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Variation in the Ability of Various Tree Species to Capture Particulate Matter in Industrial and Urban Areas

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

There are several short- and long-term negative effects on human health caused by the well-known pollutant known as particulate matter (PM), which also significantly contributes to urban air pollution. Trees can act as a sustainable air purifying filter by adsorbing and absorbing tiny airborne dust. Their effectiveness is influenced by a number of variables, including particulate matter concentration and leaf features of tree species. In this study, the particulate matter capturing capacity of commonly grown 20 tree species were compared and the best tree species were chosen for the urban plantation to reduce particulate matter pollution. In this study, *Ficus bengalensis* (0.67 mg/cm^2), *Mangifera indica* (0.61 mg/cm^2), *Polyalthia longifolia* (0.57 mg/cm^2), *Tectona grandis* (0.66 mg/cm^2) and *Terminalia catappa* (0.63 mg/cm^2) were found to be the best tree species among the 20 tree species and also it was confirmed that morphological

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characteristics of tree leaves plays an important role in capturing the particulate matter from the atmosphere. In conclusion, our findings may help in the selection of greening tree species with strong particulate matter purifying capacities for both industrial and urban areas.

Keywords: Industry; macromorphological; micromorphological; particulate matter.

1. INTRODUCTION

Due to rapid industrial expansion and the resulting increase in vehicle traffic, India's air quality has been alarmingly declining over the past three to four decades [1]. According to Shrestha et al., [2], 90% of people on earth reside in places where the WHO air quality standards are not met. This might be a result of the tremendous urban population growth that has increased traffic, industry and fuel use. By increasing gas concentrations and introducing suspended particulate matter into the atmosphere, air pollution has become a significant issue in environmental degradation [3]. And the most harmful air pollutant is particulate matter (PM), which can cause birth defects, shorten lifespan, and deteriorate respiratory and cardiovascular health [4]. $PM_{2.5}$ can float in the atmosphere for a very long period and experience large-scale spreading via atmospheric circulation because of its micromass and volume [5]. According to Han et al., [6], organic and elemental carbon, SO_2, NO_3, NH^{4+}, are the main chemical components of particulate matter. It is more dangerous to human health than other atmospheric pollutants (surface ozone, carbon monoxide, and nitrogen dioxide) and absorbs polycyclic aromatic hydrocarbons (PAHs). Non-smokers who breathe in particulate matter can develop lung cancer, respiratory problems, or even cardiovascular disease. With the growth of major cities, the issue of inhalable particulate matter pollution in the atmosphere has garnered attention on a global scale, making it important to find strategies to avoid and control it.

There are many anthropogenic factors that contribute to air pollution, including increased fossil fuel burning in thermal power plants and businesses, smoke from household sources, vehicle emissions, and dust from construction sites and roadside vegetation [7]. The four categories of PM are total suspended particles (TSP, $Dp \leq 100\ \mu m$), coarse particulates ($PM_{2.5\text{-}10}$, $Dp=2.5\text{-}10\ \mu m$), fine particles ($PM_{2.5}$, $Dp \leq 2.5\ \mu m$), and ultrafine particles (UFP, $Dp \leq 0.1\ \mu m$), according to the aerodynamic diameter (Dp) of the particulate pollutants. The different size fractions of PM have varied health impacts. TSP typically has little impact; PM_{10} has respiratory and other concerns from exposure pathways other than inhalation; $PM_{2.5}$ has respiratory, cardiovascular, and other concerns; UFP has concerns for a variety of health outcomes as well; some health effects attributed to $PM_{2.5}$ are thought to be primarily from UFP [8,9].

According to studies, tree species can successfully filter out atmospheric pollutants and retain particulate matter, which makes them a potent tool for enhancing urban environments and reducing the burden of air pollution. Each type of urban tree can accumulate different amount of atmospheric $PM_{2.5}$ on its leaves (Chen et al., 2017). According to Nowak et al., [10], trees clean the air by gathering particulate matter on their surfaces and absorbing gaseous pollutants through the stomata on their leaves. It has become commonly accepted in recent years that the removal of suspended particulate matter (SPM) from the air can be accomplished by using the right vegetation [11-13].

By absorbing, adsorbing, detoxifying, accumulating, and/or metabolising pollutants without suffering a significant loss in growth, trees serve as a sink and filter to reduce air pollution, which improves air quality by supplying the environment with oxygen. There are many ways that vegetation can lower airborne particulate pollution. For instance, vegetation can weaken wind gusts and make the terrain more uneven. Due to limited dispersion, a lower wind speed might raise pollution concentrations, which may accelerate the sedimentation of airborne particles [14]. Individual trees primarily capture particles through their leaves, and the degree to which they do so depends on the foliar structure's features including hair, trichomes, wax, shape, and others. It may be advised to use trees that can survive higher pollutant concentrations as tolerant species and as pollution scavengers. Sensitive plants cannot withstand contaminants and can therefore be employed as bioindicators, whereas tolerant trees can grow in polluted environments and assist in cleaning up diverse man-made pollution. In this way, trees serve as both the initial acceptors of air pollution and its scavengers. As a result, such tolerant trees can significantly contribute to improving air quality by exchanging gases and acting as a sink for air pollutants, which can lower their concentration in the air and aid in air pollution mitigation.

The study was conducted during 2022-2023. For the purpose of determining trees particulate matter capturing capacity, twenty tree species were chosen which are commonly present in all four study areas. The aim of the study was to assess the particulate matter capturing capacity of the tree species and screen the best tree species for taking up of plantation at the selected industrial and urban areas. The results of this study have significance for choosing industrial tree species that will reduce air pollution. The findings reported here will also help urban planners assess the prospective capacity of particulate matter removal from a long-term, expansive perspective.

2. MATERIALS AND METHODS

2.1 Study Areas

In this study, four study areas were considered namely ACC Limited, Madukkarai 10º54′18″N and 76º57′19″E; ITC Limited PSPD, Unit-Kovai, Thekkampatti, Karamadai (industrial area) 11º14′45″N and 76º52′28″E; R.S. Puram, Coimbatore (urban area) 11º00′39″N and 76º56′55″E and Botanical garden, TNAU, Coimbatore (unpolluted area) 11º00′46″N and 76º55′53″E which are all located in Coimbatore district of Tamil Nadu, India. Among the four study areas, two are industrial areas, one is taken as urban area and one is unpolluted area. ITC Limited PSPD, Unit-Kovai, Thekkampatti, Karamadai is one of the ITC Limited Paperboard and Speciality Paper Division units, located 42 km north of Coimbatore. ACC Limited, Madukkarai is a cement manufacturing industry which is 15 km away from the unpolluted area Tamil Nadu Agricultural University, Coimbatore. And as for the urban area, R.S Puram, Coimbatore was selected which is a prime residential area having a population of roughly 62,600 people with heavy crowded traffic.

2.2 Collection of Leaf Samples

The availability of common tree species in the chosen areas was the primary reason for selection. Leaf samples of the twenty commonly grown tree species were collected from in and around the four study areas. Within 24 hours after their collection, three replicates of each species completely matured and healthy leaves were randomly selected in the morning (7:00 am to 9:00 am) from the lower branches approximately 1.5 to 2.0 meters above the ground, facing the road and close to industrial areas were collected and transported in a polythene bag kept in an ice box to the laboratory for identification, preservation and further analysis. To prevent contamination, samples were sealed and labelled in plastic bags right away after collection. They were then kept in a lab freezer (-18°C) for storage.

2.3 Monitoring of Air Quality Status

Aeroqual Series 500 (S500) was used to measure NO_2, SO_2 and O_3 and live air quality value from the CPCB website was used to measure $PM_{2.5}$, and PM_{10} at the sampling locations once a month throughout the study period.

2.4 Particulate Matter Capturing Capacity

The leaf washing method, which involves washing the leaf sample and measuring the amount of particles washed from the leaf surface, is one of three main experimental techniques to measure PM on the leaf surface [15,16]; aerosol regenerator method [17]; and scanning electron microscope method [18]. In this study, leaf washing method was used. The leaf washing method is washing a sample of leaf, followed by measuring how much particles were removed from the surface of the leaves.

$$Q = (W_1-W_2)/S,$$

Where,

Q = The particulate matter capturing capacity
S = The area of the leaf surface (cm^2)
W_1 = Leaf weight before washing
W_2 = Leaf weight after washing.

3. RESULTS AND DISCUSSION

Twenty commonly grown tree species were subjected to their macromorphological and micromorphological characteristics. The detailed note about the leaves of these 20 tree species are given in Table 1.

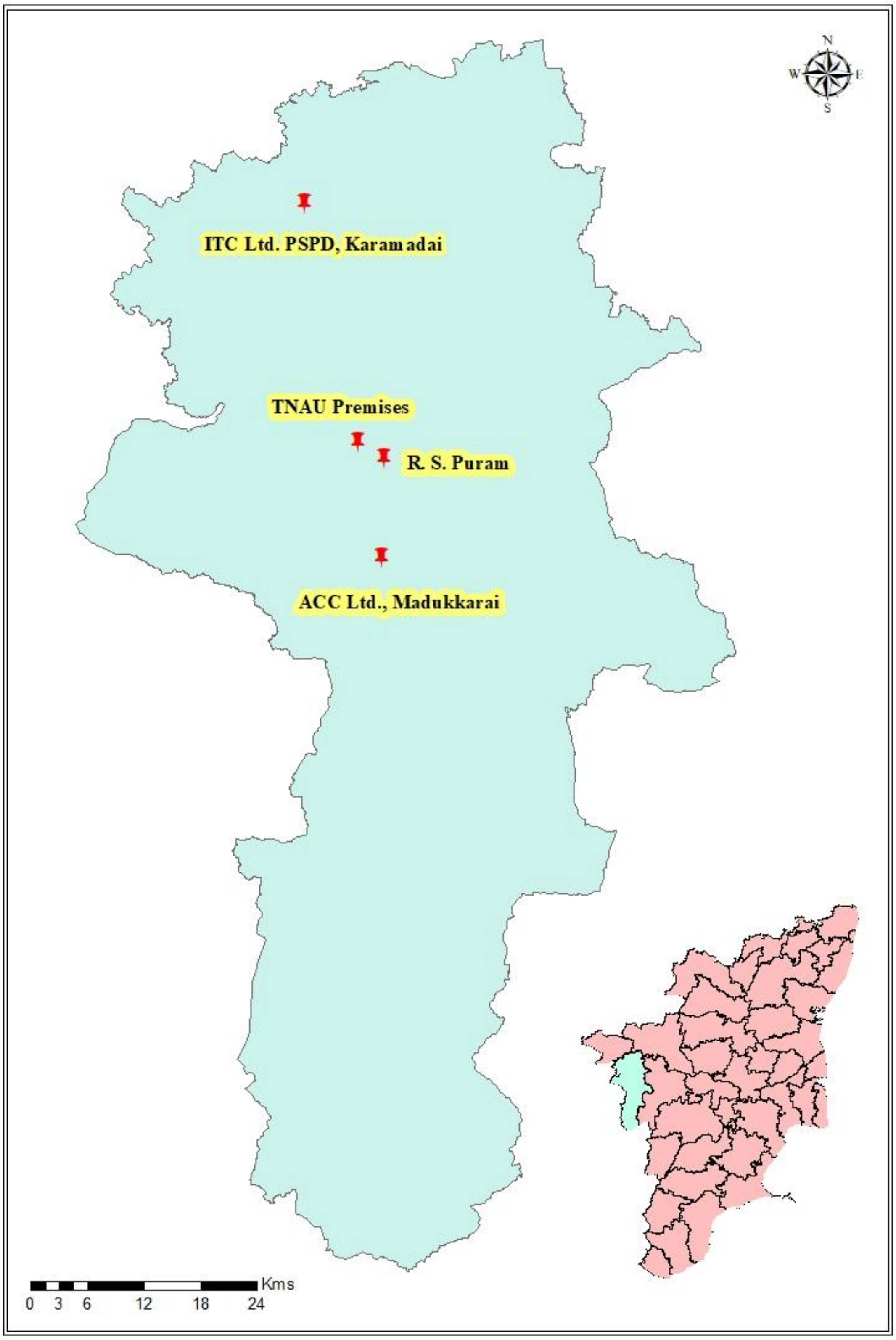

Fig. 1. Location of study areas

Table 1. Tree species with their leaf characteristics

S. No.	Common name	Scientific name	Description of the leaf characteristics including any unique micromorphological ones
1.	Devil tree	*Alstonia scholaris*	Evergreen tree. Leathery, sessile, simple leaves are elliptical, ovate, linear or lanceolate and wedge-shaped at the base, thick, oblong, with a blunt tip.
2.	Jackfruit	*Artocarpus heterophyllus*	Evergreen tree. Large oblong to ovate in shape, gummy and thick, leathery leaf blade, smooth leaf margin.
3.	Neem	*Azadiracta indica*	Evergreen tree. Lanceolate or falcate, imparipinnate, glabrous, margin serrate.
4.	Orchid tree	*Bauhinia variegata*	Semi-evergreen or deciduous tree. Simple, cleft and lobed margin, rough surface.
5.	Golden shower tree	*Cassia fistula*	Deciduous, even pinnately compound, smooth, fine, oblong-ovate, entire margin, glabrous above and pubescent below.
6.	Mayflower	*Delonix regia*	Deciduous tree. Bipinnate, alternate, feathery, minutely hairy on both sides
7.	Banyan	*Ficus bengalensis*	Evergreen tree. Oval shape, entire margin, pinnate, leathery, glossy, coarse, minutely hairy below.
8.	Sacred fig	*Ficus religiosa*	Deciduous/semi-evergreen tree, ovate in shape, leathery, margin entire or undulate.
9.	River tamarind	*Leucaena leucocephala*	Evergreen tree. Glabrous, linear-oblong or weakly elliptic.
10.	Mango	*Mangifera indica*	Evergreen tree, entire/slightly undulate margin, glabrous, shiny, coriaceous, curved upward from the midrib, leathery.
11.	Singapore cherry	*Muntingia calabura*	Evergreen, lanceolate or ovate, Rough surface, toothed margin and covered in short hairs, sticky to the touch.
12.	Copper pod	*Peltophorum pterocarpum*	Semi-evergreen tree, bipinnately compound, entire margin, oblong, Glossy, Fine
13.	False ashoka	*Polyalthia longifolia*	Evergreen tree. Simple, alternate, narrow lanceolate or linear lanceolate, glabrous, margin wavy or undulate, more or less coriaceous.
14.	Indian beech tree	*Pongamia pinnata*	Deciduous or Evergreen tree, odd-pinnately compound, ovate, elliptical to oblong, entire margin, elliptic (oval), margin entire.
15.	Rain tree	*Samanea saman*	Evergreen tree. Bipinnately compound, leaflets are rhombic-oblong or elliptic in shape, shiny green above and finely hairy beneath.
16.	Black plum	*Syzygium cumini*	Evergreen, simple leaf, waxy, leathery, medium, coarse texture, pinnate, obovate, undulate and entire margin.
17.	Tamarind	*Tamarindus indica*	Evergreen tree. Even-pinnately compound, entire margin, smooth texture.
18.	Teak	*Tectona grandis*	Deciduous tree. Large, simple leaves which are elliptic to ovate. Abaxial surface pubescent, often clasping at base.
19.	Arjuna	*Terminalia arjuna*	Deciduous tree, oblong-lanceolate, thick coriaceous, margin crenate-serrate.
20.	Indian almond	*Terminalia catappa*	Deciduous tree. Obovate to oblanceolate, both surfaces glabrous or abaxially sparsely softly hairy, leathery.

Table 2. Particulate matter capturing capacity of twenty commonly grown trees in four study areas

S. No.	Common name	Scientific name	Particulate matter capturing capacity (mg/cm^2)				
			Study area 1	Study area 2	Study area 3	Study area 4	Average
1.	Devil tree	*Alstonia scholaris*	0.39±0.01	0.36±0.01	0.63±0.01	0.36±0.01	0.44
2.	Jackfruit	*Artocarpus heterophyllus*	0.52±0.02	0.41±0.02	0.54±0.01	0.34±0.01	0.45
3.	Neem	*Azadiracta indica*	0.51±0.01	0.49±0.02	0.62±0.01	0.39±0.02	0.50
4.	Orchid tree	*Bauhinia variegate*	0.56±0.02	0.43±0.01	0.60±0.02	0.41±0.01	0.50
5.	Golden shower tree	*Cassia fistula*	0.42±0.01	0.34±0.01	0.53±0.01	0.29±0.01	0.40
6.	Mayflower	*Delonix regia*	0.41±0.01	0.32±0.01	0.47±0.01	0.24±0.00	0.36
7.	Banyan tree	*Ficus bengalensis*	0.88±0.01	0.55±0.01	0.82±0.03	0.42±0.02	0.67
8.	Sacred fig	*Ficus religiosa*	0.49±0.01	0.32±0.01	0.55±0.02	0.35±0.01	0.43
9.	River tamarind	*Leucaena leucocephala*	0.31±0.01	0.26±0.01	0.41±0.01	0.28±0.01	0.32
10.	Mango	*Mangifera indica*	0.72±0.01	0.52±0.01	0.71±0.02	0.47±0.01	0.61
11.	Singapore cherry	*Muntingia calabura*	0.59±0.02	0.35±0.01	0.54±0.02	0.34±0.01	0.46
12.	Copper pod	*Peltophorum pterocarpum*	0.41±0.01	0.36±0.01	0.54±0.01	0.38±0.01	0.42
13.	False ashoka	*Polyalthia longifolia*	0.67±0.02	0.46±0.01	0.66±0.03	0.48±0.01	0.57
14.	Indian beech tree	*Pongamia pinnata*	0.48±0.01	0.41±0.01	0.57±0.01	0.38±0.02	0.46
15.	Rain tree	*Samanea saman*	0.44±0.01	0.33±0.01	0.47±0.01	0.36±0.01	0.40
16.	Black plum	*Syzygium cumini*	0.47±0.01	0.51±0.02	0.52±0.02	0.33±0.01	0.46
17.	Tamarind	*Tamarindus indica*	0.38±0.01	0.36±0.01	0.41±0.02	0.32±0.01	0.37
18.	Teak	*Tectona grandis*	0.84±0.01	0.54±0.02	0.83±0.03	0.43±0.01	0.66
19.	Arjuna	*Terminalia arjuna*	0.68±0.02	0.44±0.02	0.68±0.01	0.37±0.01	0.54
20.	Indian almond	*Terminalia catappa*	0.72±0.02	0.53±0.02	0.79±0.01	0.46±0.02	0.63

**Study 1= ACC Limited, Madukkarai; Study area 2= ITC Limited PSPD, Thekkampatti; Study area 3= R.S. Puram, Coimbatore and Study area 4= Botanical garden, TNAU, Coimbatore*

3.1 Particulate Matter Capturing Capacity

The particulate matter capturing capacity of the tree species has been shown in Table 2. In this study, the amount of particulate matter captured on the tree leaves varied from species to species in all the study areas. The value ranges from (0.31±0.01) mg/cm^2 to (0.88±0.01) mg/cm^2, (0.26±0.01) mg/cm^2 to (0.55±0.01) mg/cm^2, (0.41±0.01) mg/cm^2 to (0.83±0.03) mg/cm^2 and (0.24±0.00) mg/cm^2 to (0.48±0.01) mg/cm^2 for ACC Limited, ITC Limited, R.S. Puram and Tamil Nadu Agricultural University, respectively. And Fig. 2. depicted the differences in particulate matter capturing capacities of selected tree species in industrial (ACC Limited, ITC Limited), urban (R.S. Puram) and the unpolluted (TNAU) areas.

3.1.1 Industrial areas

In ACC Limited, which is a cement manufacturing industry, particulate matter capturing capacity was found to have the following trends: *Ficus bengalensis* > *Tectona grandis* > *Mangifera indica* > *Terminalia catappa* > *Terminalia arjuna* > *Polyalthia longifolia* > *Muntingia calabura* > *Bauhinia variegate* > *Artocarpus heterophyllus* > *Azadiracta indica* > *Ficus religiosa* > *Pongamia pinnata* > *Syzygium cumini* > *Samanea saman* > *Cassia fistula* > *Delonix regia* > *Peltophorum pterocarpum* > *Alstonia scholaris* >

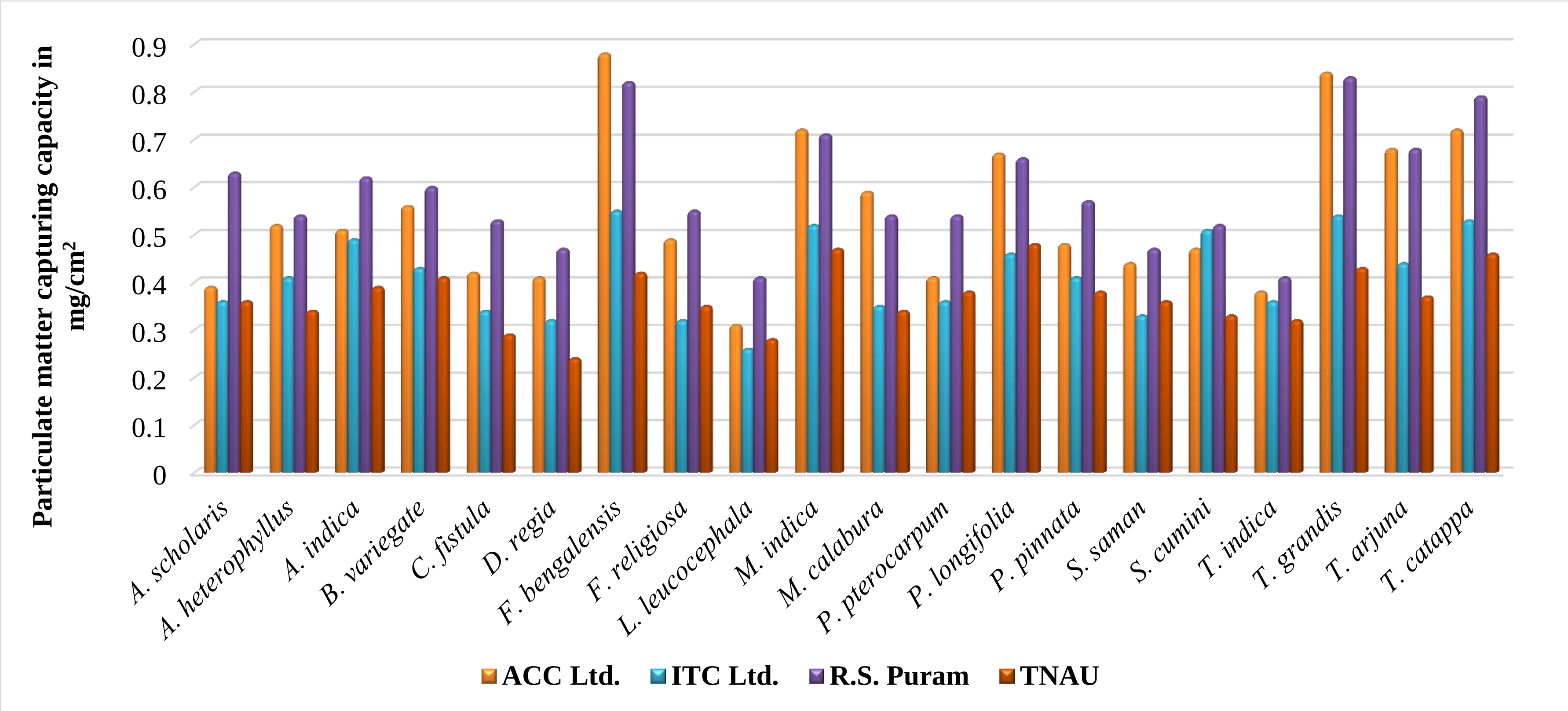

Fig. 2. Differences in particulate matter capturing capacities of selected tree species in industrial (ACC Limited, ITC Limited), urban (R.S. Puram) and the unpolluted (TNAU) areas

Tamarindus indica > *Leucaena leucocephala*. And for the other industrial area which is ITC Limited, particulate matter capturing capacity was found to have the following trends: *Tectona grandis* > *Ficus bengalensis* > *Terminalia catappa* > *Mangifera indica* > *Syzygium cumini* > *Azadiracta indica* > *Polyalthia longifolia* > *Terminalia arjuna* > *Bauhinia variegate* > *Artocarpus heterophyllus* > *Pongamia pinnata* > *Alstonia scholaris* > *Peltophorum pterocarpum* > *Tamarindus indica* > *Muntingia calabura* > *Cassia fistula* > *Samanea saman* > *Delonix regia* > *Ficus religiosa* > *Leucaena leucocephala*. Among all of them, in both ACC Limited and ITC Limited, *Ficus bengalensis* has the highest capacity to capture particulate matter (PM) with (0.88±0.01) mg/cm^2 and (0.55±0.01) mg/cm^2 respectively which may be due its rough [19] and hairy surface at below. The rough and hairy surface will not natural rains to quickly wash off leaf surfaces. The lowest value was found in *Leucaena leucocephala* with (0.31±0.01) mg/cm^2 and (0.26±0.01) mg/cm^2 because it has glabrous and smooth surface which lack the ability to capture particulate matter on it.

3.1.2 Urban area

As for urban area which is R.S Puram, Coimbatore, particulate matter capturing capacity was found to have the following trends: *Tectona grandis* > *Ficus bengalensis* > *Terminalia catappa* > *Mangifera indica* > *Terminalia arjuna* > *Polyalthia longifolia* > *Azadiracta indica* > *Bauhinia variegate* > *Pongamia pinnata* > *Ficus religiosa* > *Artocarpus heterophyllus* > *Muntingia calabura* > *Peltophorum pterocarpum* > *Alstonia scholaris* > *Cassia fistula* > *Syzygium cumini* > *Samanea saman* > *Delonix regia* > *Leucaena leucocephala* > *Tamarindus indica*. In this study area, *Tectona grandis* has shown the best PM capturing capacity with (0.83±0.03) mg/cm^2 which is due to rough surface [20], pubescent on abaxial surface and often clasping at base, followed by *Ficus bengalensis* with (0.82±0.03) mg/cm^2 as it has leathery and hairy surface. The lowest value was found in *Leucaena leucocephala* with (0.41±0.01) mg/cm^2 because it has fine surface texture and thin lamina as air movement can easily disturb the leaves [20-25] which reduces the leaf ability to capture particulate matter.

3.1.3 Unpolluted area

In the unpolluted area, particulate matter capturing capacity was found to have the following trends: *Polyalthia longifolia* > *Mangifera indica* > *Terminalia catappa* > *Tectona grandis* > *Ficus bengalensis* > *Bauhinia variegate* > *Azadiracta indica* > *Peltophorum pterocarpum* > *Pongamia pinnata* > *Terminalia arjuna* > *Alstonia scholaris* > *Samanea saman* > *Ficus religiosa* > *Artocarpus heterophyllus* > *Muntingia calabura* > *Syzygium cumini* > *Tamarindus indica* > *Cassia fistula* > *Leucaena leucocephala* > *Delonix regia*. Comparing to other study areas, the tree species grown in unpolluted study area have very less PM capturing capacity as the particulate matter concentration in this study area is relatively lower than the other study areas. *Polyalthia longifolia* with particulate matter capturing capacity (0.48±0.01) mg/cm^2 was found to perform best in capturing particulate matter which may be because of its more or less coriaceous and wavy or undulate margin which give accumulating surface structure trapping the particulate matter for longer time not letting it wash off easily. It is followed by *Mangifera indica* (0.47±0.01) mg/cm^2, *Terminalia catappa* (0.46±0.02) mg/cm^2, *Tectona grandis* (0.43±0.01) mg/cm^2 and *Ficus bengalensis* (0.42±0.02) mg/cm^2 which are all found to be well performers in other polluted areas also [26-30].

3.2 Screening of Best Tree Species

The tree species with high particulate matter capturing capacity can capture more particulate matter. Therefore the five best performing tree species namely *Ficus bengalensis*, *Mangifera indica*, *Tectona grandis*, *Terminalia arjuna* and *Terminalia catappa* have been screened and can be recommended for taking up of plantation in and around the industrial as well as urban area to combat particulate matter pollution [31-35].

4. CONCLUSION

This study examined the ability of urban trees to remove particulate matter (PM) at four different study areas (industrial, urban and unpolluted). The results of the study revealed that there is variation in abilities of different tree species to capture particulate matter (PM) which is mainly influenced by their differences in leaf characteristics. The tree species having high particulate matter capturing capacity have been screened out and recommended for taking up of plantation in the industrial and urban areas. Thus this study will help in urban greening as well as reducing particulate matter pollution.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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