Impact of Air Pollution on Morphological, Anatomical, Biochemical, and Physiological Parameters of Ficus benghalensis L.: a Comprehensive Review

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ABSTRACT

Air pollution, aggravated by increasing industrialization and urbanization, is a foremost menace to plant health and ecological stability. *Ficus benghalensis* L., a prominent tropical tree, is an indispensable indicator plant for determining the effects of vehicular and industrial pollution. This review summarizes findings from studies conducted in India to evaluate how air pollutants such as particulate matter, sulfur dioxide, nitrogen oxides, and ozone affect the tree's morphological, anatomical, biochemical, and physiological characteristics. Reduced leaf diameters, changes in leaf morphology, biochemical shifts, and altered physiological activities are among the key findings caused by air pollutant-induced stress. This comprehensive analysis emphasizes the critical need for long-term environmental management methods to reduce the negative effects of air pollution on plant ecosystems.

1. Introduction

Air pollution has now become an environmental hazard which has a harmful effect on all kinds of life forms. Climatic conditions have direct impact onlife. Atmospheric air contains 78% nitrogen, 21% oxygen 0.93% argon, 0.038% carbon di oxide and other gases [P. K. Rai ,2016]. Industrial activities and vehicular movement constitute the primary source of air pollution resulting from human actions. Major air pollutants such as particulate matter (PM), ozone (O_3), nitrogen dioxide (NO_2) and Sulphur dioxide (SO_2) is increasing day by day. Leaf is the greatestvulnerable plant portion as they are the principal acceptors of air pollutants [Singh *et al.*, 2020]. The surrounding environment that emerges from air pollutants in urban areas which has a substantialeffect on the morphological, anatomical, biochemical and physiological status of plants.

Plants reduce the capacity of the plant cell due to air pollution (Bharti *et al.*,2017).

Which interrupt the process of photosynthesis Some major chemicals responsible for the pollution are carbon, Sulphur, and nitrogen oxides. Air pollutants like SO_2 that can effect on the stomatal opening, causes excessive water loss (Thakar and Mishra ,2010). SO_2 results in discoloration of leaf tissue which result in white, yellow or brown patches. It has many negative impacts on plants such as pigments, leaf damage, slow growth rate, damage of root, seed germination and inability to photosynthesize properly (Roy *et al.*,2020). Plants reflects their damage in a several ways, including visible indication like necrotic lesions, inhibited plant growth, including chlorosis, bronzing, reddening, mottling (Tak and Kakde,2019). The atmospheric ozone also causing plant damage by stopping photosynthesis and opposing stomata, limiting respiration and inhibitingplant growth (Irwe *et al.*., 2017). It also can change the metabolic activity of plant and reduce crop yields (Mukherjee & Agarwal ,2015*)*. Excessive dust effects on leaf area, leaf length, leaf cuticle, leaf longevity. Also, pollution can effect on flowering time of a plant.

Figure- 1 *Ficus benghalensis* L.

Ficus benghalensis L. is commonly known as banyan tree or banyan [Fig:1], belonging to the Moraceae family. *F. benghalensis* L. is a tropical evergreen, deciduous tree with more than 800 species & about 2000 varieties of *Ficus* species. This large tree attains a height of about 100 feet and it has a massive tree trunk bearing widespread branches supported by aerial prop root which later form secondary trunks. The bark is soft and wood also soft porous having sticky milky latex. Mature leaves are glossy, leathery and glabrous, simple, oval, ovate, thickly coriaceous, quite entire, base rounded, basal vein strong, finely reticulate beneath. Inflorescence is hollow consist of male female and gall flowers crowded along with bracteoles in the inner walls of a pear-shaped fleshy receptacles. Ovary is superior, unilocular with a simple, stigma.Hence it would be interesting to notes the effects of various air pollutants on the morphological, anatomical, biochemical and physiological parameters of *Ficus benghalensis* L. this review discussed the various research studies conducted on assessing effects of vehicular and industrial air pollution.

2. Material and Methods

A web-based search was performed using Springer, Google Scholar, and PubMed databases from the year 1992–2024. The inclusion criteria included English written journal publications reporting primary studies where "Air pollution" AND *Ficus benghalensis* L. [air pollutants, morphological changes, anatomical changes,

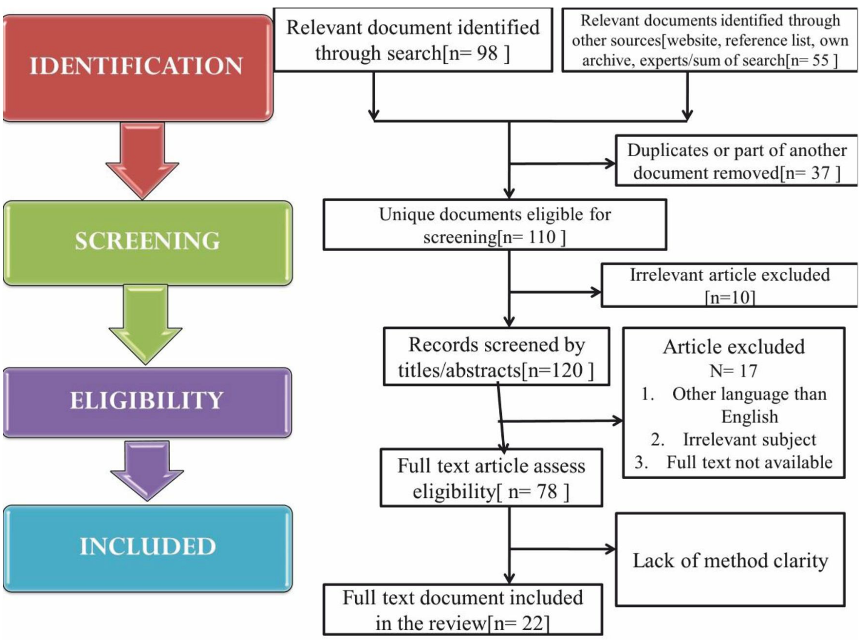

Figure- 2: Selection procedure of articles for the review

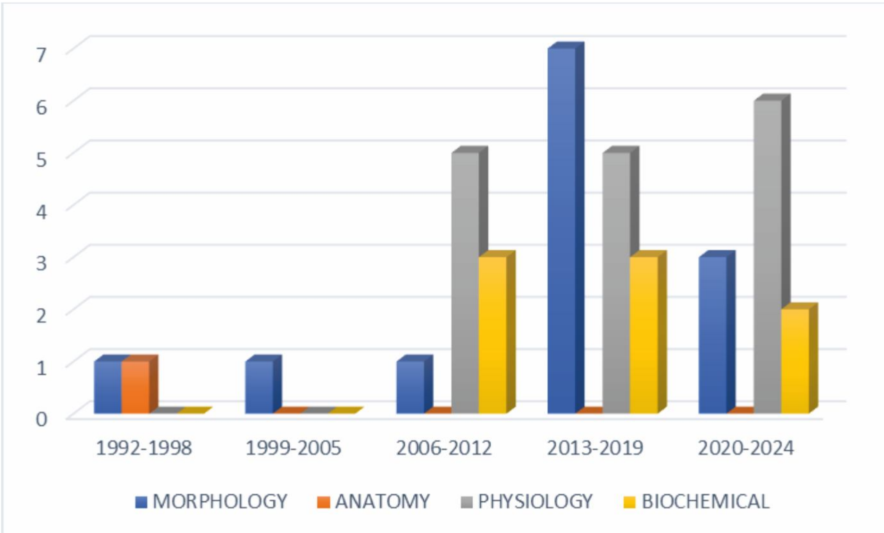

Figure 3: Distribution of articles year-wise

physiological and biochemical changes]. The following terms were used: "environmental air pollution" and "industrial" or "vehicular" AND "morphological" or "anatomical" and "physiological" or "biochemical"or "air pollutants". The reviewer (SD) judgedindividually all the applicable articles. Subsequently the full text of each of the articles were read. Discrepancies were reassessed by the reviewers (RM, SB and PPC) and deliberated until anagreement was attained. Case reports, studies in other languages, reviews and conference proceedings were excluded. Figure 2 gives an overview of the article selection procedure performed in this review.

3. Result and Discussion

A total of 153relevant articles were obtained from the search described in the earlier section. After following the screening procedure, 22 full text documents were included in this study. In Figure 3, it can be observed that the maximum research work on the effects of various air pollutants on *F.benghalensis* L. have been done in the last decade (2013-2023). From Figure 4 it is evident that it is evident that last 5 years numerous research investigation has been performed to estimate the effect of air pollution of morphological, anatomical, biochemical and physiological parameters in *F.benghalensis* L. From Figure 4 it is observed that about 76% of the selected articles described the effectof air pollutants on physiological (48%) and morphological parameters of *F.benghalensis* L. very few works existed on the anatomic alterations in *F.benghalensis* L. with regards to its response to air pollutants.

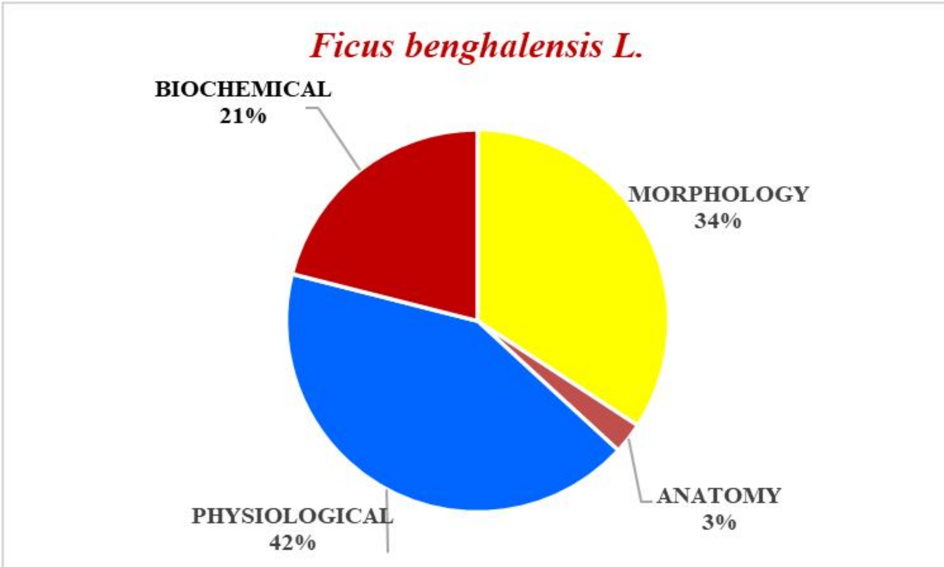

Figure 4: Distribution of articles based on parameters

Table 1: Effect of air pollutants on the Morphological parameters of *Ficus benghalensis L.*

PARAMETERS	SAMPLE SIZE (n=)	LOCATION	TYPES OF POLLUTION	RESULTS	REFERENCES
Leaf Length	13	Karachi, Pakistan	Air (vehicular)	Decreased	Jahan and Iqbal , 1992
	20	Kolkata, India	Air (vehicular)	Increased	Nandy *et al.*, 2014
Leaf Breadth	20	Kolkata, India	Air (vehicular)	Decreased	Nandy *et al.*, 2014
	13	Karachi, Pakistan	Air (vehicular)	Decreased	Jahan and Iqbal ,1992
Leaf Length/Breath ratio	20	Kolkata, India	Air (vehicular)	Increased	Nandy *et al.*, 2014
Petiole Length	13	Karachi, Pakistan	Air (vehicular)	Decreased	Jahan and Iqbal ,1992
Leaf area	13	Karachi, Pakistan	Air pollution (Vehicular)	Decreased	Jahan and Iqbal ,1992
	10	Kannur, Kerala.	Air pollution (Vehicular)	Increased	Shackira and Mirshad *et al.*, 2018
	4	Varanasi, Uttar Pradesh	Air pollution (Vehicular)	Decreased	Mukherjee et.al 2015
Dust deposition on leaves	40	Talkatora industrial area, Lucknow	Air (vehicular)	Increase	*Bharti et al.,2017*
	Not defined	Jharsuguda of Western Orissa	Air (vehicular emissions)	Increase	Thakar and Mishra ,2010
	15	Jharkhand & Ranchi	Air (vehicular)	Increased	Roy *et al.*,2020
	6	Bundelkhand University campus, Jhansi district, Uttar Pradesh, India	Air (vehicular)	Increase	Singh and Pal,2017
	6	Government Vidarbha Institute of Science and Humanities, Amravati (M.S.), India	Air (vehicular)	Increase	Irwe *et al.*., 2017
	6	Marudhamalai, Coimbatore	Air (vehicular)	Increase	Yogaraj and Jayabalakrishn, 2020
	9	Delhi, Chennai, Jaipur, Udaipur, Vadodara, Mumbai, Pune, and Bengaluru,	Air (vehicular)	Increase	Tak and Kakde,2019
	15	Jharkhand & Ranchi	Air (vehicular)	Increase	Roy *et al.*,2020
	54	Varanasi, India	Air (vehicular)	Increase	Prajapati and Tripathi, 2008

Table 2: Effect of air pollutions on the Anatomical parameters of *Ficus benghalensis L.*

PARAMETERS	SAMPLE SIZE (n=)	LOCATION	TYPES OF POLLUTION	RESULTS	REFERENCES
Leaf Epidermis	13	Karachi, Pakistan	Air (vehicular)	Upper cuticle & upper palisade decreased. Upper and lower epidermis increased Lower palisade & spongy parenchyma increased No changes in lower epidermis in polluted samples	Jahan &Iqbal,1992

Table 3: Effect of air pollutions on the physiological parameters of *Ficus benghalensis L.*

PARAMETERS	SAMPLE SIZE (n=)	LOCATION	TYPES OF POLLUTION	RESULTS	REFERENCES
Leaf extract pH	125	Talkatora industrial area, Lucknow, India	Air (vehicular emissions)	decrease	*Bharti et al.,2017*
	36	Aizawl, Mizoram, India	Air (industrial)	Decrease [acidic]	*Rai and Panda, 2013*
	30	Asansole, WB India	Air (Industrial)	Increased	Chowdhury and Banerjee, 2009
	50	Pune, India	Air (vehicular)	Decrease [acidic]	Kazi et. al, 2022
	20	Narasapura, India	Air [Industrial]	Decrease	Pragasan and Ganeshan 2022
	Not defined	Dhaka Bangladesh	Air [Industrial]	Increase	Shahrukh *et al.* 2023
Relative Water Content	125	Talkatora industrial area, Lucknow	Air (vehicular)	decrease	*Bharti et al.,2017*
	36	Aizawl,Mizoram,India	Air (industrial)	decrease	*Rai and Panda, 2013*
	2 tree sp	Dhanbad, Jharkhand, India	Air (Industrial)	Increased	Mishra *et al.*,2024
	30	Asansole, WB India	Air (Industrial)	Increased	Chowdhury and Banerjee, 2009
	50	Pune, India	Air (vehicular)	Increased	Kazi et. al, 2022
	20	Narasapura, India	Air [Industrial]	Decrease	Pragasan and Ganeshan 2022
	Not defined	Dhaka Bangladesh	Air [Industrial]	Increase	Shahrukh *et al.* 2023
Air Pollution Tolerance Index	Not defined	Jharsuguda, India	Air (industrial)	Tolerant [P]	*Thakar and Mishra.,2010*
	36	Aizawl,Mizoram, India	Air (industrial)	High	*Rai and Panda , 2013*
	40	Talkatora industrial area, Lucknow	Air (vehicular emissions)	High	*Bharti et al.,2017*
	30	Asansole, WB India	Air (Industrial)	High	Chowdhury and Banerjee, 2009
	20	Narasapura, India	Air [Industrial]	High	Pragasan and Ganeshan 2022
	6	Pune India	Air [Vehicular]	High	*Kamble et al.., 2021*
	2 tree sp	Dhanbad, Jharkhand, India	Air (Industrial)	High	Mishra *et al.*,2024

	6	Pune India	Air [Vehicular]	Decrease	*Kamble et al.., 2021*
	Not defined	Jharsuguda, Orissa, India	Air (industrial)	Decrease	*Thakkar and Mishra, 2010*
	36	Rourkela, Aizawl,Mizora m, India	Air (industrial)	decrease	*Rai and Panda, 2013*
CAROTENOIDS	6	Talkatora industrial area, Lucknow, India	Air (vehicular)	decrease	*Bharti et al.,2017*
	15	Asansole, WB India	Air (Industrial)	Increased	Chowdhury and Banerjee, 2009
CHLOROPHYLL CONTENT	Not defined	Varanasi, India	Air (vehicular)	Decrease	Prajapati and Tripathi, 2008
	54	Narasapura, India	Air [Industrial]	Decrease	Pragasan and Ganeshan 2022
	20	Dhaka Bangladesh	Air [Industrial]	Increase	Shahrukh *et al.* 2023
	Not defined	Jharsuguda Orissa, India	Air (industrial)	Decrease	*Thakkar and Mishra, 2010*
	Leaves of 40 tree species	Aizawl, Mizoram, India	Air (industrial)	decrease	*Rai and Panda, 2013*
PHOTOSYNTHETIC RATE	Not defined	Jharsuguda Orissa, India	Air (industrial)	Decrease	*Thakkar and Mishra, 2010*
HEAVY METALS DEPOSITION	36	Aizawl, Mizoram, India	Air (industrial)	decrease	*Rai and Panda, 2013*
	9	Jaipur, Udaipur, Vadodara, Mumbai, Pune, and Bengaluru, India	Air (vehicular)	Increase	Tak and Kakde,2 019

Table 4: Effect of air pollutions on the Biochemical parameters of *Ficus benghalensis L.*

PARAMETERS	SAMPLE SIZE (n=)	LOCATION	TYPES OF POLLUTION	RESULTS	REFERENCES
Ascorbic acid	36	Aizawl,Mizoram, India	Air (industrial)	Decrease	*Rai & Panda, 2013*
	Not defined	Jharsuguda Orissa, India	Air (industrial)	Decrease	*Thakar and Mishra .2010*
	125	Talkatora, Lucknow	Air (vehicular)	Decrease	*Bharti et al.,2017*
	30	Asansole, WB India	Air (Industrial)	Increased	Chowdhury and Banerjee, 2009
	54	Varanasi, India	Air (vehicular)	Decrease	Prajapati and Tripathi, 2008
	50	Pune, India	Air (vehicular)	Decrease	Kazi et. al, 2022
	Not defined	Dhaka Bangladesh	Air [Industrial]	Increase	Shahrukh *et al.* 2023
CARBOHYDRATE	95	Barjoraforest Bankura Ballavpur Santiniketan, WB, India	Air	Decrease	*Thambavani et al.. 2014*

Most of the studies were conducted in India [States of Delhi, West Bengal, Orissa, Uttarakhand Jharkhand, Kerala] while in Pakistan [states of Karachi] as observed in Table 1-4. The morphological parameters evaluated include leaf length, leaf breadth, leaf length/ breath ratio, petiole length, leaf weight, leaf area and dust deposition on leaves of *F. benghalensis* L. in response to air pollutants as a result of industries or vehicles. From table 1 it is observed that most of the studies have reported decreased in the leaf length of plants exposed to air pollutants as compared to plants growing in the non-polluted areas [Jahan & Iqbal, 1992]. This decrease in the leaf length may be due to effect of air pollution at that site which reduces the gases exchange for photosynthesis and productivity of leaf [Jahan &Iqbal, 1992]. On the contrary Nandy *et al.* 2014 suggested that most plants experienced physiological changes before exhibiting visible damage to leaves. It is also reported that decrease in the leaf breadth, petiole length and leaf area of plants which are from the polluted site compare to non-polluted site. This is due to heavy air pollutants affected the morphological characters of a leaf. [Jahan &Iqbal, 1992]. Leaf weight is increased due to dust deposition on leaves [Singh *et al.*, 2020]. Also observed that all of the results have reported that the dust deposition increase on the leaves.Till date only one research group studied the anatomical changes of *F.benghalensis* L. leaf due to various air pollutants in vehicular emission [Table 2]. There was decrease in cuticle, epidermis, palisade, hypodermis, parenchyma cells in polluted leaves as compared to leaves collected from non-polluted area. The parenchymatous cells of spongy parenchyma become compactedas a result of incessantcontact with air pollutants. [Jahan &Iqbal, 1992].

Table 3 summarizes the various physiological parameters that have been assessed to comprehend the effects of industrial or vehicular air pollutants which comprise of leaf extract pH, relative water content, air pollution tolerance index, carotenoids, chlorophyll content, photosynthesis rate and heavy metal deposition. Leaf extract pH is found to be acidic from the polluted site compared to non-polluted site [S.K. Bharti *et al.*, 2017, Rai &Panda, 2013] due to presence of acidic pollutants such as SOx and NOx in the prevalent air. Relative water content is decreased in most of the studies from the polluted sites. [S.K. Bharti *et al.*,2017, Rai & Panda, 2013]why. The Air Pollution Tolerance Index (APTI) is an important metric for measuring the efficiency with which trees and plants manage air pollution [Zahid *et al.*, 2023].In case of *F.benghalensis* L. the APTI varied for different studies ranging from tolerant to the most sensitive species. Researchers have suggested that the plant could be used to develop a green belt due to higher APTI value greater making it a tolerant species [Thakar and Mishra 2010; Rai & Panda, 2013;S.K. Bharti *et al.*,2017; Chowdhury and Banerjee, 2009]. Pragasan and Ganeshan 2022 considered*F.benghalensis* L. as one the topmost air pollution tolerant species in India. Kamble *et al.*., 2021 reported decreased level of carotenoids in the leaves collected from polluted sites as compared to non-polluted site. Carotenoids shield chlorophyll from photo-oxidant degradation. All studies revealed that chlorophyll contents in leaves and photosynthetic rate of plants are decreased in polluted sites as comparedto non-polluted sites. [Rai & Panda, 2013, Thakar *et al.*, 2010]. Total chlorophyll content recorded for *F. benghalensis*L. was significantly reduced at the polluted sites [Rai *et al.*, 2020; Shahrukh *et al.*, 2023]. Tak and Kakde, (2019) suggested that *F. benghalensis* L. could be planted along roadside where vehicular emission is more, as biofilters of air pollution. These trees seem to accumulate some toxic heavy metals into their root system, making the soil less toxic.

Ascorbic acid is considered as an antioxidant occurring in huge quantity in developing plant organs. Significantly higher level of ascorbic acid promotes tolerance against air pollutants which suggests it to be a defense mechanism of the respective plant [Rai and Panda, 2013]

Significantly higher levels of ascorbic acid values accompanied with low pH values were observed in a number of studies [Chowdhury and Banerjee, 2009; Sharukh *et al.* 2023]. It is observed thatdecreased carbohydrate level in leaves collected from polluted sites may be considered as the chief stress diminishing approach to less enimpairment [Thambavani *et al.,* 2014].

4. Conclusion

In conclusion, studies till date show that *F. benghalensis* L. leaves undergo considerable morphological and physiological alterations when exposed to air pollution from industrial and vehicle sources. Morphological metrics such as leaf length,breadth and area as well as petiole lengthare reduced in polluted environments, indicating the negativeconsequence of air pollutants on leaf morphometry. This decrease is often linked to impaired gas exchange and reduced photosynthetic productivity due to pollutant-induced stress. In contrast, some studies reported an increase in leaf length, which may suggest initial physiological reactions before observable damage occurs.

Analysis of physiological parametersdemonstratedpersistent trends of amplified acidity in leaf extracts, diminished relative water content, and variable APTI values, highlighting the adaptability and resilience of*F. benghalensis* L. to polluted environments. Despite variations in APTI across studies, the species often exhibits tolerance, implying its potential for biofiltration in polluted areas. Reduced chlorophyll and carotenoid levels further underscore the impact of pollutants on photosynthetic efficiency and antioxidant defences. Furthermore, studies reported the accumulation of heavy metals in roots, potentially mitigating soil toxicity.

These data highlight the intricate interactions between *F. benghalensis* L. and air contaminants, underlining the species' resilience and possible ecological functions in urban pollution reduction. Further research into biochemical and molecular reactions will help us better understand plant adaption mechanisms and guide sustainable urban design and environmental management techniques.

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