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Effects of stone crushing industry on *Shorea robusta* and *Madhuca indica* foliage in Lalpahari forest

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ABSTRACT

One of the various causes of forest decline is certainly the industrial expansion and the resultant air pollution of anthropogenic origin. Gradual and extensive encroachment of the forest area by the quarrying (mining) and crushing activities of the naturally occurring stones since early 1960s is found in the district of Birbhum, West Bengal, India. The aim of this study was to evaluate the effect of stone crushing industry on different foliar parameters of *Shorea robusta* and *Madhuca indica* which are two dominant broad–leaved tree species of the forest concerned. Measurement of suspended particulate matter (SPM), dustfall and gaseous pollutants in ambient air were done. Heavy deposition of dust particles on leaf surfaces was noted. Various types of foliar anomalies, both microscopic and macroscopic, were detected externally. Decrease in amount of chlorophyll and total carbohydrate in foliar tissues indicated reduction of photosynthesis. Reduction of protein content in foliar tissues was also noted. Site–wise and season–wise variations of almost all data were found to be statistically significant. Comparison of air pollution status and foliar biochemical parameters with those recorded in a control forest was done along with study of spatial significance between polluted sites at Lalpahari with increasing distance from the source of pollution. A significant correlation was established in many cases between foliar parameters and air pollutants present in ambient air in the highly polluted site of the forest close to the source of pollution.

Keywords:
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1. Introduction

According to Deputy Director (Environment), National Productivity Council, New Delhi (Patil, 2001): (i) over 12 000 stone crusher units were operating in India, (ii) stone crushing industry sector had an annual turnover of Rs. 5 000 crores (over 1 billion US $), (iii) this sector provided direct employment to over 500 000 people engaged in various activities like mining, crushing and transportation and (iv) it was a source of livelihood for the uneducated poor and unskilled rural people. Clusters of stone crushing and sizing units are located at Baromasia along the road (State Highway 7) from Rampurhat to Dumka (Figure 1b and 1c). The stone crushing industry and the associated traffic in the area generate a number of air pollutants which exceed the air quality standards, particularly during daytime. The stone crushing industry at Lalpahari include two main operations: (1) quarrying or mining operations (drilling of stone beds, blasting of stone bed with the help of dynamites, loading of bigger chunks of stones onto trucks and transportation of blasted stones to crusher sites) and (2) crushing operations (hammering of bigger chunks of stones into smaller pieces or chellies, crushing of chellies by feeding them in jaw crushers, screening into different sizes by vibratory or rotary screens, conveying by conveyor belts, dumping or heaping of stone chips outdoors according to size, removal of dust or solid waste and loading of stone chips onto trucks for transportation). But, there is a lack of environmental governance in both the quarries and the crushers which has resulted in considerable degradation of the environment surrounding the locations where stone crushing industry is established (ES, 1998).

The suspended particulate matter (SPM), depending on the size and weight of particles, remain in the air for varying length of time. Those larger than 10 µm in size settle under forces of gravity on surfaces of vegetations and soil but the smaller ones remain suspended in air for longer periods of time, get dispersed and diffused by the wind, and eventually deposited on various surfaces including foliar ones (Rao, 1985).

Stone dust is a primary aerosol and it is released directly from the source. It has a detrimental effect on people and environment including flora and fauna, for example, changed soil pH and productivity, formation of haze reducing visibility in the surrounding areas, destruction of habitat, damage of natural resources like valuable vegetations and wild lives, promotion of spreading of many diseases etc. (Semban and Chandrasekhar, 2000; Das and Nandi, 2002; Mishra, 2004; Sivacoumar et al., 2006). Effects of cement, petroleum–coke dust, fly ash, coal dust, automobile exhaust and other airborne particulates on various morphological and physiological parameters in different plants were well–studied by many workers (Singh and Rao, 1980; Prasad and Rao, 1981; Armbrust, 1986; Agrawal and Agrawal, 1989; Pyatt and Haywood, 1989; Naidoo and Chirkoot, 2004; Verma and Singh, 2006; Prajapati and Tripathi, 2008).

Trees have long been known to act as a sink for air pollutants and to suffer from the harmful consequences. Reduction of ascorbic acid, protein, carbohydrate and pigments was noticed by Prasad and Rao (1981) in petroleum–coke treated plant, *Phaseolus aureus*. Reduction of dry weight in *Gossypium hirsutum* due to reduced photosynthesis as a result of dust deposition was noticed

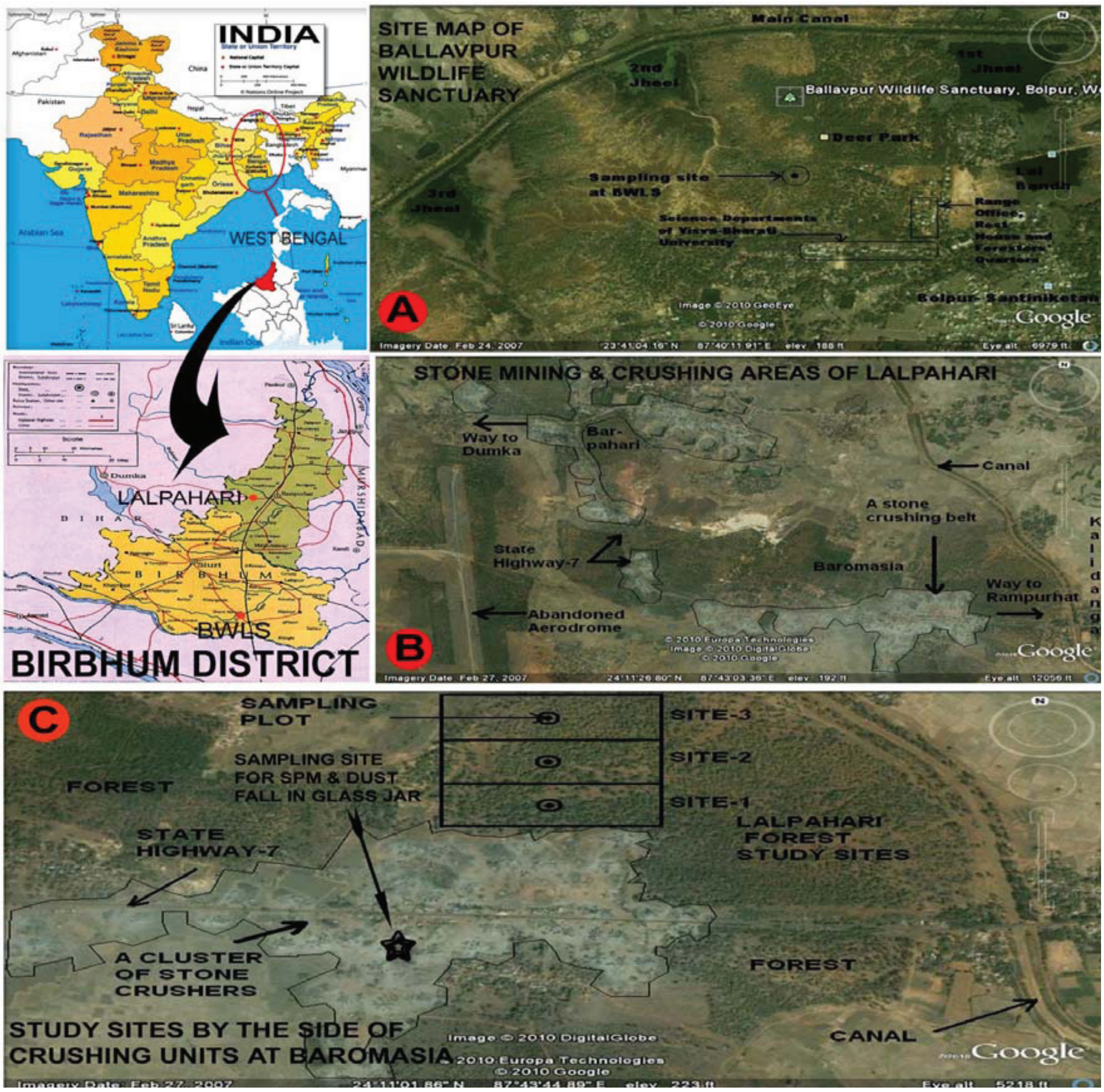


Figure 1. *Location of the study areas (BWLS at Bolpur Beat, Santiniketan and Lalpahari Forest at Tumboni Beat, Rampurhat) in Birbhum District, West Bengal, India. Satellite Pictures of BWLS at Santiniketan* ***(A)*** *and Lalpahari Forest at Baromasia, Rampurhat* ***(B*** *and* ***C)*** *(source: internet and Google Earth).*

by Armburst (1986). According to Fowler et al. (1989) particulate and gaseous pollutants have a greater impact in woodlands than in vegetations of shorter length. The growth and development aspects of plants are adversely affected by airborne particulates depending on their physical and chemical nature. Jahan and Iqbal (1992) observed reduction in leaf blade area of five tree species as a result of extensive dust and SO_2 pollution. Most of the plants experience physiological alterations before morphological injury symptoms become visible on their leaves (Liu and Ding, 2008). Prajapati and Tripathi (2008) studied species–wise and season–wise dust deposition patterns on six selected tree species and their effects on chlorophyll and ascorbic acid content in foliar tissues. Investigations on ten annual plant species by Rai et al. (2010) reveals that the foliar surface was an excellent receptor of atmospheric pollutants leading to a number of structural and functional changes.

Carbohydrate is an important storage and structural material for the plants. It is mainly produced in green leaves where mesophyll tissue is full of green pigments called chlorophylls. Chlorophyll a and b occur in higher plants, ferns and mosses. Therefore, the level of these pigments and the amount of total carbohydrate present in leaf tissue indicate the photosynthetic efficiency of these plants. Protein is the main component of protoplasm and a primary growth factor for all living creatures. The main constituent of all the enzymes required for different physiological processes is protein.

According to Nayar (1985), leaf area is the main component of tree canopies and the leaf area index gives quantitative data of the depth of canopies. Forest canopies constitute the bulk of photosynthetically active foliage and biomass in forest ecosystems (Lowman and Wittman, 1996). Therefore, any fluctuation in chlorophyll, carbohydrate or protein content of foliar tissues of dominant tree species of a forest can be treated as disturbances in overall growth of forest biomass.

This study investigates the status of particulate and gaseous pollution around stone crusher units at Lalpahari forest area and their effects on various foliar parameters of *Shorea robusta* and *Madhuca indica*.

2. Materials and Methods

2.1. Description of the study area and selection of study sites

Situated between 23° 32' 30" (right above the tropic of cancer) and 24° 35' 0" north latitude and 87° 5' 25" and 88° 1' 40" east longitudes, and about 4 550 km^2 in area, the district of Birbhum has a forest coverage of 159 km^2. The Birbhum Forest

Division, located in the ”7B Bio–geographic zone” of Chhotonagpur plateau, is divided into 5 Ranges: Rajnagar, Rampurhat, Mahammad Bazar, Bolpur and Suri. Two different study areas were selected. The control site, Ballavpur Wild Life Sanctuary (BWLS) situated at Santiniketan (Figure 1a), under Bolpur Range, is an ideal home for a large number of flora and fauna. On the other hand, Lalpahari forest at Baromasia (situated about 60 km north of BWLS and 3 km west of Rampurhat town) under Tumboni Beat of Rampurhat Range, is a polluted one as huge mining and crushing of naturally occurring stones take place all along the roadways (Figure 1c). As for instance, over 40 crusher units are found on both sides of the state highway along a distance of only 1 km at Baromasia situated in between Kalidanga and Barpahari at the study area generating a high degree of particulates and other pollutants in the air from morning to evening hours of the day. Three polluted study sites were selected in Lalpahari forest with increase in distance from the source of pollution: ”site 1” situated adjacent to the cluster of crushers, ”site 2” situated farther 500 m north and “site 3” farther 500 m north, for studying every parameter except SPM (as the High Volume Sampler or HVS for measuring SPM could not be operated without electricity deep inside the forest) and “dustfall in glass jar” (as the jar could not be left in the forest unattended for a long time). SPM and dustfall in glass jar were, however, recorded in a site selected among a small sub–cluster of 9 crusher units (about 15 to 25 meters away from the units concerned, i.e., from an average distance of 20 meters from the crusher units). So the statue of the Lalpahari sites was: (i) site 1– highly polluted, (ii) site 2– moderately polluted and (iii) site 3– less polluted (Figure 1c). The BWLS was selected as a control site due to absence of any significant source of pollution in the vicinity. One sampling plot of 50 m radius per site was selected for sampling of foliage and gaseous pollutants at the middle of each rectangular study site (approx. 500 m × 1 500 m).

2.2. Climatic conditions

The climate is generally dry and mild with three distinct seasons, i.e., summer (March–June), rainy season (July–October) and winter (November–February). Maximum temperature recorded in summer is 41 ˚C and minimum recorded in winter is 6 ˚C. Rainfall recorded is about 1 400 mm to 1 450 mm (annual average), 75% of which occurred during July to September. Maximum relative humidity recorded during rainy season is 89.4% and minimum recorded during winter is 48.5%. The direction of wind was generally from southeast in summer, from east in rainy season and from northwest in winter.

2.3. Selection of tree species and branch locations

Dominant tree species in these two forests, out of 75 identified trees (Padhi, 2005), are Sal (*Shorea robusta*), Mohul or Mohua (*Madhuka indica*), Eucalyptus (*Eucalyptus citriodora*), Sonajhuri (*Acacia moniliformis*) and Arjun (*Terminalia arjuna*). Here, two broad–leaved tree species, namely, *Shorea robusta* and *Madhuca indica* were selected for measurement of different foliar parameters. These tree species are big and high enough, so it was difficult to collect leaves from the upper layers of a tree crown. Therefore, the lower branches were selected for collection of leaf samples. Almost similar branch locations (at a height of 2 – 4 m) were selected among all the study sites.

2.4. Study of ambient air quality

SPM, dustfall and gaseous pollutants were measured ten times every season (summer, rainy season and winter) on weekly basis, on Sunday, from each sampling plot. At Lalpahari, SPM and dustfall in glass jar were recorded in a site selected among a small sub–cluster of 9 crusher units (about 15 to 25 meters away from the units concerned, i.e., from an average distance of 20 meters) as shown in Figure 1c.

Measurement of SPM. High volume samplers (Envirotech APM 415) were used to quantify the SPM in the air. In these samplers, airborne particulates are measured by passing air at a high flow rate of 1.1 – 1.7 m^3/minute through a high efficiency filter paper which retains the particles. The instrument measures the volume of air sampled, while the amount of particulates collected is determined by measuring the change of weight of the filter paper as a consequence of the sampling. The following calculation was used to measure concentration of SPM in the ambient air (Jalees and Dave, 1979; IM, 2005):

$$SPM\ Concentration\ (\mu g/m^3) = \frac{W_2 - W_1}{[(Q_1+Q_2)/2]\ x\ Time} x 10^6 \qquad (1)$$

where, W_2 is the weight of the filter paper after sampling (g), W_1 is the weight of the fresh filter paper (g), Q_1 is the initial sampling rate (m^3/minute), Q_2 is the final sampling rate (m^3/minute).

The samplers were placed on the rooftops of single–storey buildings (offices or quarters). It is customary to operate the sampler not more than 15 meters above the ground level having no obstruction in front to prevent free flow of air. One sampler was used per site at a time. The sampler was operated during daytime for 8 hours. The average sampling flow rate, $(Q_1+ Q_2)/ 2$, was 1.7 m^3/minute. Whatman GF/A grade filter papers were used. The filters were kept in an oven overnight for 16 hours at 25 ˚C temperature and below 50% humidity each time prior to weighing.

Measurement of dustfall. Amount of dustfall on the leaf surface of the selected tree species was measured. Particular leaves were marked in the lower branches of marked trees. Surfaces were cleaned gently and repeatedly with the help of wet cotton. The leaves were plucked after seven days and each of them was kept in pre–weighed (*b*) self–sealing poly–packs. The weight of the leaf along with pack was recorded (*a*). Then the leaf was gently washed in flow of tap water in the laboratory and then dried in room temperature. Then the weight of the clean leaf was recorded (*c*). The weight of dust deposited on the leaf surface in seven days was calculated as: [*a*–(*b*+*c*)]. Leaf surface area was measured with the help of a Leaf Area Meter (Systronics, model–211). The dustiness of the leaf surface was expressed as g/m^2 month.

Dustfall was also measured weekly, ten times in a season with the help of glass jar kept on rooftop. However, dustfall in glass jar was not measured in the rainy season. The total dustfall was expressed as g/m^2 month by using the following formula (Rao, 1971):

$$PM\ Dustfall\ (g/m^2\ month) = \frac{PM\ mass\ (g)\ x\ 30}{AC\ x\ n} \qquad (2)$$

where AC (m^2) is the cross sectional area (πr^2) of the jar mouth, 30 is the average number of days per month, and n is the number of days for which the jar was exposed.

Measurement of gaseous pollutants. CO, NO, NO_2, SO_2 and O_3 were measured in ppm (parts per million) in the selected sites using Yes Plus Air Quality Monitor (YES Environment Technologies Inc., Canada). The instrument is equipped with one micro-processor–controlled circuit board with built–in temperature and humidity sensors and combined with some sensors which provide a comprehensive indication of gaseous air quality. It has an internal sample pump for active sampling of air. This portable digital instrument is allowed to worm up for 20 minutes (for maximum accuracy of reading) before recording the actual reading.

2.5. Foliar measurements

Some biochemical and morphological aspects in the foliage of selected tree species were taken into consideration.

Collection of leaf samples. Five trees of each selected species of equal girth were marked for sampling of leaves. Samplings per site were done twice in each season. The **"**5^{th} leaf" counting from the apical bud in each small lower branch was collected in every case for studying different biochemical parameters of foliar tissues. Freshly collected leaves from BWLS were brought to the laboratory (situated by the side of BWLS) for the investigations, while in case of Lalpahari, freshly collected leaves were first kept in self–sealing poly–packs, preserved in an ice can and then brought to the laboratory for the investigations.

Measurement of biochemical parameters. Measurements of the following parameters in the leaf tissue were done: (1) Chlorophyll a and b: following method designed by Arnon (1949); foliar chlorophyll content is expressed in mg/g tissue; (2) Total carbohydrate: following Anthrone method designed by Hedge and Hofreiter (1962); foliar carbohydrate content is expressed in µg/100 mg tissue; (3) Protein: following Lowry method designed by Lowry et al. (1951); foliar protein content is expressed in mg/g tissue.

Study of foliar morphology. (a) With the help of naked eye, magnifying glass and compound microscope (as was required) various foliar anomalies were detected. For this purpose, 10 small branches were observed keenly at random in each tree species at each selected site during each of the three principal seasons. Leaf area damage (measured in cm^2 out of total leaf area) was calculated in terms of percentage. The measurement was done with the help of a Leaf Area Meter. Percentage count of damaged leaves having one or more degenerative symptoms (out of total leaves counted) was calculated. Damaged and dead vegetative buds (both apical and lateral in each branch) were also counted and the result is given out of a total 100 random counts in each case. (b) Scanning Electron Microscopic (SEM) studies of leaf samples were done. Leaves of almost equal maturity were brought to the laboratory in ice can, washed thoroughly and repeatedly in gentle flow of tap water, areas having no apparent injury symptoms were cut into 0.3 cm^2 pieces, fixed in 2.5% gluteraldehyde, dehydrated in ethanol series and then both surfaces were examined and photographed under SEM (FEI Quanta 200 MK2).

2.6. Statistical analyses

Student's t–test for comparison of air pollution status and foliar biochemical parameters between the two forests (control and polluted), between seasons and between polluted sites at Lalpahari with increasing distance from the source of pollution using S–plus package by Tibco Software (Stable Release 8.1.1/Nov.14, 2008) was done. A correlation was also done in between ambient air quality and foliar parameters of selected plant species in highly polluted Lalpahari site 1. For all primary data: n = 10, degrees of freedom = 18, significance was tested at 5% level of significance (i.e., $p = 0.05$). We considered drawing the graphs with the absolute or mod values of the observed t statistic. We have calculated t–statistic corresponding to each of the values of the observed correlation by the formula $t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}}$ where, t = calculated t value, r = correlation value and n = sample size on the basis of the observed t value. We have judged the significance of the correlation coefficient. We applied "Bonferroni correction" to adjust p–levels to make sure that these levels were not deflated artificially. However, we did not test for inter–species differences, as our main aim was to examine the effect of air pollutants (originating from stone crushing industrial sector) on foliar parameters, irrespective of species.

3. Results and Discussion

3.1. SPM

The air quality parameters recorded at Baromasia, Lalpahari provided an idea about how the air becomes dusty and suffocative during daytime when almost all the crusher units run simultaneously along the roadways. Crusher dusts assumed a cloud–like appearance throughout the area including the adjacent forest sites. Transparency of the air is greatly lost. The amount of stone dust suspended in the air at crusher sites was 4 – 7 times higher than the prescribed norm in India. The SPM should not exceed the level of 500 µg/m^3 in industrial areas according to National Ambient Air Quality Standards (NAAQS) provided by the Central Pollution Control Board (CPCB, 1995). According to Notification regarding SPM of Stone Crushing Unit, the Environmental (Protection) Rules, 1986 (MoEF Notification, 1986), the SPM value of a unit located in a cluster measured from a distance of 40 meters should be less than 600 µg/m^3. However, in our study the SPM was measured from an average distance of 20 meters from the crusher units concerned as per the practical situation. It was noted that the SPM was highest in winter and lowest during rainy season. SPM recorded at Lalpahari in summer, rainy season and winter were 20, 18 and 23 times greater respectively than in control site and proved to be quite significant (Figure 2 and Figure 3, upper). The Mean (n = 10) values recorded at Lalpahari in summer, rainy season and winter were 3 490, 2 530 and 4 264 µg/m^3 respectively in comparison to the same values recorded at BWLS, being 167, 137 and 183 µg/m^3 respectively. Das and Nandi (2002) recorded pre–monsoon and post–monsoon maximum concentration of SPM among a cluster of crushers in this area which were 3 204 and 4 354 µg/m^3 respectively. Based on ambient air quality monitoring study carried out in a few units for generating information on the existing level of emissions from uncontrolled or partially controlled stone crushing operations, Patil (2001) concluded that the SPM in the ambient air at crusher sites ranged from 2 340 to 24 000 µg/m^3 which is substantially higher than the desirable limits.

3.2. Dustfall

The dustfall in glass jar was found to be higher in summer than in winter at Lalpahari. The value (Lalpahari) in summer exceeded 16 times that of control (BWLS). Dust deposition on foliar surface was minimum in rainy season and maximum in summer. Quantity of dustfall in all three sites of Lalpahari in three principal seasons exceeded that in BWLS. About 14 times higher dustfall observed on *Madhuca indica* leaf surface in site 1 as compared to control site during summer. Difference in dustfall in glass jar in between polluted and the control site was significant (Figure 2). Regarding foliar dust fall, the absolute (mod) values of observed t statistic value were greater than the tabulated value in all cases except in testing of dustfall data on *Madhuca indica* leaf surface in rainy season between BWLS and Lalpahari site 3. It was, therefore, established that there was a significant difference in foliar dustfall in between the two forests. A thick coat of dust was always found on leaf surface in site 1 of Lalpahari forest. Spatial and season–wise significances of foliar dustfall are represented in Table 1 and Figure 3 (lower) respectively. Testing of all these data was significant at 5% level. In terms of dust–capturing capacity these two species proved to be quite efficient. Being dorsiventral leaves the adaxial (dorsal) surfaces received more dust than the abaxial (ventral) ones. *Shorea robusta* leaf is slightly different from *Madhuca indica* leaf regarding the surface texture, the former being smooth but the latter is velvet–like in appearance at least in its early stages of growth. Thus, in general, Mohul leaf received more dust than Sal, which was reflected from the study in rainy season and winter. However, many factors including wind speed and precipitation, may influence particulate deposition (Farmer, 2002). Pyatt and Haywood (1989) examined the effects of leaf characteristics in terms of shape, surface area, presentation and

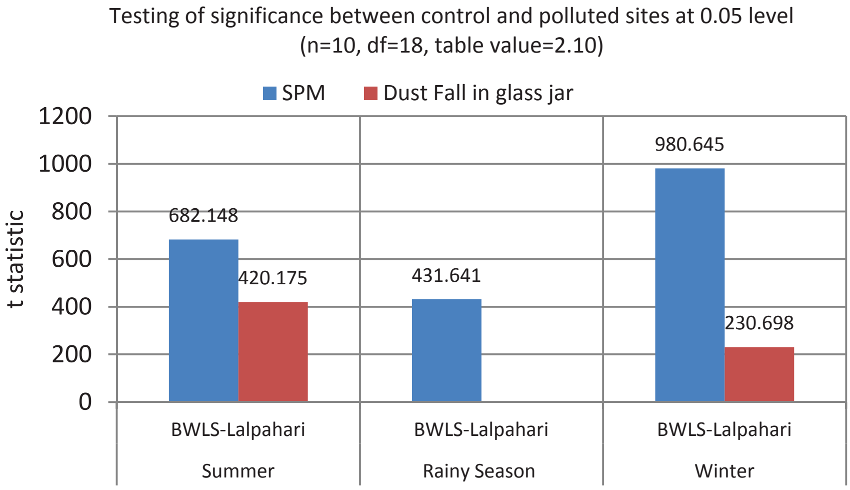


Figure 2. *Testing of significance of SPM and dustfall in glass jar in between BWLS and Lalpahari. All are significant (mod values of observed t statistic are greater than table value). Dustfall in glass jar in rainy season was not measured.*

cuticular texture on particulate accumulation. Beckett et al. (2000) quantified the effectiveness of five tree species in capturing pollutant particles. They found that trees having finer, more complex structure of the foliage possessed greater effectiveness at capturing particles. Prajapati and Tripathi (2008) studied dust interception efficiency of some selected tree species and found that all species have maximum dust deposition in winter followed by summer and rainy season.

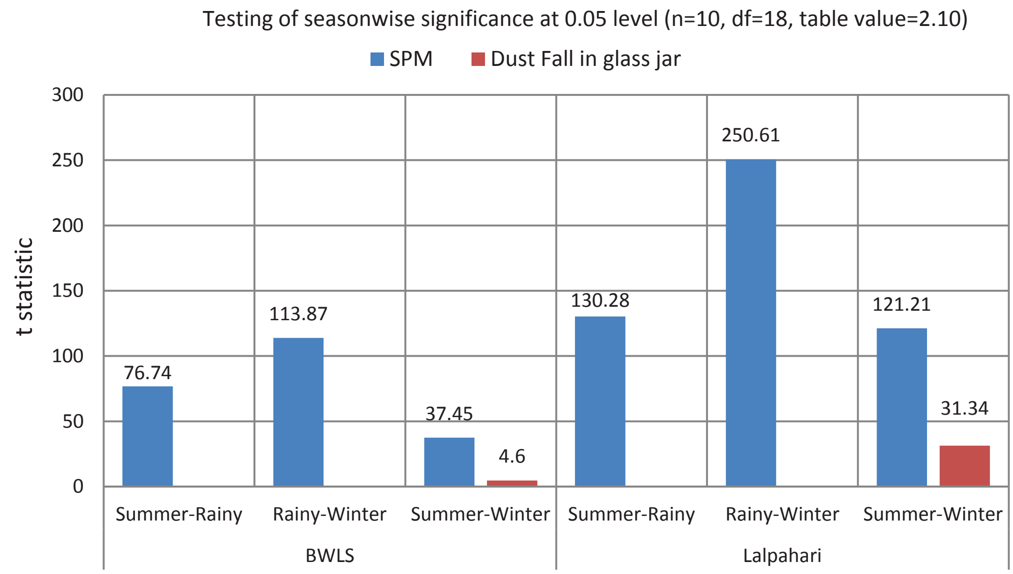
3.3. Gaseous pollutants

Mean±SD data (in ppm) of the pollutant gases available in ambient air at BWLS and Lalpahari were analyzed statistically. CO in winter and NO_2, SO_2 and O_3 concentrations in rainy season were "below detection limit" (BDL) of the Yes Plus Air Quality Monitor. Otherwise, the absolute (mod) values of observed t–statistic were greater than the tabulated values at 5% level in all cases except in testing of O_3 data in summer and winter between BWLS and Lalpahari site 3. It was, therefore, established that there was a significant difference in gaseous air pollution, in most cases, between the two forests. Study of spatial significance of gaseous pollutants at Lalpahari is presented in Table 2. The stone crushers do not release toxic gases unless they are operated by fossil fuels. In Baromasia, crusher units are primarily operated by electricity. Therefore, it is assumed that the toxic gases in the ambient air like CO, NO, NO_2 and SO_2 are result of vehicular emissions.

Table 1. *Student's t-test (spatial) of foliar dustfall data (on leaf surface) in between polluted sites at 5% level (n = 10, df = 18, p = 0.05, table value = 2.10)*

Tree Name/Season	Testing between Lalpahari sites	Mean 1	SD 1	Mean 2	SD 2	Combined s	t statistic	conclusion
S. robusta/Sum	Site 1-2	195.733	52.9	114.408	38.206	46.142	88.125	S
	Site 2-3	114.408	38.206	30.217	4.623	27.213	154.69	S
	Site 1-3	195.733	52.9	30.217	4.623	37.549	220.403	S
S. robusta/Rain	Site 1-2	56.788	10.381	30.346	7.632	9.111	145.114	S
	Site 2-3	30.346	7.632	20.92	8.986	8.337	56.534	S
	Site 1-3	56.788	10.381	20.92	8.986	9.709	184.723	S
S. robusta/Win	Site 1-2	163.556	24.442	78.524	15.84	20.595	206.437	S
	Site 2-3	78.524	15.84	32.778	2.888	11.385	200.901	S
	Site 1-3	163.556	24.442	32.778	2.888	17.403	375.727	S
M. indica/Sum	Site 1-2	175.916	29.188	102.71	14.501	23.046	158.827	S
	Site 2-3	102.71	14.501	60.854	4.057	10.647	196.553	S
	Site 1-3	175.916	29.188	60.854	4.057	20.837	276.094	S
M. indica/Rain	Site 1-2	91.634	22.958	57.651	12.059	18.337	92.663	S
	Site 2-3	57.651	12.059	10.292	1.869	8.629	274.424	S
	Site 1-3	91.634	22.958	10.292	1.869	16.287	249.707	S
M. indica/Win	Site 1-2	172.61	54.658	93.817	35.537	46.1	85.459	S
	Site 2-3	93.817	35.537	39.389	15.337	27.369	99.434	S
	Site 1-3	172.61	54.658	39.389	15.337	40.142	165.938	S

Sum=summer, Rain=rainy season, Win=winter, SD=standard deviation, df=degrees of freedom, S=significant



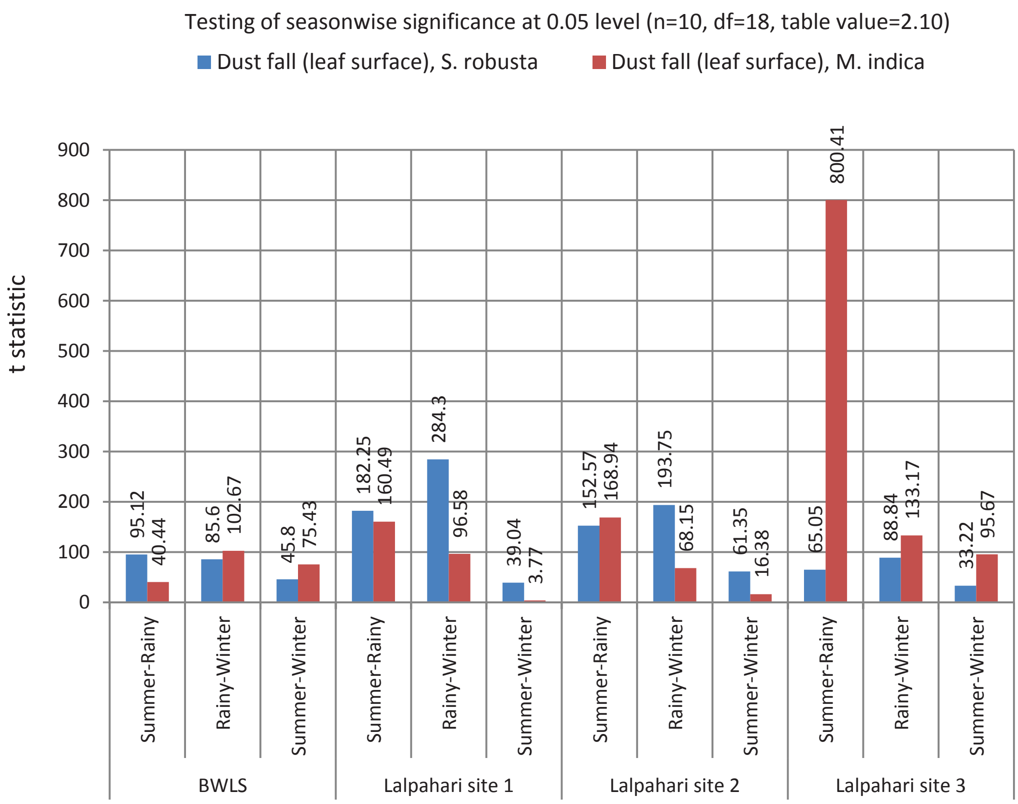


Figure 3. *Testing of season-wise significance of SPM and dustfall in glass jar (upper) and foliar dustfall in S. robusta and M. indica (lower). All are significant (mod values of observed t statistic are greater than table value).*

3.4. Biochemical parameters

Results of the present study showed the reduction in foliar chlorophyll and carbohydrate content in polluted sites which indicated that the process of manufacturing food by these trees was reduced as a result of air pollution. In both tree species concerned, foliar protein content was also found to be reduced in the highly polluted site as compared to the control. Testing the data of foliar chlorophyll, total carbohydrate and protein in both the trees in between control and polluted sites proved to be mostly significant. The season–wise significance and spatial significance (in between polluted sites) of foliar parameters are shown in Figures 4 and 5 respectively.

Singh and Rao (1980) found incidence of foliar injury symptoms and decrease in concentration of chlorophyll in plants in the vicinity of cement factories. Prasad and Rao (1981) found decrease in protein and carbohydrate content in petroleum–coke treated plants. In their experiment, chlorophyll initially increased but later on decreased. Agarwal and Agarwal (1989) found reduction in photosynthetic pigment in *Mangifera indica* around a thermal power plant. Whereas Pandey and Nand (1995) assessed the effect of stone crusher dust on grain characteristics of maize and found lower values of protein as compared to control. Trivedi and Singh (1995) noticed significant reduction in protein content in a few plants as a result of fly ash particulates. Williams and Banerjee (1995) found considerable reduction in chlorophyll and protein content but an increase in sugar content in leaves of *Mangifera indica* and *Shorea robusta* affected by emissions from a nearby thermal power plant. Marked alterations in photosynthetic pigments and protein content in foliar tissues as a result of auto–exhaust pollution were noticed by Verma and Singh (2006). Similarly, decrease in chlorophyll content as a result of increased dust deposition was noticed by Prajapati and Tripathi (2008). Most

Table 2. *Student's t test (spatial) of gaseous pollutant data in between polluted sites at 5% level (n = 10, df = 18, p = 0.05, table value = 2.10)*

Parameter/Season	Testing between Lalpahari Sites	Mean 1	SD 1	Mean 2	SD 2	combined s	t statistic	conclusion
CO/Sum	Site 1-2	2.963	0.534	3.133	0.749	0.650	-13.068	S
	Site 2-3	3.133	0.749	1.904	0.426	0.609	100.855	S
	Site 1-3	2.963	0.534	1.904	0.426	0.483	109.621	S
CO/Rain	Site 1-2	6.829	1.11	4.847	0.226	0.801	123.722	S
	Site 2-3	4.847	0.226	3.972	0.211	0.219	200.111	S
	Site 1-3	6.829	1.11	3.972	0.211	0.799	178.799	S
CO/Win	Site 1-2	BDL	-	BDL	-	-	-	
	Site 2-3	BDL	-	BDL	-	-	-	
	Site 1-3	BDL	-	BDL	-	-	-	
NO/Sum	Site 1-2	2.545	0.661	1.181	0.163	0.482	141.67	S
	Site 2-3	1.181	0.163	1.455	0.397	0.303	-45.146	S
	Site 1-3	2.545	0.661	1.455	0.397	0.545	99.96	S
NO/Rain	Site 1-2	0.078	0.016	0.079	0.017	0.017	-3.029	S
	Site 2-3	0.079	0.017	0.074	0.007	0.013	19.231	S
	Site 1-3	0.078	0.016	0.074	0.007	0.012	16.196	S
NO/Win	Site 1-2	0.254	0.094	0.297	0.062	0.08	-27.002	S
	Site 2-3	0.297	0.062	0.301	0.094	0.08	-2.512	S
	Site 1-3	0.254	0.094	0.301	0.094	0.094	-25	S
O_3/Sum	Site 1-2	0.017	0.007	0.017	0.007	0.007	0	NS
	Site 2-3	0.017	0.007	0.013	0.005	0.006	32.88	S
	Site 1-3	0.017	0.007	0.013	0.005	0.006	32.88	S
O_3/Rain	Site 1-2	BDL	-	BDL	-	-	-	
	Site 2-3	BDL	-	BDL	-	-	-	
	Site 1-3	BDL	-	BDL	-	-	-	
O_3/Win	Site 1-2	0.03	0.007	0.03	0.005	0.006	0	NS
	Site 2-3	0.03	0.005	0.031	0.006	0.006	-9.054	S
	Site 1-3	0.03	0.007	0.031	0.006	0.007	-7.67	S
SO_2/Sum	Site 1-2	0.01	0.002	0.008	0.002	0.002	50	S
	Site 2-3	0.008	0.002	0.006	0.001	0.002	63.246	S
	Site 1-3	0.01	0.002	0.006	0.001	0.002	126.491	S
SO_2/Rain	Site 1-2	BDL	-	BDL	-	-	-	
	Site 2-3	BDL	-	BDL	-	-	-	
	Site 1-3	BDL	-	BDL	-	-	-	
SO_2/Win	Site 1-2	0.011	0.002	0.007	0.002	0.002	100	S
	Site 2-3	0.007	0.002	0.006	0.001	0.002	31.623	S
	Site 1-3	0.011	0.002	0.006	0.001	0.002	158.114	S
NO_2/Sum	Site 1-2	0.029	0.004	0.025	0.003	0.004	56.569	S
	Site 2-3	0.025	0.003	0.021	0.003	0.003	66.667	S
	Site 1-3	0.029	0.004	0.021	0.003	0.004	113.137	S
NO_2/Rain	Site 1-2	BDL	-	BDL	-	-	-	
	Site 2-3	BDL	-	BDL	-	-	-	
	Site 1-3	BDL	-	BDL	-	-	-	
NO_2/Win	Site 1-2	0.027	0.005	0.021	0.003	0.004	72.761	S
	Site 2-3	0.021	0.003	0.015	0.003	0.003	100	S
	Site 1-3	0.027	0.005	0.015	0.003	0.004	145.521	S

Sum=summer, Rain=rainy season, Win=winter, SD=standard deviation, df=degrees of freedom, BDL=below detectable limit, S=significant, NS=non-significant

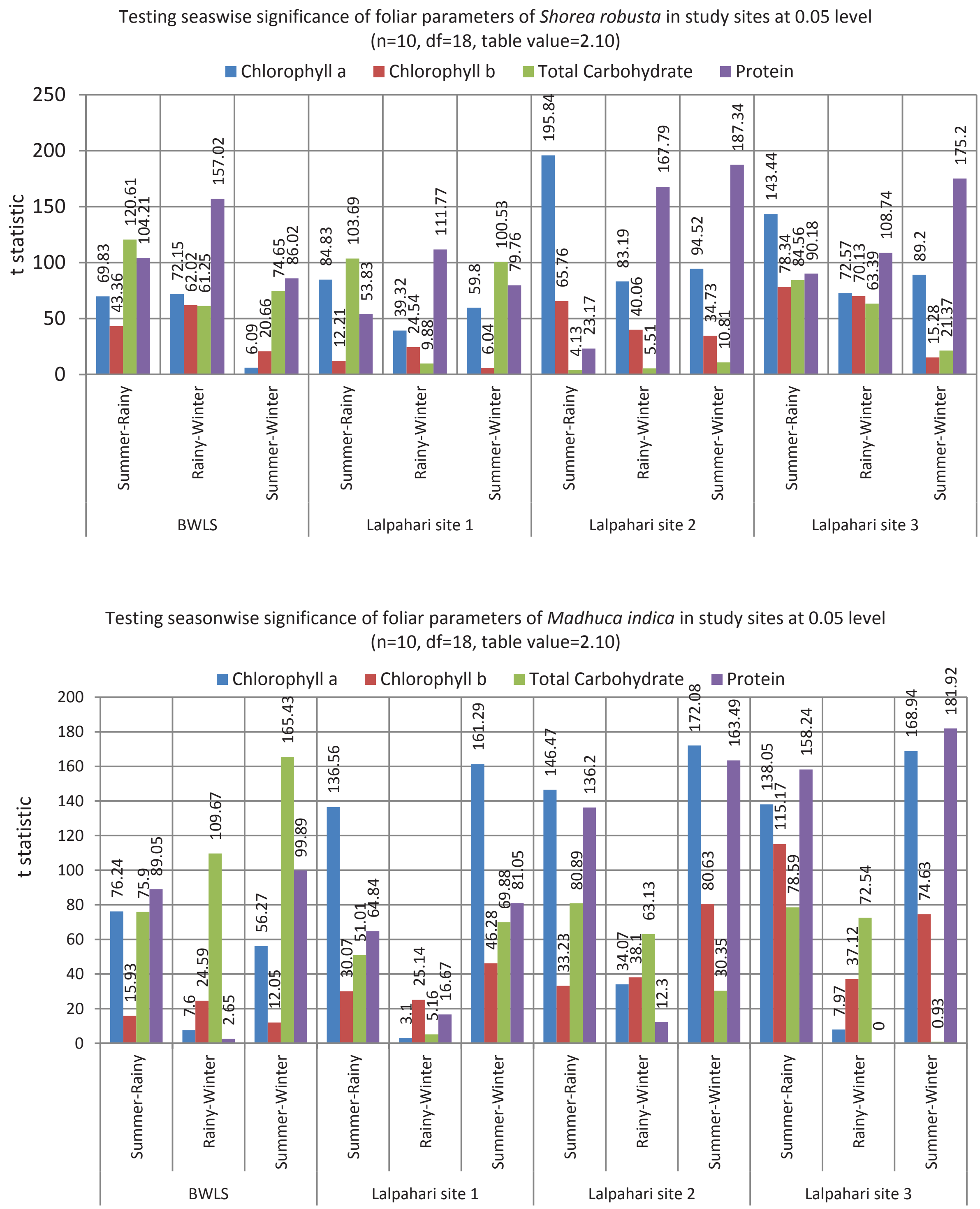
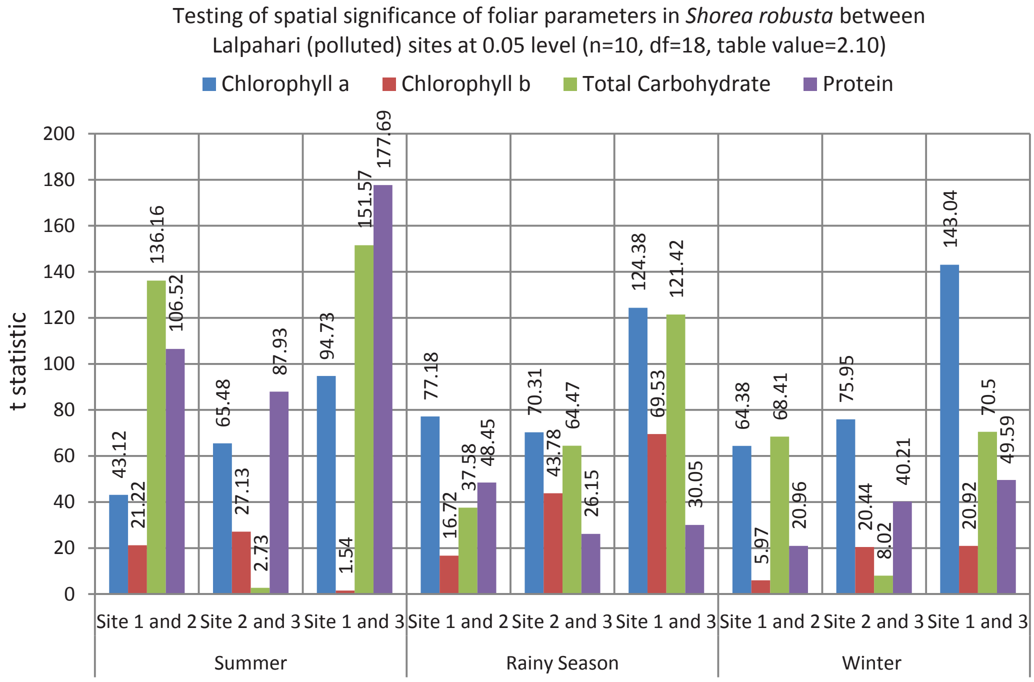


Figure 4. *Testing of season-wise significance of foliar biochemical parameters in S. robusta (upper) and M. indica (lower). All are significant (mod values of observed t statistic are greater than table value) except two i.e., between rainy season and winter in case of protein and between summer and winter in case of total carbohydrate both in Lalpahari site 3 in M. indica.*

of the above–mentioned studies showed reduction in foliar pigment, carbohydrate and protein content as a result of particulate pollution from various sources. Though stone dust is the major pollutant present in the air at Lalpahari forest, various gaseous pollutants were also detected in the ambient air. Therefore, any change in the normal level of biochemical parameters like total carbohydrate and protein in foliar tissues might be associated with air pollution caused by the stone crushing and associated activities at Lalpahari. Correlations have been done in between ambient air quality status and foliar parameters of selected plant species for Lalpahari site 1 and are summarized in Table 3.

3.5. Leaf injury symptoms

Macro–morphology. Detected list of foliar anomalies and injury symptoms promoted by stone dust in our study is long, especially at site 1 of Lalpahari forest: tissue necrosis (both marginal and



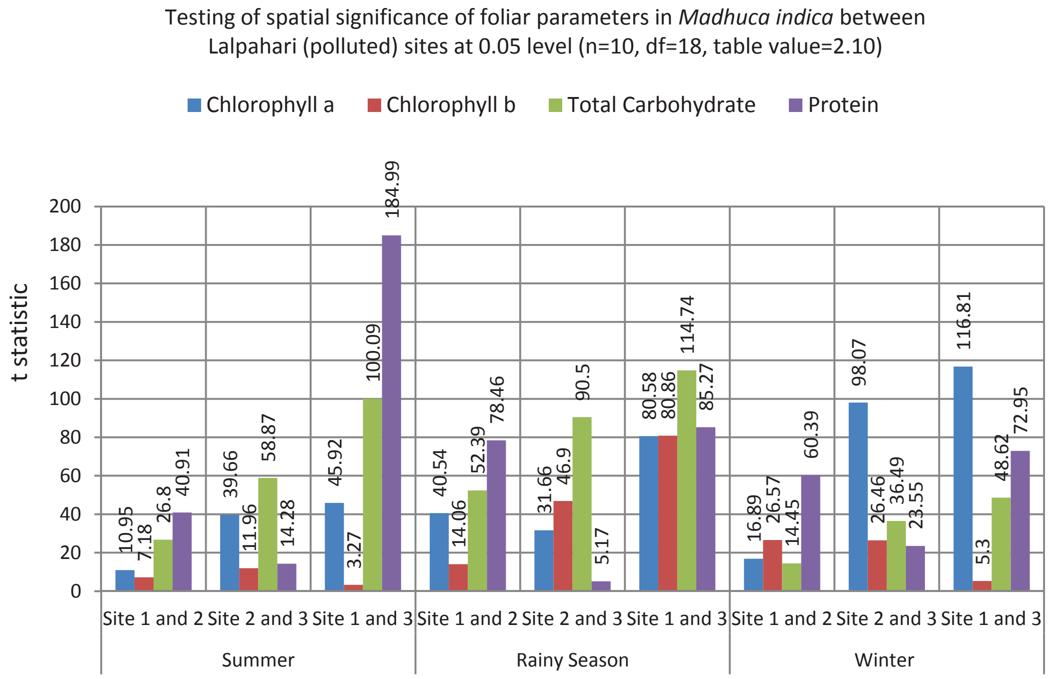


Figure 5. *Testing of spatial significance of foliar biochemical parameters in S. robusta (upper) and M. indica (lower) at Lalpahari study sites. All are significant (mod values of observed t statistic are greater than table value) except one i.e. between site 1 and site 3 in S. robusta in summer in case of Chlorophyll b.*

interveinal), brown patches, yellow patches, black spots, surface lesion, curling, insect eating, parasitic galls, growth retardation, cement–like surface with general hardness, dryness, lack of green pigments (paleness), lack of brightness and, in extreme cases, death of leaves (Figure 6). It is evident from Table 4 that injury symptoms are predominant throughout the year especially during winter. Figure 7 represents the extent of foliar injury symptoms in Lalpahari site 1 during winter.

This could be due to the heavy amount of SPM present in ambient air and subsequent deposition on leaves in the polluted site. Greater percentage of leaf area damage was noted for *M. indica*, suggesting it is more susceptible to air pollution. Injury to various external parts like crown, leaves, buds and branches of mango and lemon trees as a result of coal dust pollution was studied by Rao (1971). Pawar et al. (1982) compared foliar injury

Table 3. *Summary of correlations established between ambient air quality and foliar parameters at Lalpahari site1 in S. robusta and M. indica*

Shorea robusta			***Madhuca indica***		
Air Quality Parameter	**Season**	**Foliar Parameter**	**Air Quality Parameter**	**Season**	**Foliar Parameter**
SPM	Summer	-	SPM	Summer	[a] Chl b, [b] Carbohydrate
	Rainy	[a] Chl a, [a] Chl b, [a] Carbohydrate		Rainy	[a] Carbohydrate, [a] Protein
	Winter	-		Winter	-
CO	Summer	-	CO	Summer	[b] Chl a
	Rainy	[a] Chl a, [a] Chl b, [a] Carbohydrate		Rainy	[a] Carbohydrate, [a] Protein
	Winter	-		Winter	-
NO	Summer	-	NO	Summer	-
	Rainy	-		Rainy	-
	Winter	[b] Carbohydrate, [b] Protein		Winter	[b] Chl a, [b] Chl b, [b] Carbohydrate
NO_2	Summer	[a] Chl a, [a] Chl b, [a] Carbohydrate	NO_2	Summer	[b] Chl a, [a] Carbohydrate
	Rainy	-		Rainy	-
	Winter	-		Winter	[b] Chl a, [b] Chl b
SO_2	Summer	[a] Chl b	SO_2	Summer	[b] Chl a, [a] Carbohydrate
	Rainy	-		Rainy	-
	Winter	[a] Chl b		Winter	[a] Chl a, [a] Chl b
O_3	Summer	[a] Chl b, [a] Protein	O_3	Summer	[b] Carbohydrate, [a] Protein
	Rainy	-		Rainy	-
	Winter	[a] Chl b		Winter	[a] Chl a, [a] Chl b, [a] Carbohydrate

Chl=Chlorophyll, Rainy=rainy season
[a] 5% level (p=0.05), [b] 10% level (p=0.1)

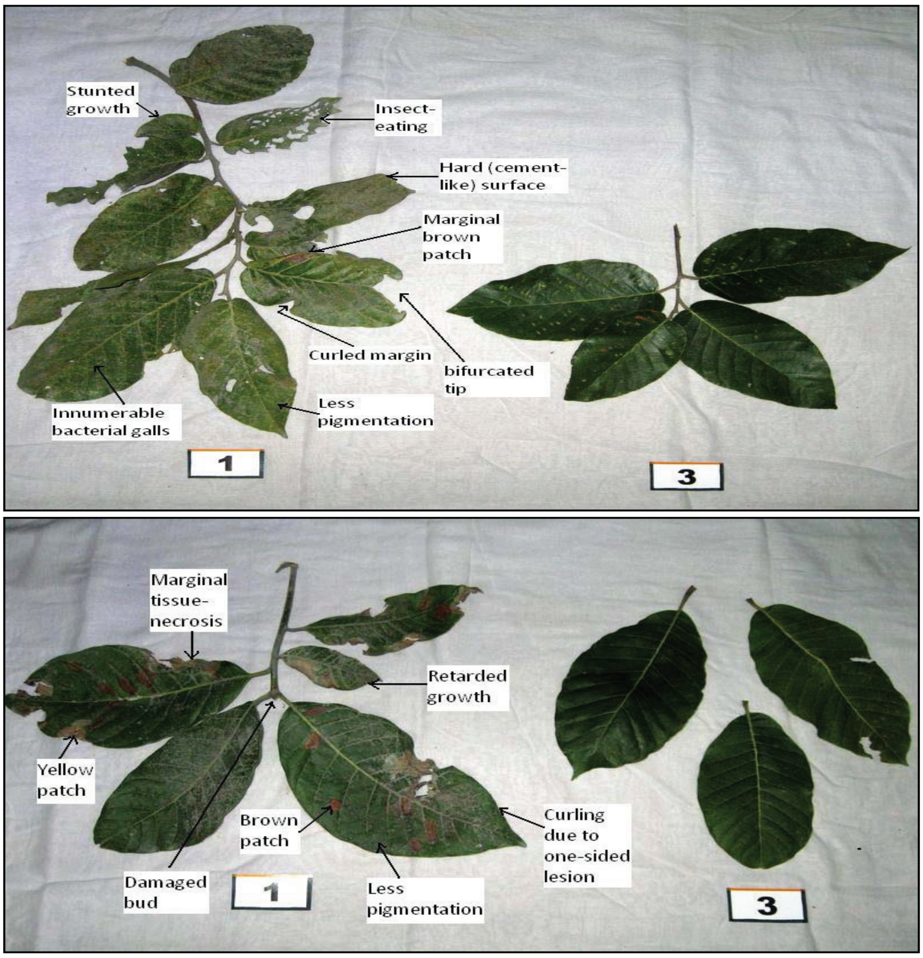


Figure 6. *Foliar injury symptoms of freshly collected leaves of Shorea robusta (Top) and Madhuca indica (Bottom) at site 1 of Lalpahari forest in comparison to those of site 3.*

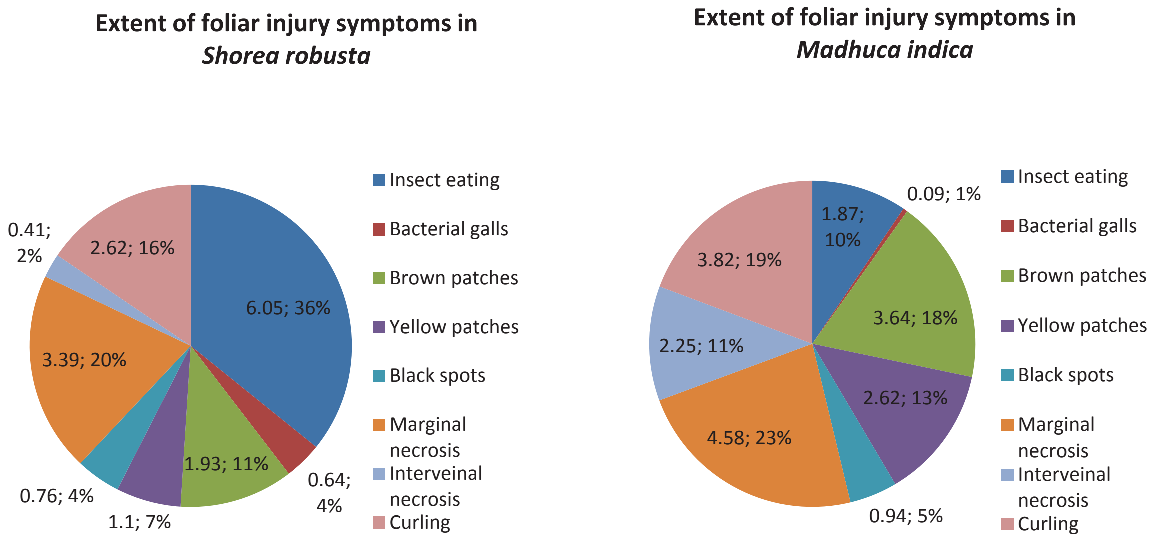


Figure 7. *Percentage leaf area covered by foliar injury symptoms in pie chart in Shorea robusta and Madhuca indica in winter at site 1 of Lalpahari forest as per Table 4.*

symptoms and weight (both fresh and dry) of leaves of *Abelmoschus esculantus* sprayed with cement dust, coal dust and fly ash at 2 g/m^2 day. They found chlorotic injury symptoms on cement and coal dust treated leaves. Foliar weight showed maximum reduction in case of cement dust–treated plants. Singh and Rao (1980) found incidence of foliar injury symptoms in plants in the vicinity of cement factories. Alteration of leaf morphology and anatomy as a result of air pollution were also studied by Prasad and Rao (1981), Agarwal and Agarwal (1989), Verma and Singh (2006) and Rai et al. (2010).

Micro–morphology. Microscopic examination of peeled leaf surface from polluted sites revealed that stomatal apertures were heavily blocked by dust particles, a fact that could directly affect respiration, photosynthesis and transpiration, and could indirectly affect ascent of sap in plants. Although apparently visible leaf injury symptoms are many, the portions of leaf surface having no such apparent symptoms were examined under SEM to assess any alteration in cuticular structures and stomatal configuration. Main findings noted were: (a) Damage of cuticle and epicuticular structure, (b) Damage of oil glands, (c) Damage of guard cells, (d) Reduction in stomatal size and (e) Thick embedding of stone dust on foliar surface (even after thorough and repeated washing). Some of these symptoms are evident from electron micrograph of *S. robusta* leaf collected from Lalpahari site 1 (Figure 8). It is also evident from electron micrograph of *M. indica* leaf collected from Lalpahari site 1 that wax layer over the cuticle is thin, damaged and discontinuous to a great extent in comparison to that of control which is spread thickly and evenly throughout the foliar surface (Figure 9). The surface texture of leaves is greatly altered as a result of pollution load. In control site, the cuticle is smooth in Sal leaves whereas this is granular, disrupted and irregular in polluted site 1. Verma and Singh (2006) observed distorted wax, damaged stomata and disturbances in the ornamentation of cuticles in their SEM studies of leaf surface exposed to auto pollution.

Table 4. *Intensity and extent of foliar damage promoted by air pollutants in Lalpahari forest*

Intensity and extent of damage	Season	BWLS		Lalpahari					
				Site1		Site2		Site3	
		S. robusta	*M. indica*	*S. robusta*	*M. indica*	*S. robusta*	*M. indica*	*S. robusta*	*M. indica*
% leaf area damage (average of 20 observations)	Summer	5.58	6.86	16.53	18.36	9.11	10.1	5.03	5.4
	Rainy	1.72	3.9	6.8	9.9	4.68	4.8	3.3	3.7
	Winter	4.8	7.53	16.9	19.81	11.51	11.89	6.21	9.13
% of leaves counted showing one or more injury symptoms	Summer	27.35	13.64	55.17	41.82	25.74	17.31	29.59	13.59
	Rainy	15.84	8.74	46.15	45.65	24.49	20.69	28.85	21.43
	Winter	38.33	36.54	69.35	55.17	55.77	22.22	37.5	15.94
% vegetative bud damage or death (out of 100 count each type)	Summer	1	0	16	23	11	7	4	3
	Rainy	0	0	3	5	2	2	0	1
	Winter	3	4	21	19	14	22	2	3

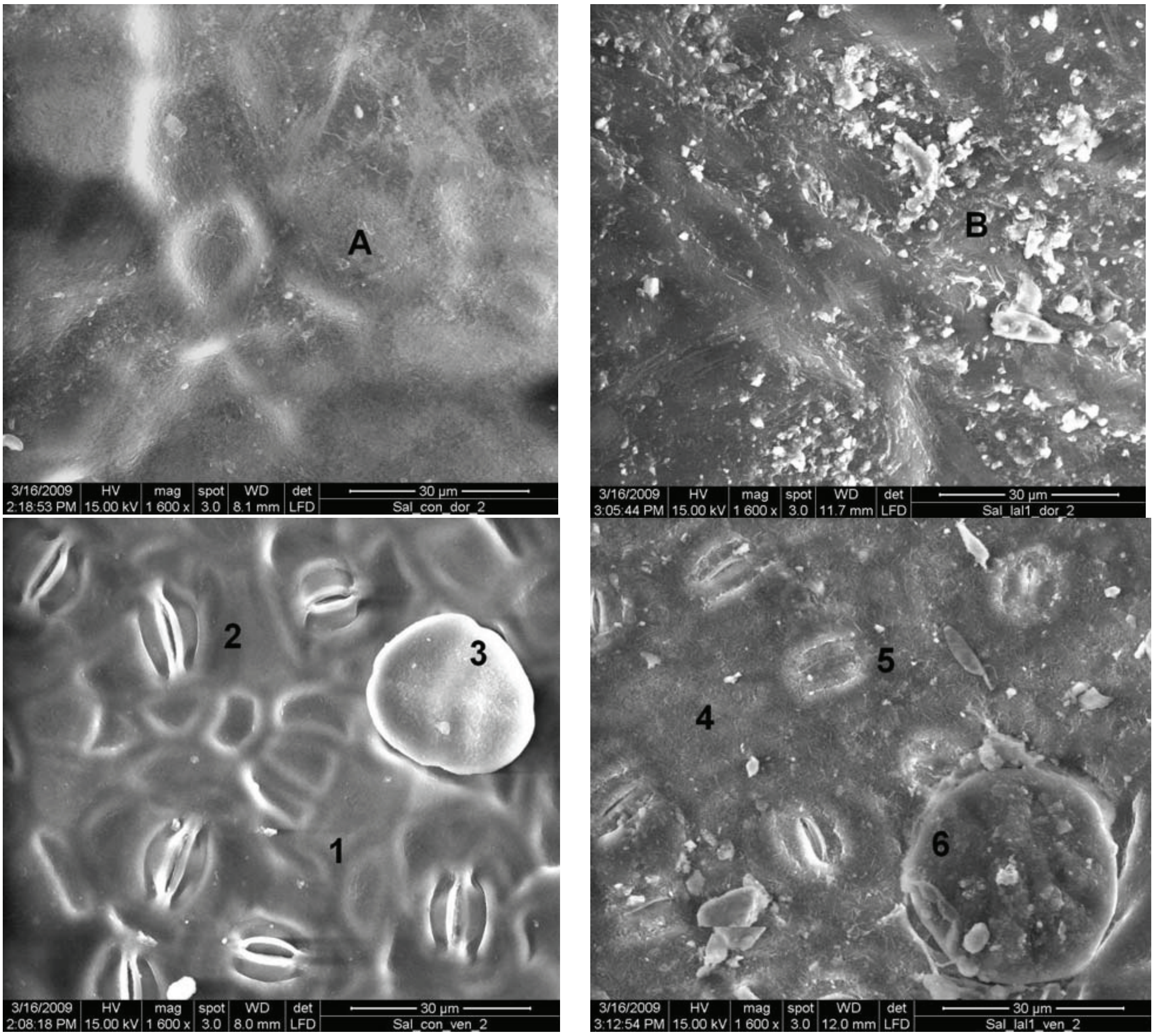


Figure 8. *Scanning electron micrographs of Shorea robusta leaves (magnification: 1600X): upper left- dorsal surface (control), A- scanty dust deposition; upper right- dorsal surface (polluted site 1), B- Plenty dust deposition even after thorough washing; lower left- ventral surface (control), 1, 2 and 3- healthy cuticle, stomata and oil gland respectively; lower right- ventral surface (polluted site 1), 4, 5 and 6- distorted cuticle, stomata and oil gland respectively.*

4. Conclusions

Trees are planted around industries and along roadsides to absorb pollutants in air including particulate matter so as to reduce air pollution. Although trees possess some stress–tolerant mechanisms within them, considerable amount of damage is caused to them which are evident from this study showing physical damage of leaves as a result of dust deposition, inhibition of photosynthetic activities and protein synthesis as well as susceptibility to injuries caused by microorganisms and insects. Dustfall depends on SPM in the ambient air. Both the parameters (SPM and dust fall) contributed significantly to the degraded air quality at Lalpahari. These two tree species are thriving with hardship in this polluted environment. There is a spatial influence on effects of pollutants observed; so the trees at the site closest to the crushing activities had the greatest effects as compared to others. Some regulations like implementation of dust containment and suppression measures must be imparted on this vital industrial sector for better survival of plants at Lalpahari forest.

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Supporting Material Available

Correlation between ambient air quality and foliar parameters in *S. robusta* at highly polluted Lalpahari site 1 in summer, rainy season and winter (Figure S1), Correlation between ambient air quality and foliar parameters in *M. indica* at highly polluted Lalpahari site 1 in summer, rainy season and winter (Figure S2). This information is available free of charge via the Internet at http://www.atmospolres.com.

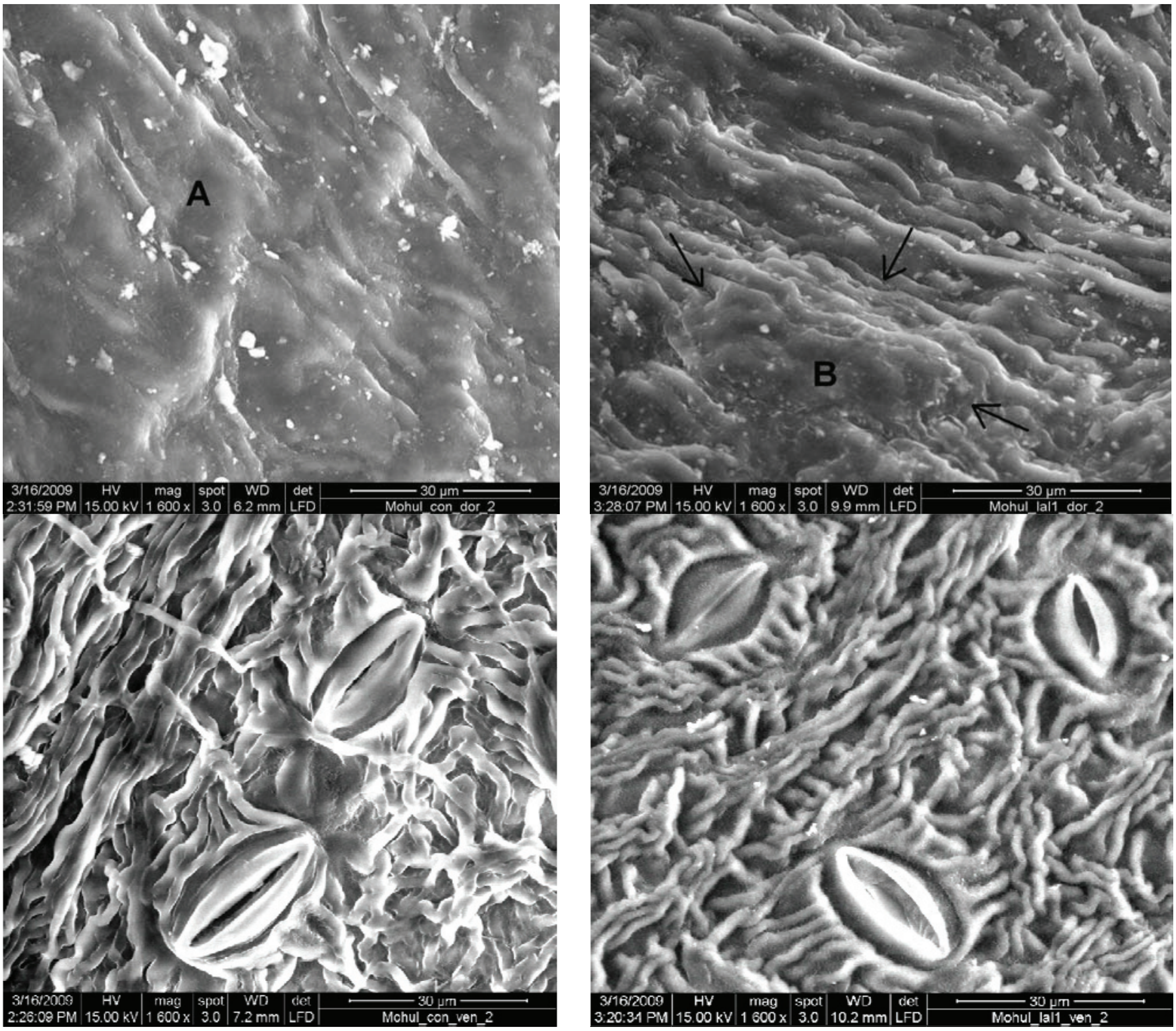

Figure 9. *Electron micrographs of Madhuca indica leaves (magnification: 1600X): upper left- dorsal surface (control), A- thick layer of evenly distributed wax; upper right- dorsal surface (polluted site1), B- wax layer unevenly distributed and damaged to a great extent; lower left- ventral surface (control), healthy with clear texture; lower right- ventral surface (polluted site 1), no major abnormality detected.*

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