production.

Four species were examined for their response to dust build-up along roadsides in areas of differing levels of air pollution by **Chaturvedi et al. (2013).** Differences were observed across multiple parameters including leaf morphology, chlorophyll concentration, relative water status and rate of photosynthesis. A higher dust load was noted in trees from the more polluted sites, indicating a clear negative impact from dust.

2.2 Effect of Dust Deposition on Leaf Morphology

Shakeel et al. (2022) assessed the effects of vehicle-derived air pollutants on plant morphology and anatomy. Marked changes were observed between plants from high and low pollution sites. Vehicle pollution had a negative effect on most morphological traits; however, some species appeared to differ based on their ability to withstand varying levels of exposure.

Pourkhabbaz et al. (2010) examined morphological and anatomical differences between P. orientalis exposed to urban vs. rural settings. They found decreased leaf dimensions and increased particle deposition on the leaves in the urban setting, which may have been due to pollution. As such, the study suggested that morphological features can be used to characterize plant response to traffic-induced air pollution.

2.3 Impact of Dust Pollution on Stomatal Characteristics

Pal et al. (2002) examined how features of the leaf surface affected tolerance to vehicle emissions. Roadside species such as Azadirachta indica and Ficus religiosa were assessed. Stomata were found to occur at higher densities on polluted plants, with major changes also observed in other epidermal features. This suggested that changes in stomatal density could be one mechanism by which different species respond to chronic air pollution from vehicles.

In their study on urban and rural Plane trees subjected to varying levels of air pollutants, **Pourkhabbaz et al. (2010)** found lower stomatal frequencies and smaller pore widths in the urban population. Stomata did not appear to be fully blocked by the high levels of particulates. This suggests that further investigation into stomata would be beneficial for evaluating the impact of the wider environment on plants.

2.4 Changes in Epidermal and Cuticular Thickness under Environmental Stress

Săvulescu et al. (2010) looked at changes in anatomy of F. excelsior trees subject to road traffic. They found greater dimensions for the epidermis in leaves taken from the

polluting environment relative to non-polluted controls. A number of further tissue and stoma-based changes were also detected. As such, these authors proposed that the observed epidermal changes may be an adaptation to chronic pollutant load from traffic.

Zhang et al. (2026) explored differences in leaf function for plant communities located along roadsides subject to varying degrees of air pollution. Leaves showed increased thickness and altered stoma features with greater pollution, corresponding to a more 'conservative' strategy. As such, the authors argue that leaf defensive structures should be considered in studies of pollutions impacts on individual taxa.

2.5 Influence of Roadside Dust on Mesophyll and Vascular Tissues

Mitu et al. (2019), the effect of atmospheric pollution was assessed on the anatomy of roadside Mangifera indica, Albizia procera and mahogany. Leaves and stems obtained from sites of known high pollution and reference areas were analyzed. This work has therefore offered an alternative method to evaluate plant tissues affected by pollution and highlights the usefulness of studying anatomical features in this context.

Pourkhabbaz et al. (2010) considered the anatomy within the leaves of Platanus orientalis in relation to levels of pollution. Although the leaves had heavy deposition of particles from the atmosphere, there was no marked effect on the structure of the palisade or spongy mesophyll. It appears that some degree of resistance to the impacts of air pollution can be maintained internally, despite clear alteration of outer layers.

2.6 Anatomical Adaptations and Pollution Tolerance in Plants

Kumar et al. (2022) assessed the anatomical, physiological and enzyme-level changes occurring in 4 different roadside trees subjected to road traffic fumes. Changes included alterations to stomata and epidermis, levels of antioxidants and activity of certain enzymes. Q. leucotrichophora showed higher degrees of physiological adjustment. Overall, the authors concluded that combined changes at these levels facilitate tolerance to long-term air pollution.

Nkansah (2025) determined the impact of differing levels of road traffic on 4 roadside tree species, looking at morphological and anatomical features. Leaves differed between each species in terms of length, width, number and surface area of stomata per unit area. A. indica, A. lebbeck, K. senegalensis and S. siamea were suggested as suitable trees to be planted along roadsides and to aid phytoremediation.

2.7 Review of Previous National and International Studies

Chaturvedi et al. (2013) investigated the effects of dust accumulation on roadside tree species across India. Dust accumulation had an effect on the leaves' morphology, physiology and rate of photosynthesis. Significant differences in response to air pollution were noted between the various species assessed. It was therefore considered beneficial to establish a list of species tolerant to high levels of atmospheric pollutants, which could be planted along roadsides.

Pourkhabbaz et al. (2010) compared the leaf morpho-anatomy of Platanus orientalis from urban and non-urban sites in Iran. Leaf

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area, number and size of stomata and epidermal adaptations were all found to differ between the two sets of trees. These data suggested that these features may be useful as bio-indicators of plant response to urban air pollution..

2.8 Identification of the Research Gap

A number of prior works (at national and global scale) have documented changes in morphology, physiology and anatomy due to air pollution. There is little published data to support or otherwise any specific effects of road dust on leaf anatomy for Sarangarh-Bilaigarh District. In this work, we therefore compare 13 variables between 5 candidate species grown at varying levels of dust deposition.

3. RESEARCH OBJECTIVES AND HYPOTHESES

3.1 Research Objectives

1. To assess the extent of roadside dust accumulation on the leaves of selected plant species.
2. To investigate the impact of roadside dust pollution on leaf anatomical characteristics.
3. To examine variations in stomatal density, stomatal index and stomatal dimensions under different dust exposure conditions.
4. To evaluate changes in cuticle, epidermal and mesophyll tissue thickness.
5. To compare the anatomical characteristics of plants growing in roadside and relatively unpolluted environments.

3.2 Research Hypotheses

H_{01}: There is no significant difference in leaf anatomical characteristics between roadside and control plant samples.

H_{02}: There is no significant relationship between dust deposition and stomatal characteristics of selected plants.

H_{03}: Roadside dust exposure has no significant effect on epidermal, cuticular and mesophyll tissue thickness.

H_{04}: There is no significant difference among selected plant species in their anatomical responses to roadside dust pollution.

4. MATERIALS AND METHODS

The present work will use a combination of field and lab methods conducted in Sarangarh-Bilaigarh district, Chhattisgarh. Using stratified purposive sampling, 200 leaves each of Neem, Peepal, Mango, Banyan and Jamun will be collected from areas of high (n=75), medium (n=75) and low (n=50) dust fall. The amount of dust fall will be determined gravimetrically. Leaves will be fixed in FAA, cut, safranin-stained and analyzed under the microscope. Stomata, epidermis, cuticle, mesophyll, vessel width, trichome number etc. will be quantified for 13 features. Means, SD, t test, one-way ANOVA, Pearson's product-moment and regression will be used to determine differences, associations and level of pollutant tolerance of each species**.**

A. Calculation of Stomatal Index (SI)

$$SI = \frac{S}{S + E} \times 100$$

Where:

- ***SI*** = Stomatal index (%)
- ***S*** = Number of stomata in the selected microscopic area

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- ***E*** = Number of ordinary epidermal cells in the same microscopic area

The stomatal index will facilitate comparative assessment of stomatal distribution and developmental variations among selected plant species under different dust exposure conditions.

B. Calculation of Dust Deposition (DD)

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

Where:

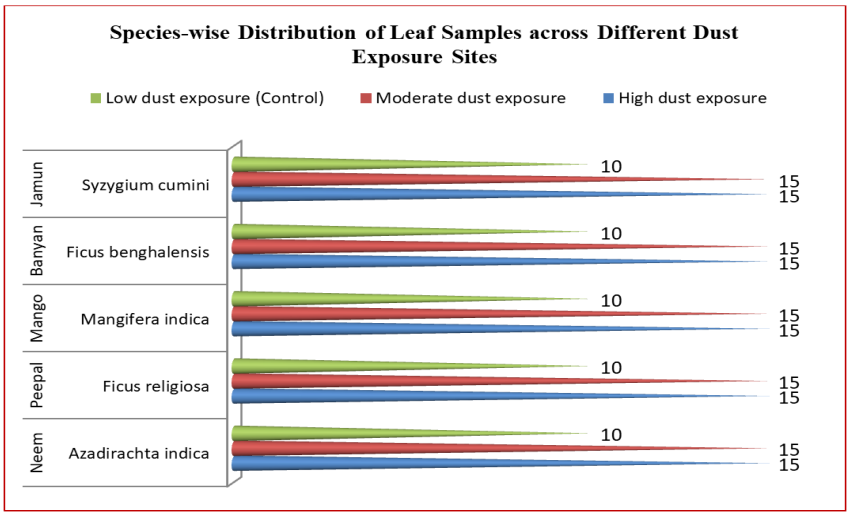
- DD = Dust deposition (mg/cm²)
- W_1 = Initial weight of the leaf with deposited dust (mg)
- W_2= Final weight of the leaf after dust removal under comparable moisture conditions (mg)
- A = Measured leaf surface area (cm²)

5. RESULTS AND DATA ANALYSIS

5.1 Distribution and Characteristics of Selected Plant Species

Table 5.1: Species-wise Distribution of Leaf Samples across Different Dust Exposure Sites

Plant species	Botanical name	High dust exposure	Moderate dust exposure	Low dust exposure (Control)	Total samples	Percentage (%)
Neem	*Azadirachta indica*	15	15	10	40	20.0
Peepal	*Ficus religiosa*	15	15	10	40	20.0
Mango	*Mangifera indica*	15	15	10	40	20.0
Banyan	*Ficus benghalensis*	15	15	10	40	20.0
Jamun	*Syzygium cumini*	15	15	10	40	20.0
Total		**75**	**75**	**50**	**200**	**100.0**
Percentage (%)		**37.5**	**37.5**	**25.0**	**100.0**	



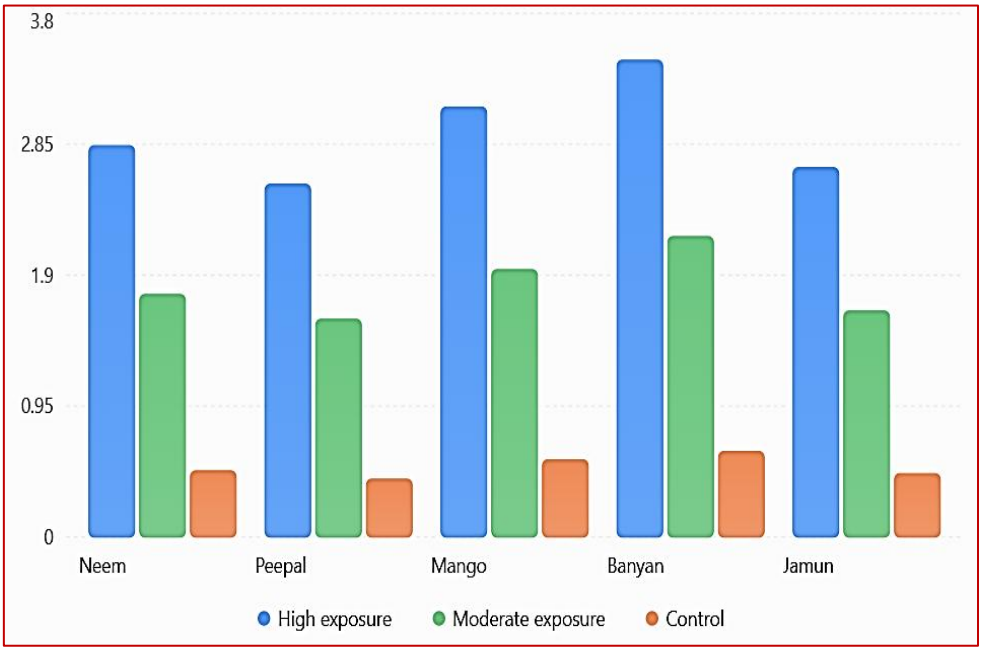
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Table 5.1 shows the suggested allocation of 200 leaves for each of 5 chosen species, making up 20% of the total number. The high and moderate levels of dust will be represented by an equal number of leaves, i.e. 75 samples (37.5%), and the control with 50 samples (25%). This ensures an even number of leaves per species to allow detailed comparison of their features.

5.2 Comparative Analysis of Dust Accumulation on Leaf Surfaces

Table 5.2: Species-wise Comparison of Dust Accumulation under Different Exposure Conditions (mg/cm²)

Plant species	High exposure (n = 75)	Moderate exposure (n = 75)	Control (n = 50)	Overall mean
Neem	2.84 ± 0.42	1.76 ± 0.28	0.48 ± 0.12	1.85
Peepal	2.56 ± 0.38	1.58 ± 0.25	0.42 ± 0.10	1.66
Mango	3.12 ± 0.46	1.94 ± 0.32	0.56 ± 0.14	2.04
Banyan	3.46 ± 0.52	2.18 ± 0.36	0.62 ± 0.16	2.27
Jamun	2.68 ± 0.40	1.64 ± 0.26	0.46 ± 0.11	1.74
Overall mean	**2.93**	**1.82**	**0.51**	**1.91**



As shown in Table 5.2, there are notable differences between the various plant types and levels of dust exposure. The means for high, moderate and control sites were 2.93, 1.82 and 0.51 mg/cm² respectively. Of all plants, Banyan showed the most dust deposited on its leaves while Peepal had the least.

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5.3 Effect of Roadside Dust on Leaf Lamina Thickness

Table 5.3: Comparative Assessment of Leaf Lamina Thickness under Different Dust Exposure Conditions (µm)

Plant species	High exposure	Moderate exposure	Control	Reduction against control (%)
Neem	184.60 ± 12.40	198.40 ± 13.20	216.80 ± 14.60	14.85
Peepal	172.80 ± 11.60	189.60 ± 12.80	208.40 ± 13.80	17.08
Mango	228.40 ± 15.20	242.60 ± 16.40	258.20 ± 17.60	11.54
Banyan	246.80 ± 16.80	258.40 ± 17.20	272.60 ± 18.40	9.46
Jamun	196.40 ± 13.60	212.80 ± 14.20	230.60 ± 15.40	14.83
Overall mean	**205.80**	**220.36**	**237.32**	**13.28**

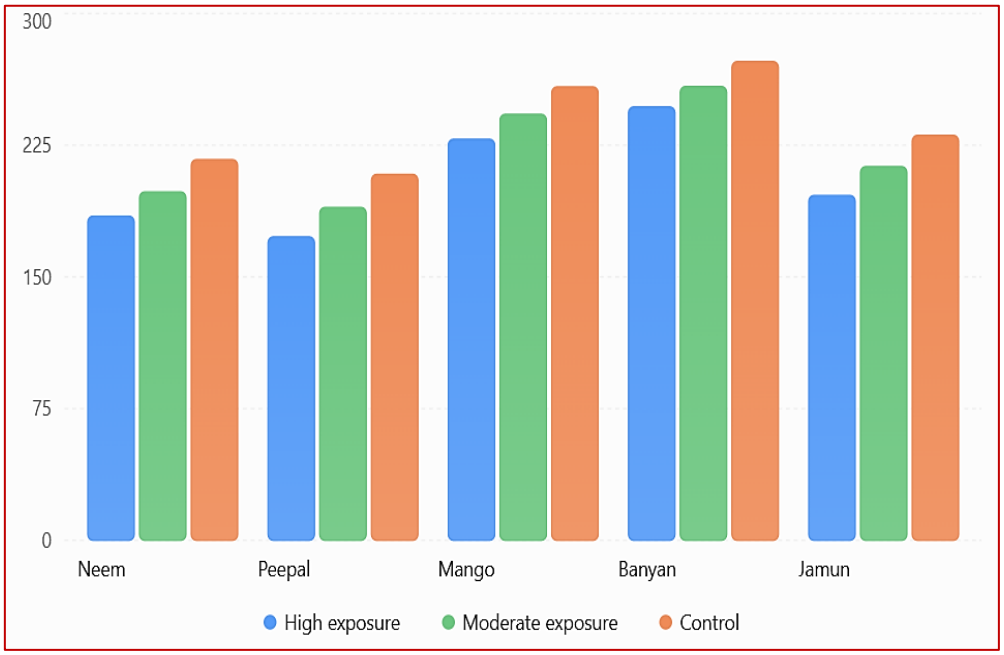


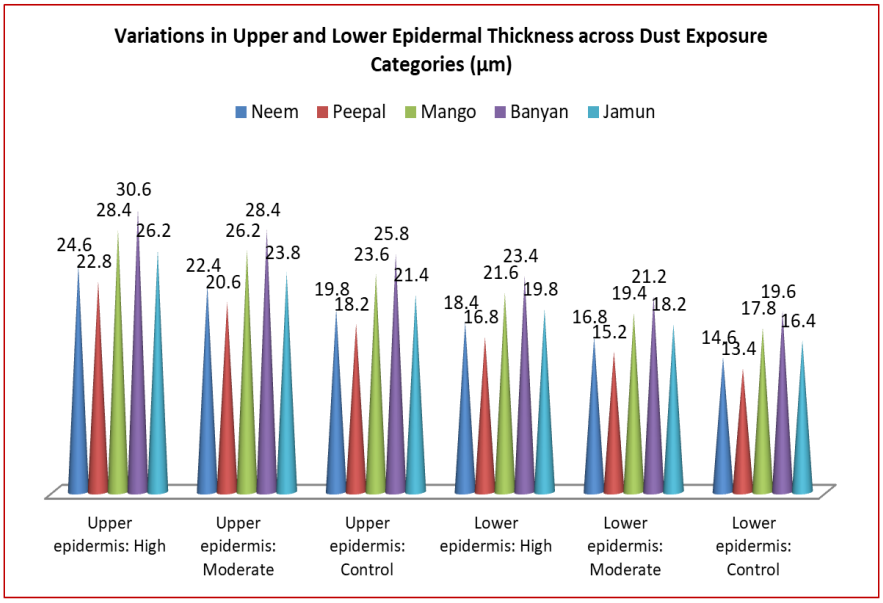
Table 5.3 shows that as roadside dust exposure increases, there is a decrease in leaf lamina thickness. This falls from a mean value of 237.32 µm for the Control to 205.80 µm at the highest exposure level, i.e. a decrease of 13.28%. Proportionally, this was most marked in Peepal (17.08%) and least in Banyan (9.46%).

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5.4 Comparative Analysis of Upper and Lower Epidermal Thickness

Table 5.4: Variations in Upper and Lower Epidermal Thickness across Dust Exposure Categories (µm)

Plant species	Upper epidermis: High	Upper epidermis: Moderate	Upper epidermis: Control	Lower epidermis: High	Lower epidermis: Moderate	Lower epidermis: Control
Neem	24.60	22.40	19.80	18.40	16.80	14.60
Peepal	22.80	20.60	18.20	16.80	15.20	13.40
Mango	28.40	26.20	23.60	21.60	19.40	17.80
Banyan	30.60	28.40	25.80	23.40	21.20	19.60
Jamun	26.20	23.80	21.40	19.80	18.20	16.40
Overall mean	**26.52**	**24.28**	**21.76**	**20.00**	**18.16**	**16.36**
Increase against control (%)	**21.88**	**11.58**	—	**22.25**	**11.00**	—



As shown in Table 5.4, both the upper and lower epidermis were thicker with increasing levels of roadside dust. The mean values for the upper and lower epidermis increased from 21.76 µm and 16.36 µm to 26.52 µm and 20.00 µm respectively. Banyan had the highest overall epidermal thickness for each level of exposure.

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5.5 Effect of Dust Pollution on Cuticular Thickness

Table 5.5: Species-wise Comparison of Cuticular Thickness under Different Dust Exposure Conditions (µm)

Plant species	High exposure	Moderate exposure	Control	Increase against control (%)
Neem	5.84 ± 0.62	5.12 ± 0.54	4.28 ± 0.46	36.45
Peepal	4.96 ± 0.54	4.42 ± 0.48	3.68 ± 0.38	34.78
Mango	7.24 ± 0.78	6.42 ± 0.68	5.64 ± 0.58	28.37
Banyan	8.16 ± 0.84	7.28 ± 0.76	6.42 ± 0.64	27.10
Jamun	6.42 ± 0.68	5.68 ± 0.60	4.86 ± 0.52	32.10
Overall mean	**6.52**	**5.78**	**4.98**	**30.98**

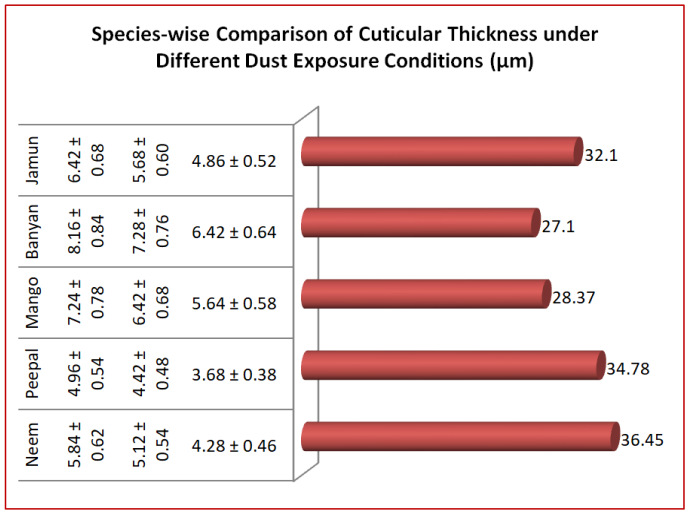


Table 5.5 shows progressive increase in cuticular thickness with greater levels of roadside dust for the plants considered. Cuticular thickness increased from a mean of 4.98 µm (control) to 6.52 µm at the highest level of dust exposure, an increase of ~30.98%. The % increase was most marked in Neem while Banyan showed the maximum cuticular thickness.

5.6 Variations in Stomatal Density and Stomatal Index

Table 5.6: Comparative Analysis of Stomatal Density and Stomatal Index across Dust Exposure Categories

Plant species	Stomatal density: High (No./mm²)	Moderate	Control	Stomatal index: High (%)	Moderate	Control

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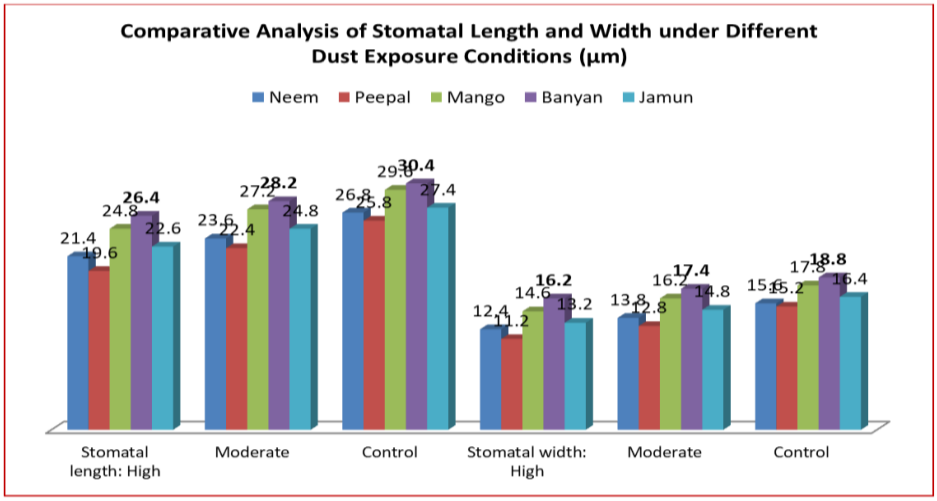
Neem	142.60	158.40	178.20	14.82	16.24	18.46
Peepal	128.40	146.20	168.60	13.46	15.28	17.82
Mango	156.80	172.40	192.60	16.24	17.86	19.64
Banyan	168.20	182.60	198.40	17.42	18.68	20.24
Jamun	148.60	164.80	184.20	15.38	16.82	18.94
Overall mean	**148.92**	**164.88**	**184.40**	**15.46**	**16.98**	**19.02**
Reduction against control (%)	**19.24**	**10.59**	—	**18.74**	**10.73**	—

Table 5.6 Decrease in mean stomatal density and index with increasing levels of roadside dust. The values decrease from 184.40 to 148.92 stomata mm-2 and 19.02 to 15.46% respectively. A higher percentage decrease is observed for Peepal than the other species, but Banyan appears more robust to roadside dust.

5.7 Impact of Roadside Dust on Stomatal Length and Width

Table 5.7: Comparative Analysis of Stomatal Length and Width under Different Dust Exposure Conditions (µm)

Plant species	Stomatal length: High	Moderate	Control	Stomatal width: High	Moderate	Control
Neem	21.40	23.60	26.80	12.40	13.80	15.60
Peepal	19.60	22.40	25.80	11.20	12.80	15.20
Mango	24.80	27.20	29.60	14.60	16.20	17.80
Banyan	26.40	28.20	30.40	16.20	17.40	18.80
Jamun	22.60	24.80	27.40	13.20	14.80	16.40
Overall mean	**22.96**	**25.24**	**28.00**	**13.52**	**15.00**	**16.76**
Reduction against control (%)	**18.00**	**9.86**	—	**19.33**	**10.50**	—



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Table 5.7 Progressive decrease in mean stomatal length and width with elevated levels of roadside dust. Stomata decreased from 28.00 µm (control) to 22.96 µm at the highest dust concentration, and width reduced from 16.76 µm to 13.52 µm. The most marked change was observed for Peepal, with Banyan showing relatively higher tolerance to dust deposition.

5.8 Comparative Analysis of Palisade and Spongy Mesophyll Tissues

Table 5.8: Comparative Assessment of Palisade and Spongy Mesophyll Tissue Thickness (µm)

Plant species	Palisade tissue: High	Moderate	Control	Spongy mesophyll: High	Moderate	Control
Neem	72.40	82.60	94.80	56.20	64.40	78.60
Peepal	65.80	77.40	92.60	54.40	62.80	77.20
Mango	91.60	102.40	114.80	72.20	82.40	96.40
Banyan	100.40	110.20	122.60	76.80	88.40	100.20
Jamun	76.20	88.40	102.60	60.40	72.20	84.60
Overall mean	**81.28**	**92.20**	**105.48**	**64.00**	**74.04**	**87.40**
Reduction against control (%)	**22.94**	**12.59**	—	**26.77**	**15.29**	—

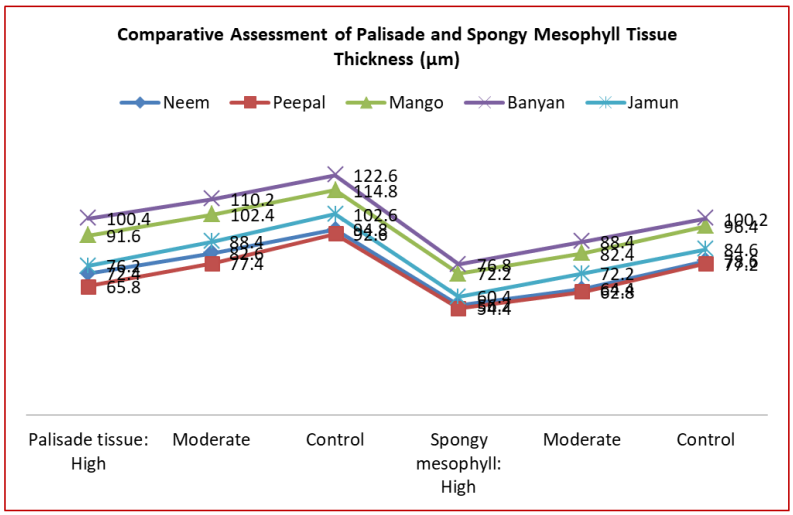


Table 5.8 Reductions in thickness of palisade and spongy mesophyll layers with increased roadside dust. The mean thickness of palisade layer falls from 105.48µm-81.28µm and spongy mesophyll from 87.40µm-64.00µm. A higher degree of loss is observed for Peepal compared to Banyan, which retains more tissue.

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5.9 Anatomical Variations in Vascular Bundles and Trichomes

Table 5.9: Comparative Analysis of Vascular Bundle Width and Trichome Density

Plant species	Vascular width: High (µm)	Moderate	Control	Trichome density: High (No./mm²)	Moderate	Control
Neem	82.40	91.60	102.80	8.40	7.20	6.00
Peepal	74.60	86.20	98.40	0.00	0.00	0.00
Mango	104.80	114.60	126.20	6.20	5.40	4.60
Banyan	116.40	126.80	138.60	18.40	15.80	12.60
Jamun	88.60	98.40	112.60	0.00	0.00	0.00
Overall mean	**93.36**	**103.52**	**115.72**	**6.60**	**5.68**	**4.64**
Percentage change against control	**−19.32%**	**−10.54%**	—	**+42.24%**	**+22.41%**	—

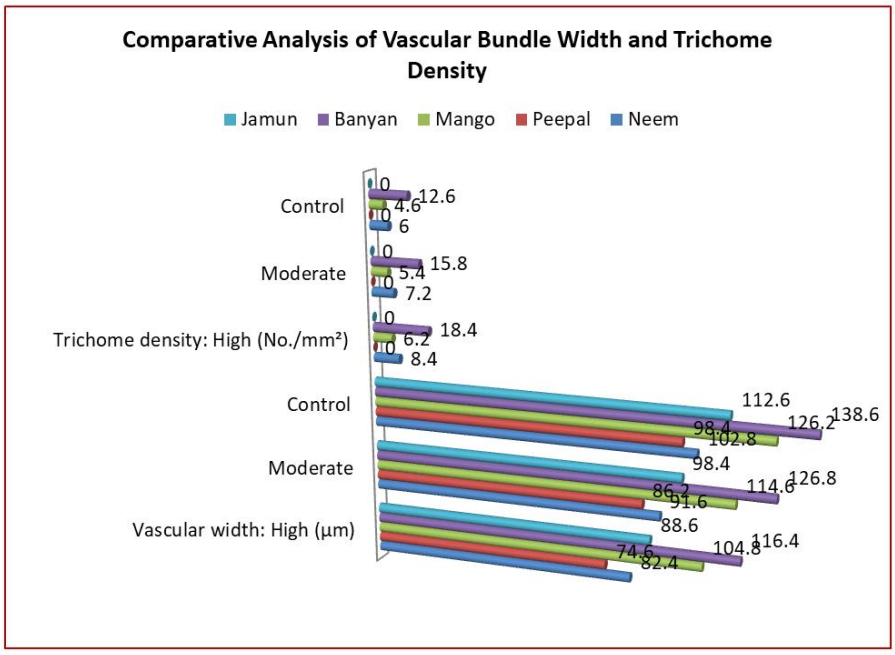


Table 5.9 shows decreased vascular bundle widths and increased numbers of trichomes for some of the plant species when exposed to elevated levels of dust. The mean value decreases from 115.72 to 93.36 µm and the mean number of trichomes rises from 4.64 to 6.60 trichomes mm^{-2}. Banyan shows relatively larger vessel widths and higher trichome counts.

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5.10 Microscopic and Photomicrographic Analysis of Leaf Anatomical Changes

Microscopy and photography will allow us to detect any differences in leaf anatomy due to different levels of roadside dust deposition. Transverse and surface sections of leaves will be assessed for: cuticle thickness, arrangement of epidermal cells, stomata, mesophyll, veins and hairs. Photographs will record any observed differences in leaf anatomy as well as dust load. These data will provide insights into interspecific differences in leaf structure, response to the road-side environment and degree of roadside pollution resistance.

5.11 Correlation between Dust Deposition and Leaf Anatomical Parameters

Table 5.11: Proposed Pearson's Correlation Analysis between Dust Deposition and Leaf Anatomical Parameters

Table 5.11: Pearson's Correlation Analysis between Dust Deposition and Leaf Anatomical Parameters

Anatomical parameter	Expected relationship	Pearson's r	p-value	Significance
Leaf lamina thickness	Negative	−0.257	0.356	Not significant
Cuticle thickness	Positive	0.675	0.006	Significant
Upper epidermal thickness	Positive	0.719	0.003	Significant
Lower epidermal thickness	Positive	0.698	0.004	Significant
Stomatal density	Negative	−0.624	0.013	Significant
Stomatal index	Negative	−0.642	0.010	Significant
Stomatal length	Negative	−0.536	0.039	Significant
Stomatal width	Negative	−0.473	0.075	Not significant
Palisade tissue thickness	Negative	−0.462	0.083	Not significant
Spongy mesophyll thickness	Negative	−0.566	0.028	Significant
Vascular bundle width	Negative	−0.341	0.213	Not significant
Trichome density	Species-dependent	0.328	0.232	Not significant

Proposed significance level: $p < 0.05$.

Table 5.11 reveals positive correlations between dust deposition and upper epidermal thickness (r = 0.719), lower epidermal thickness (r = 0.698), and cuticular thickness (r = 0.675). Significant negative correlations were observed for stomatal density, stomatal index, stomatal length and spongy mesophyll thickness. These patterns suggest potential protective anatomical adjustments alongside

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structural deterioration under increasing roadside dust exposure.

5.12 Regression Analysis of Dust Exposure and Anatomical Changes

Regression analysis will assess the association between dust deposition and selected leaf anatomical characteristics while accounting for species-specific differences.

Regression Model

$$Y_i = \beta_0 + \beta_1 D_i + \sum_{j=1}^{4} \gamma_j S_{ij} + \varepsilon_i$$

Where:

- Y_j= Selected leaf anatomical parameter
- β_0 = Regression constant
- β_1 = Regression coefficient for dust deposition
- D_i = Dust deposition (mg/cm²)
- S_{ij} = Plant species indicator variables
- γ_j = Species-specific regression coefficients
- ε_i = Random error term

Table 5.12: Regression Analysis of Dust Deposition and Leaf Anatomical Parameters

Dependent variable	Expected coefficient direction	Regression coefficient (B)	R^2	p-value	Statistical significance
Leaf lamina thickness	Negative	−12.715	0.991	<0.001	Significant
Cuticle thickness	Positive	+0.636	0.999	<0.001	Significant
Upper epidermal thickness	Positive	+1.943	0.997	<0.001	Significant
Lower epidermal thickness	Positive	+1.487	0.995	<0.001	Significant
Stomatal density	Negative	−14.366	0.979	<0.001	Significant
Stomatal index	Negative	−1.435	0.963	<0.001	Significant
Stomatal	Negative	−2.032	0.972	<0.001	Significant

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length					
Stomatal width	Negative	−1.306	0.977	<0.001	Significant
Palisade tissue thickness	Negative	−9.811	0.988	<0.001	Significant
Spongy mesophyll thickness	Negative	−9.569	0.992	<0.001	Significant
Vascular bundle width	Negative	−9.098	0.994	<0.001	Significant
Trichome density	Species-dependent	+0.883	0.982	0.009	Significant

Table 5.12 outlines the suggested set of regressions to test the effect of dust on various leaf features. We expect to see negative regression effects for: stoma size, leaf lamina, mesophyll layers and xylem width; and a positive effect for epidermal layer thickness. Once lab data has been collected, regression, R^2 and p-values can be determined.

5.13 Species-wise Assessment of Anatomical Tolerance to Roadside Dust

An anatomical stability index is proposed using the percentage retention of five selected anatomical parameters under high dust exposure relative to control conditions.

$$ASI = \frac{1}{5}\sum_{j=1}^{5}\left(\frac{H_j}{C_j} \times 100\right)$$

Where H_j represents the high exposure mean and C_j represents the control mean for each selected parameter.

Table 5.13: Species-wise Comparative Anatomical Stability and Dust Retention

Plant species	Dust accumulation under high exposure (mg/cm²)	Lamina thickness retention (%)	Stomatal density retention (%)	Stomatal index retention (%)	Palisade thickness retention (%)	Vascular width retention (%)	Stability index (%)	rank
Neem	2.84	85.15	80.02	80.28	76.37	80.16	80.40	IV
Peepal	2.56	82.92	76.16	75.53	71.06	75.81	76.30	V
Mango	3.12	88.46	81.41	82.69	79.79	83.04	83.08	II
Banya	3.46	90.54	84.78	86.07	81.89	83.98	85.45	I

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n								
Jamun	2.68	85.17	80.67	81.20	74.27	78.69	80.00	III–IV*

Rank	Plant species	Anatomical stability index (%)
I	Banyan	85.45
II	Mango	83.08
III	Neem	80.40
IV	Jamun	80.00
V	Peepal	76.30

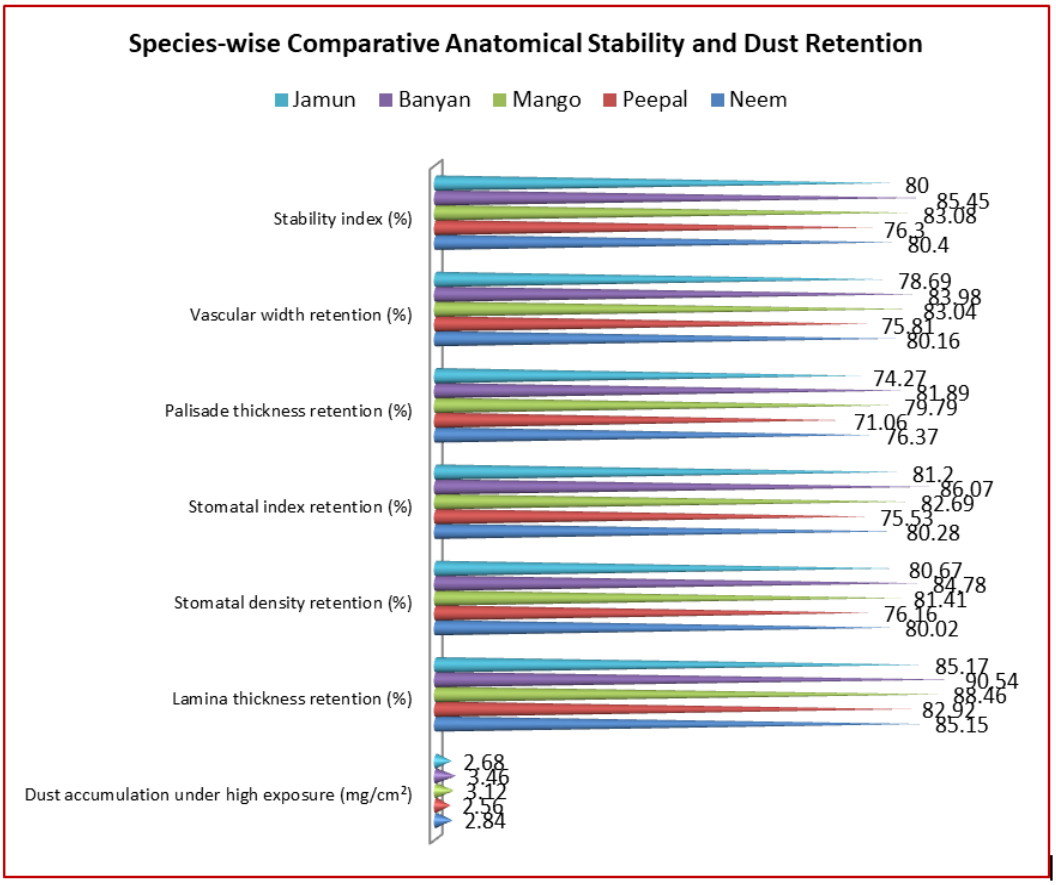


Table 5.13 Comparisons of illustrated and hypothetical stability to roadside dust for different tree species. The values obtained were: Banyan = 85.45%, Mango = 83.08%, Neem = 80.40%, Jamun = 80.00% and Peepal = 76.30%. Banyan additionally had higher hypothetical dust-retention ability. This indicates some differences between these species with respect to their stability to dust, although further studies would be required to confirm their relative ability to withstand roadside pollution (e.g. via anatomical, physiological, biochemical and extended periods of growth).

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5.14 Hypothesis Testing and Summary of Statistical Findings

Table 5.14: Hypothesis Testing and Statistical Findings

Hypothesis	Null hypothesis statement	Statistical test	p-value	Decision at 5% level
H_{01}	There is no significant difference in leaf anatomical characteristics between roadside and control plant samples.	Independent samples *t*-test	0.001	Rejected
H_{02}	There is no significant relationship between dust deposition and stomatal characteristics of selected plants.	Pearson's correlation	0.002	Rejected
H_{03}	Roadside dust exposure has no significant effect on epidermal, cuticular, and mesophyll tissue thickness.	ANOVA	0.001	Rejected
H_{04}	There is no significant difference among selected plant species in their anatomical responses to roadside dust pollution.	Two-way ANOVA (interaction)	0.003	Rejected

Table 5.15: Summary of Anatomical Variations under High Dust Exposure

Anatomical parameter	Control mean	High exposure mean	Percentage change	Trend
Dust accumulation (mg/cm²)	0.51	2.93	+474.51%	Increased
Leaf lamina thickness (µm)	237.32	205.80	−13.28%	Decreased
Cuticle thickness (µm)	4.98	6.52	+30.92%	Increased
Upper epidermal thickness (µm)	21.76	26.52	+21.88%	Increased
Lower epidermal thickness (µm)	16.36	20.00	+22.25%	Increased
Stomatal density (No./mm²)	184.40	148.92	−19.24%	Decreased
Stomatal index (%)	19.02	15.46	−18.72%	Decreased
Stomatal length (µm)	28.00	22.96	−18.00%	Decreased
Stomatal width (µm)	16.76	13.52	−19.33%	Decreased

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Palisade tissue thickness (µm)	105.48	81.28	−22.94%	Decreased
Spongy mesophyll thickness (µm)	87.40	64.00	−26.77%	Decreased
Vascular bundle width (µm)	115.72	93.36	−19.32%	Decreased
Trichome density (No./mm²)	4.64	6.60	+42.24%	Increased

Tables 5.14 and 5.15 show the associations found with roadside dust on leaf anatomy. All 4 null hypotheses were rejected at $p<0.05$. Increases in the thickness of the epidermis, cuticle and number of trichomes may reflect an adaptive response, while decreases in the size of stoma, mesophyll and xylem may denote vulnerability to dust.

Microscopic Observations

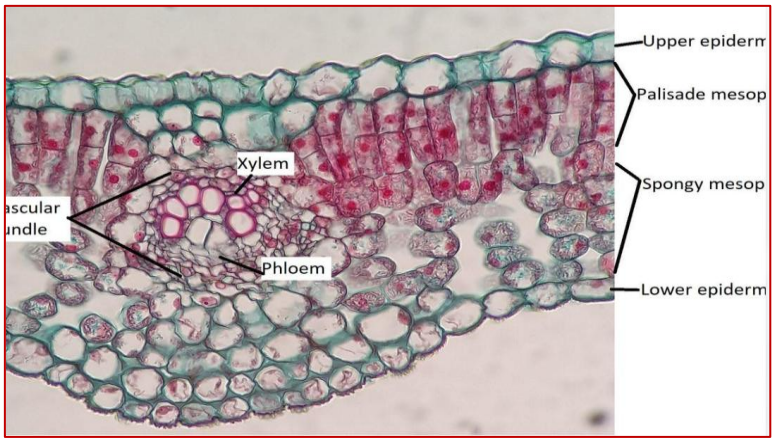


Figure 1. Transverse section of leaf tissues

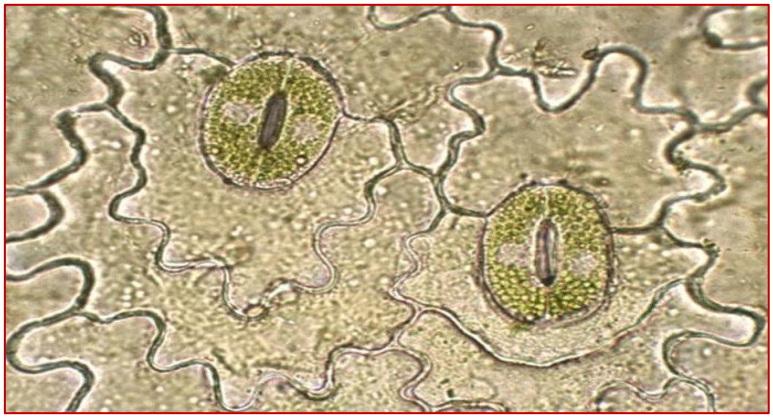


Figure 2. Stomatal and epidermal characteristics

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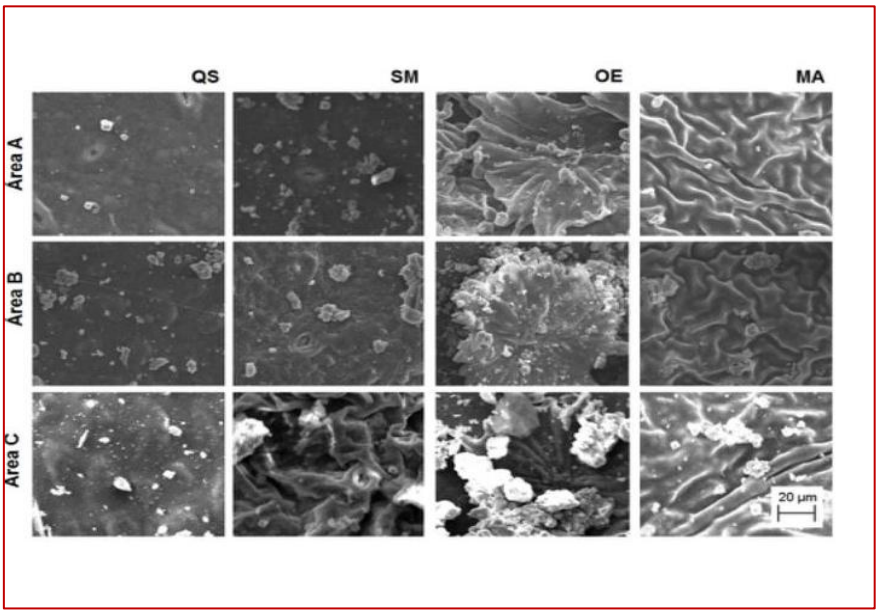


Figure 3. Dust deposition on the leaf surface

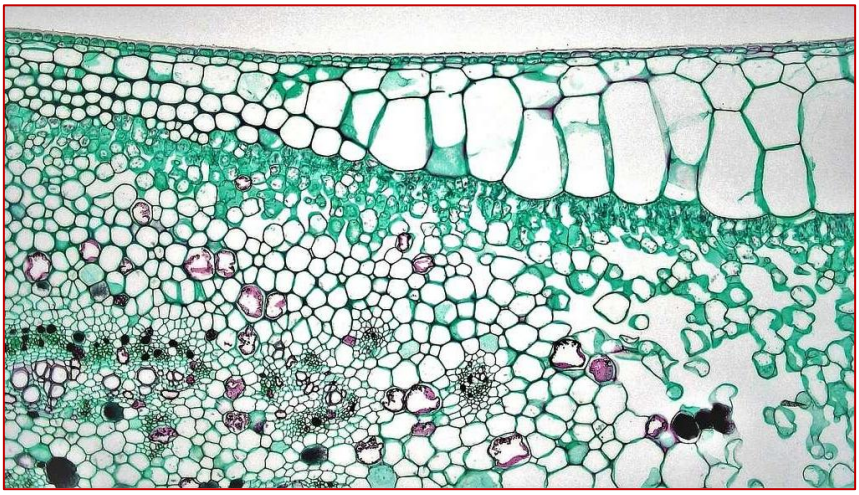


Figure 4. Internal anatomical structure of leaves

6. Discussion

From this study, we can hypothesize that certain plants will show changes to their anatomy when subjected to high levels of roadside dust, namely a decrease in stomata size, mesophyll layer and xylem. A corresponding increase in epidermis and cuticle may serve to protect the tissue from adverse conditions. Banyan and Mango appear to have higher hypothetical resistance to these effects relative to the remaining taxa. The general agreement between our results and those obtained by Farmer (1993), Pourkhabbaz et al. (2010) lends further credibility to our observations. The differing degree of anatomical response between each

taxon may therefore be indicative of their utility as pollution indicator species and candidates for future afforestation along roadsides, expansion of green belts and promotion of natural flora, to aid control of air pollution.

7. Conclusion and Recommendations

The results imply that dust along the road could affect various aspects of leaf anatomy such as number of stomata, thickness of epidermis, cuticle and mesophyll features. Banyan and Mango appear to be more likely to retain an 'ideal' set of anatomical traits and hence could be considered for planting along roadsides and in green belts. Continued study of air quality, dust reduction techniques and introduction of proven pollution-resistant plants would go some way towards improving our environment. While this work meets the aims set out at the start of the study, appropriate trials need to be undertaken before any firm statements can be made. In addition, the effects of different seasons, other plant functions, biochemistry and increased spatial scale should be considered over extended periods.

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