Chapter III
RESULTS

RESULTS

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3.1. FIELD SURVEY

3.1.1. SURVEY OF GENERAL VEGETATION NEAR A FERTILIZER PLANT

3.1.1.1. Response of vegetation at 0.5 Km from source :

Careful observations of the vegetation revealed various damaging symptoms in most of the plant species. Entire vegetation was clothed with whitish particulate matter, besides being subjected to regular exposure of toxic gases.

Barren branches due to heavy defoliation were observed in most of the trees and shrubs like Mangifera indica, Holoptelea integrifolia, Azadirechta indica, Bougainvillaea spectabilis, etc. In Mangifera, bleaching effect was evident, leading to pale brown necrotic zones extending from margin to midrib. Trees like Acacia nilotica sub sps. indica, Azadirechta indica, Moringa pterygosperma, Pithecellobium dulce etc., were often defoliated completely due to acute pollution exposures. Canopy of Lawsonia inermis, Streblus asper, Zizyphus jujuba etc., was often distorted beyond recognization. The pattern of damage to the branches indicate the extent and direction of pollution source. On the windward side leaves were completely absent due to premature leaf fall and only barren leafless branches observed, whereas on the leeward side often partially damaged foliage remained intact (Table 8).

Fig.3.3.1. Air pollution damage on vegetation

A. A highly damaged Mangifera indica L. (mango) tree showing severe foliar necrosis

B. A closer view of Mangifera indica L. (mango) leaves showing further details of the symptom

A

B

Fig.3.3.2. Air pollution damage on vegetation

A. Manilkara hexandra Dubard. (rayan) leaves showing necrosis

B. Syzygium cumini Skeels (jamun) leaves tip burning symptoms

A

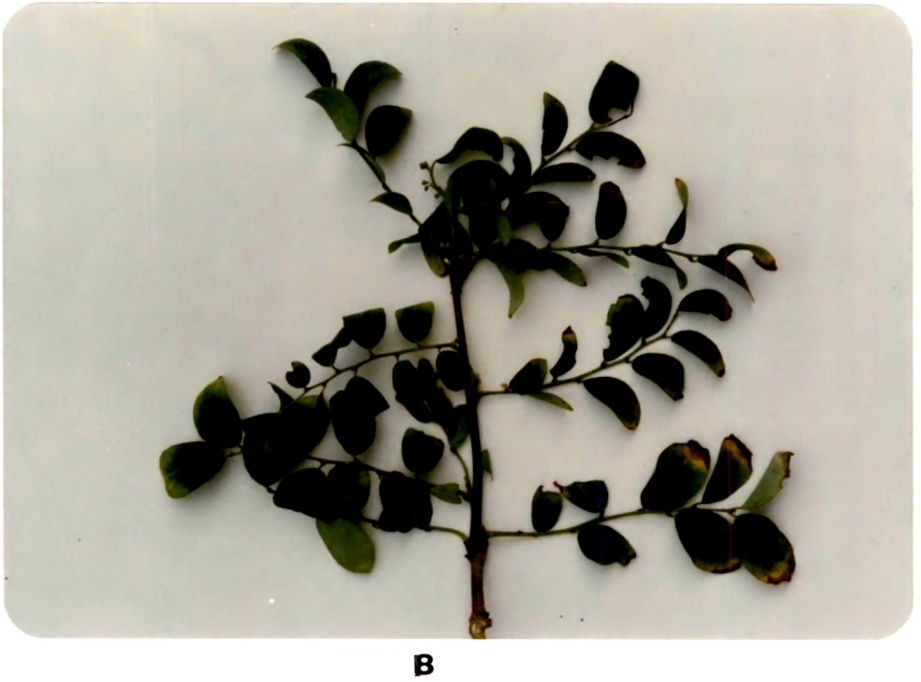
B

Fig. 3.3.3.Air pollution damage on vegetation

A. Pithecellobium dulce Bth. leaves showing necrotic symptoms

B. Kirganelia reticulata Bail leaves showing chlorotic and necrotic symptoms

A



B

Fig.3.3.4. Air pollution damage on vegetation

A. Zizyphus jujuba Lam. leaves showing severe necrosis

B. Eucalyptus leaves showing necrotic symptoms

C. Diospyros cordifolia Roxb. leaves showing interveinal chlorosis and necrotic tip

A

B

C

All the herbaceous species recorded here also exhibited visible damaging symptoms. Reduction in leaf size was observed in Amaranthus viridis, A. spinosus, Sida grewioides, Cassia tora etc. Mostly all the plants showed stunted appearance and appeared whitish rather than greenish. Bleached white dots surrounded by tan coloured zones were common in the leaves of Raphanus sativus, Euphorbia hirta, Gomphrena celosioides etc. (Table 9).

3.1.1.2. Response of vegetation at 1.5 Km from source:

All the trees and shrubs here exhibited visible foliar symptoms like marginal burning, tip burning etc.. Tip burning was evident in most of the trees and shrubs like Azadirechta indica, Ficus religiosa, Syzygium cumini, Lantana camara etc.. Tree species like Mangifera indica, Acacia nilotica sub sp. indica, Pithecelobium dulce, Moringa pterygosperma etc. exhibited severe damage . Chlorotic symptoms were observed in the leaves of Ficus benghalensis, Manilkara hexandra, Tamarindus indica, Kirganelia reticulata etc. (Table 8).

Except some prostrate herbs like Evolvulus alsinoides, Gomphrena celosioides, Portulaca quadrifida, Boerhavia diffusa etc., all other species exhibited foliar symptoms (Table 8). Tip burning was the common symptoms in herbs like Achyranthes aspera, Amaranthus spinosus, Corchorus capsularis, Cocculus villosus, Desmodium triflorum, Gynandropsis pentaphylla, Peristophe bicalyculata etc. (Table 9).

Table 8. Response of general vegetation near a fertilizer complex

(Tree and Shrubaceous species)

Name	Freq-quency	Symptoms / Degree of damage — Distance from the source (Km.)		
		0.5	1.5	2.5
Acacia nilotica (L.) Del. subsp. indica (Bth.) Brenan	C	DF,NT/HD	C/HD	C/LD
Anogeissus latifolia Wall. ex Bedd	LC	-	N/LD	NCS/Nil
Azadirechta indica A. Juss	C	DF,N/HD	NT/D	NT/LD
Bauhinia racemosa Lam.	LC	-	MB/D	Ch/LD
Carica papaya L.	Cul	-	N/D	N/D
Casuarina equisetifolia L.	Cul	-	-	NCS/Nil
Cocos nucifera L.	Cul	-	Ch, NT/LD	-
Dalbergia sissoo Roxb.	Cul	DF,N/HD	-	-
Diospyros cordifolia Roxb.	C	DF, TB, Int.ch./ HD	TB/D	Ch,NT/LD
Eucalyptus sps.	Cul	N/D	-	NCS/Nil
Ficus benghalensis L.	C	DF.MB/LD	Ch/LD	NCS/Nil

Table 8. Contd.

Ficus religiosa L.	C	DF,MB/LD	TB/D	Ch,NT/LD
Holoptelea integrifolia Planch	VC	DF,N/HD	MB/D	N,TB/D
Mangifera indica L.	Cul	DF,N,MB/HD	DF,MB/HD	DF,MB/HD
Manilkara hexandra (Roxb.) Dubard.	C	DF,N,Ch/HD	DF,Ch/D	DF,Ch/D
Moringa pterygosperma Goert.	Cul	DF,Ch/HD	DF,Ch/HD	DF,Ch/D
Pithecellobium dulce (Roxb.) Bth.	C	DF,N/HD	DF,Ch/HD	Ch/LD
Polyalthia longifolia (Sonn.) Thw.	Cul	MB/D	NT/LD	NCS/Nil
Prosopis spicigera L.	LC	DF,N/HD	DF,Ch/D	Ch/LD
Steblus asper Lour.	C	DF,MB/HD	DF,MB/D	MB/D
Syzygium cumini Skeels	LC	DF,TB/HD	DF,TB/D	TB/D
Tamarindus indica L.	C	DF,N/HD	DF,Ch/D	NCS/Nil
Terminalia catappa L.	LC	DF,N/LD	-	NCS/Nil
SHRUB SPECIES				
Bougainvillea spectabilis Willd.	Cul	N/HD	-	NT/LD
Capparis sepiaria L.	C	DF,Ch/D	Ch/D	NCS/Nil
Euphorbia tirucalli L.	R	Ch/LD	NCS/Nil	NCS/Nil

Table 8. Contd.

Kirganelia reticulata (Poir) Bail	VC	DF,N,Ch/HD	Ch/D	NCS/Nil
Lantana camara L.	C	MB/D	NT/D	NCS/Nil
Lawsonia inermis L.	C	DF,N/HD	DF,N/HD	N/D
Opuntia dilleni Grah.	C	Ch/LD	NCS/Nil	NCS/Nil
Ricinus communis L.	Cul	N/HD	N/HD	Ch,N/D
Zizyphus jujuba Lam	C	DF,N/HD	DF,MB/D	NT,Ch/LD

(Abbreviations are explained in the page No. 76)

Table 9. Response of general vegetation near a fertilizer complex

(Herbaceous species)

Name	Frequency	Symptoms / Degree of damage		
		Distance from the source (Km.)		
		0.5	1.5	2.5
Abutilon indicum (L) Sw.	C	MB/D	MB/D	TB/LD
Achyranthes aspera L.	VC	MB/D	TB/LD	NCS/Nil
Aeschynomene indica L.	LC	-	TB/LD	NCS/Nil
Aerva lanata (L.) Juss.	C	-	-	NT/LD
Amaranthus polygamus L.	C	-	-	NT/LD
Amaranthus spinosus L.	VC	MB/HD	TB/D	NCS/Nil
Amaranthus viridis L.	VC	MB/HD	MD/D	NT/LD
Anisomeles ovata R.Br.	C	-	-	NCS/Nil
Boerhavia diffusa L.	C	N/D	NCS/Nil	NCS/Nil
Boerhavia repanda Willd.	C	-	-	NCS/Nil
Calotropis procera R.Br.	C	Ch/D	Ch/D	NCS/Nil
Canavalia ensiformis DC. var virosa Baker	C	TB/LD	NT/LD	NCS/Nil

Table 9. Contd.

Chloris barbata Sw.	VC	TB/HD	TB/D	NT/LD
Cissampelos pareira L.	LC	-	-	NCS/Nil
Cassia occidentalis L.	VC	DF,MB/HD	MB/HD	TB/D
Cassia tora L.	VC	DF,N/HD	DF,N/D	NT/D
Coccinia indica W. & A.	LC	N/D	Int.Ch/D	NCS/Nil
Cocculus villosus DC	LC	MB/LD	NT/LD	NCS/Nil
Commelina benghalensis L.	LC	-	TB/D	Ch,NT/LD
Corchorus capsularis L.	C	-	TB/D	NT, Ch/LD
Cyanodon dactylon (L.) Pers.	VC	TB/HD	TB/D	NT/LD
Datura stramonium L.	C	MB/D	TB/D	NCS/Nil
Desmodium triflorum DC	C	-	NT/LD	NCS/Nil
Eclipta prostrata (L.) L.	LC	N/D	-	NCS/Nil
Euphorbia hirta L.	VC	N/D	NCS/Nil	NCS/Nil
Evolvulus alsinoides L.	C	MB,Ch/D	NCS/Nil	NCS/Nil
Gomphrena celosioides Mart.	C	NT/D	NCS/Nil	NCS/Nil
Glysine wightii (Grah.ex W & A.) Verdcourt	Cul	-	TB, Ch/D	-

Table 9. Contd.

Gynandropsis pentaphylla DC	C	N/HD	TB/HD	NT,Ch/D
Hibiscus esculentus L.	Cul	TB/D	NCS/Nil	-
Indigofera enneaphylla L.	C	-	Ch/D	NCS/Nil
Ipomoea sepiaria Koen.ex Roxb.	C	-	NT/LD	NCS/Nil
Launaea nudicaulis (L.) HK.	R	TB/LD	NCS/Nil	NCS/Nil
Leptadenia reticulata W. & A.	C	-	TB/LD	NCS/Nil
Lippia nodiflora A. Rich	C	-	NT/LD	NCS/Nil
Mollugo hitra Thumb	C	N/D	-	NCS/Nil
Mollugo oppositifolia L.	C	-	CT/LD	NCS/Nil
Peristrophe bicalyculata Nees	VC	DF,N/HD	TB/D	NCS/Nil
Phyllanthus niruri L.	C	DF,Ch/D	Ch/D	NCS/Nil
Plumbago zeylanica L.	C	Ch,MB/D	Ch/LD	NCS/Nil
Portulaca oleracea L.	VC	N/D	NT/LD	NCS/Nil
Portulaca quadrifida L.	C	-	NCS/Nil	NCS/Nil
Raphanus sativus L.var. *caudatus* L.	Cul	N/HD	-	-
Sida grewioides Guill.et Perr	C	Int.Ch/HD	TB/D	NT/LD

Table 9. Contd.

Solanum nigrum L.	Cul	-	TB/D	NCS/Nil
Tephrosia purpurea (L.) Pers	VC	DF,N/HD	DF,N/D	N/D
Trianthema monogyna L.	C	NT/D	NCS/Nil	NCS/Nil
Tribulus terrestris L.	C	N/HD	N/D	NCS/Nil
Tridax procumbens L.	C	MB/LD	NT/LD	NCS/Nil
Tubiflora acaulis O.Ktze.	C	-	MB/LD	NCS/Nil
Urena lobata L.	C	-	-	Ch/LD
Vernonia cinerea (L) Less	VC	MB/HD	MB/D	NT/LD
Vitis trifolia Cooke	LC	-	TB/D	NT/D
Xanthium strumarium L.	VC	N/HD	N,Ch/HD	MB/D

Frequency

VC = Very common
C = Common
LC = Less common
R = Rare
Cul = Cultivated

Symptoms

DF = Defoliation
N = Necrosis (irregular)
Ch = Chlorosis (irregular)
MB = Marginal burning
TB = Tip burning
Int.Ch = Interveinal chlorosis
NT = Necrotic tip
CT = Chlorotic tip
NCS = No characteristic symptoms.

Degree of damage

HD = Highly damaged
D = Damaged
LD = Less damaged
Nil = No visible damage

3.1.1.3. Response of vegetation at 2.5 Km from the source:

The increasing distance from the source of pollution, reduced the damage to vegetation considerably. Among the trees and shrubs recorded, 61.3% exhibited foliar symptoms. Chlorotic symptoms were observed in Acacia nilotica sub sp. indica, Bauhinia racemosa, Diospyros cordifolia, Manilkara hexandra, Pithecellobium dulce etc.. Mangifera indica was found to be severely damaged even at this distance, exhibiting marginal burning of leaves and defoliation. No characteristics symptoms were observed in Terminalia catappa, Polyalthia longifolia, Ficus benghalensis, Lantana camara etc. (Table 8).

The number of herbaceous species without visible symptoms as well as species diversity increased significantly at this distance. The plants like Abutilon indicum, Amaranthus viridis, A. polygamus, Cassia occidentalis, C. tora, Gynandropsis pentaphylla, Sida grewioides, Vernonia cinerea etc., exhibited foliar necrotic tips. No characteristic symptoms were noticed in Aeschynomene indica, Achyranthes aspera, Anisomeles ovata, Boerhavia diffusa, B. repanda, Calotropis procera, Desmodium triflorum, Eclipta prostrata, Indigofera enneaphylla, Mollugo oppositifolia, M. hirta, Peristrophe bicalyculata etc.. (Table 9).

3.1.2. STUDY ON TREES GROWING ALONG THE NATIONAL HIGHWAY NO. 8 : A GRADIENT ANALYSIS

Dalbergia sissoo Roxb. was recorded in all the seven sectors under investigation. Syzygium cumini Skeels was growing only from sector 4 to 7 (Table 10).

3.1.2.1. Effect on height of the trees

3.1.2.1.1. D. sissoo : In sector 1 and 2 trees represented classes from B to G. The maximum percentage of trees (36) in sector 1 were representing the class G (above 10 mts) whereas in sector 2 maximum trees (42%) were under class E (8 to 9 mts). In sector 3, trees represented classes from A to E and maximum under class E (41%), followed by class B (24%), A (21%), D (9%) and C (5%). In sector 4, all the trees were falling under class A (below 5 mts). In sector 5, maximum trees were recorded under class A (53%) followed by class B (26%) and C (19%). In sector 6, class D was represented by 49% of trees and class E by 45% of trees. In sector 7, maximum trees (47%) were under class E, followed by class F (27%), C (16%) and D (9%). (Table 11; Fig.4.9.1.).

3.1.2.1.2. S. cumini : In sector 4, maximum percentage of trees (40%) were falling under class C, followed by class D (37%), B (19%), and A (4%). In sector 5, class D was represented by 67% of trees, and remaining trees were falling under class C (28%) and class B (8%). In sector 6 and

Table 10. Study on trees growing along the National Highway No. 8

Total number of trees in each sector

SECTOR	*Dalbergia sissoo* Roxb. Total trees		No. of cutdown/dead dried trees during observation	*Syzygium cumini* Skeels Total trees		No. of cutdown/ dead and dried trees during observation
	Planted	At present		*Planted	At present	
1	480	134	4		N.P.	-
2	660	152	45		N.P.	-
3	420	118	7		N.P.	-
4	720	5	Nil		36	3
5	540	31	Nil		18	1
6	360	39	Nil		14	Nil
7	420	32	1		18	Nil

* Plantation data not available. N.P. Not planted.

Gradient study on trees growing along the National Highway No. 8

Effect on height of the trees (Mts.)

Table 11. Dalbergia sissoo Roxb.

SECTOR	Number of trees recorded under class						
	A (Below 5)	B (5 to 6)	C (6 to 7)	D (7 to 8)	E (8 to 9)	F (9 to 10)	G (Above 10)
1	-	20	27	14	17	5	47
2	-	8	19	6	45	9	10
3	22	27	6	10	46	-	-
4	5	-	-	-	-	-	-
5	17	8	6	-	-	-	-
6	-	2	-	19	18	-	-
7	-	-	5	2	15	8	-

Table 12. Syzygium cumini Skeels

SECTOR	Number of trees recorded under class					
	A (Below 6)	B (6 to 7)	C (7 to 8)	D (8 to 9)	E (9 to 10)	F (Above 10)
4	2	6	13	12	-	-
5	-	1	5	12	-	-
6	-	-	-	-	5	9
7	-	-	-	-	2	16

7 trees showed fairly good growth. In sector 6, 63% of trees were registered under class F and 37% of trees under class E. In sector 7, maximum percentage of trees (91%) were represented class F (above 10 mts) and remaining were class E. (Table 12; Fig.4.9.2.).

3.1.2.2. Effect on circumference of trunk at breast height (CBH)

3.1.2.2.1. D. sissoo : In sector one, 40% of the trees were recorded under class F (above 90 cm) followed by 37% under E and 23% under class D. In sector 2, class E was represented by 44% of trees, whereas class B and C were represented by 14% and 25% of trees respectively. In sector 3, trees represented classes from A to E, maximum percentage of trees (31%) were recorded under class B. In sector four, 60% of trees were recorded under class B and remaining 40% trees under class C. In sector 5, class B was represented by 67% of trees followed by class A (22%) and class C (11%). Increasing pattern of CBH was observed in sector 6 and 7. In sector 6, trees represented classes from B to E. Maximum percentage of trees (43%) were observed under class B followed by class D (33%), E (17%) and C (7%). In sector 7, class D was represented by 40% of trees recorded and class E by 27%, remaining trees were falling under class C (18%) and F (15%). (Table 13; Fig.4.9.2.).

Effect on circumference at breast height of the trunk (Cms.)

Table 13. Dalbergia sissoo Roxb.

SECTOR	Number of trees recorded under class					
	A (Below 30)	B (30 to 45)	C (45 to 60)	D (60 to 75)	E (75 to 90)	F (Above 90)
1	-	-	-	30	48	52
2	-	15	27	-	47	18
3	11	34	26	23	17	-
4	3	2	-	-	-	-
5	7	21	3	-	-	-
6	-	16	3	13	7	-
7	-	-	6	12	8	5

Table 14. Syzygium cumini Skeels

SECTOR	Number of trees recorded under class					
	A (Below 100)	B (100 to 120)	C (120 to 140)	D (140 to 160)	E (160 to 180)	F (Above 180)
4	4	22	7	1	-	-
5	-	7	6	2	3	-
6	-	-	5	4	5	-
7	-	-	3	2	6	7

3.1.2.2.2. S. cumini : In sector four, 64% of trees were falling under class B (100 to 120 cm) and remaining trees were recorded under class C (21%), A (12%) and D (3%). In sector 5, maximum percentage of trees (39%) were recorded in class B, followed by class C (33%), E (17%) and D (11%). In sector six, class E and C were represented by 36% and 35% of trees respectively and remaining 29% of trees were recorded under class D. In sector 7, maximum trees (38%) were falling under class F, followed by class E (33%), C (17%) and D (11%). (Table 14; Fig.4.9.2.).

3.1.2.3. Effect on tree canopy cover

3.1.2.3.1. D. sissoo : In sector 1, class G (above 50 m^2) was represented by 52% of the trees recorded. The other classes represented in sector 1, are class C (19%), B (18%) and F (11%). In sector 2, maximum percentage of trees (31%) were falling under class F, followed by class D (23%), B (21%), E (15%) and C (10%). In sector 3, trees represented classes from A to E. Maximum percentage (26) was recorded in class B and classes A, C and E were represented by 21% each. In sector four, 60% of trees recorded were under class A and remaining 40% under class B. In sector 5, also 42% of trees were falling under class A followed by class B (29%), C (21%) and D (8%). In sector 6, class E was represented by maximum number of trees (42%). In sector 7, class G was represented by 34% of trees. The other classes represented in sector 7, were class F (29%), D (28%) and E (9%).(Table 15; Fig.4.9.1.).

Effect on tree canopy cover (m^2)

Table 15. Dalbergia sissoo Roxb.

SECTOR	Number of trees recorded under class						
	A (Below 15)	B (15 to 20)	C (20 to 25)	D (25 to 30)	E (30 to 35)	F (35 to 50)	G (Above 50)
1	-	23	25	-	-	14	68
2	-	23	11	25	16	32	-
3	23	29	23	13	23	-	-
4	3	2	-	-	-	-	-
5	12	9	7	3	-	-	-
6	-	6	3	14	16	-	-
7	-	-	-	8	3	9	11

Table 16. Syzygium cumini Skeels

SECTOR	Number of trees recorded under class						
	A (Below 50)	B (50 to 75)	C (75 to 100)	D (100 to 125)	E (125 to 150)	F (150 to 175)	G (Above 175)
4	6	4	12	7	5	-	-
5	-	-	6	2	6	3	2
6	-	-	-	1	-	3	10
7	-	-	-	-	2	2	14

3.1.2.3.2. S. cumini : Canopy of Syzygium was also highly affected in sector 4. Maximum number of trees were registered under class C (36%), followed by D (20%), A (17%), E (16%) and B (11%). In sector 5, 33% of trees were falling under class E and classes F and G were represented by 18% and 10% of trees respectively. In sector 6, maximum trees (74%) were recorded under class G. In sector 7, class G was represented by 78% of trees and remaining trees were registered under class F (12%) and E (10%). (Table 16; Fig.4.9.2.).

3.1.2.4. Effect on defoliation

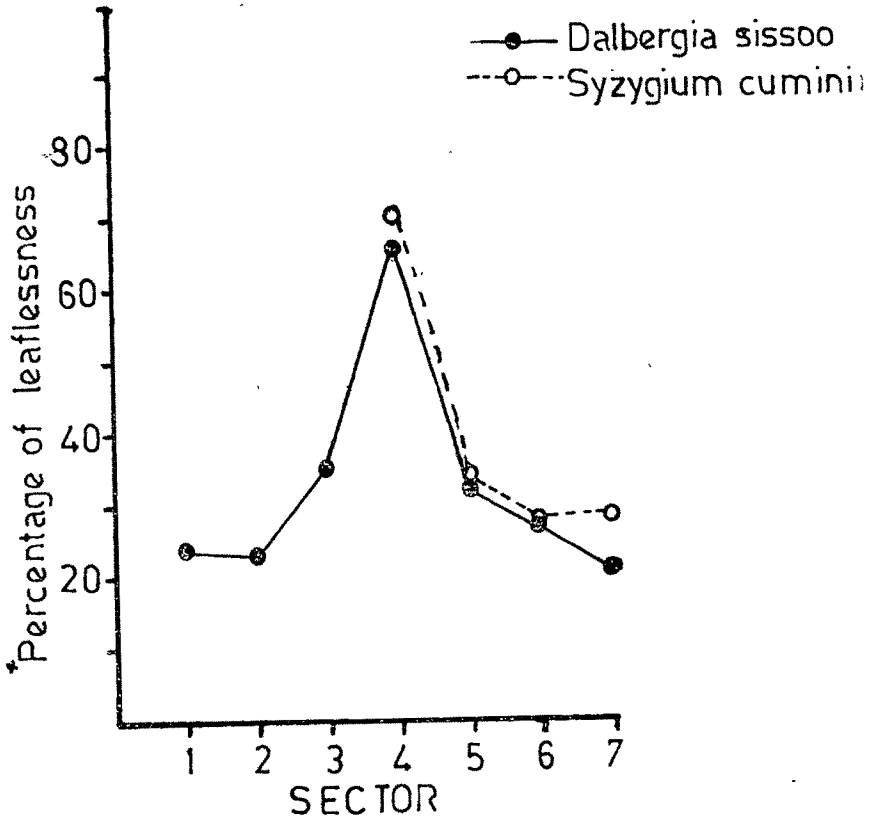
The percentage leaflessness was very high in both the species in sector 4. The mean percentage leaflessness of D. sissoo trees growing in sector 1, 2 and 3 was 24, 23 and 36% respectively, whereas in sector 4 it was 65%. The percentage leaflessness declined sharply while moving away from sector 4, i.e. in sector 5, 6 and 7 it was 32, 27 and 21% respectively.

Syzygium also exhibited same trend of damage i.e. in sector 4, opposite to a fertilizer complex the leaflessness was 70%, whereas in sectors 5, 6 and 7 it was 35, 28 and 29% respectively (Fig.3.4.1.).

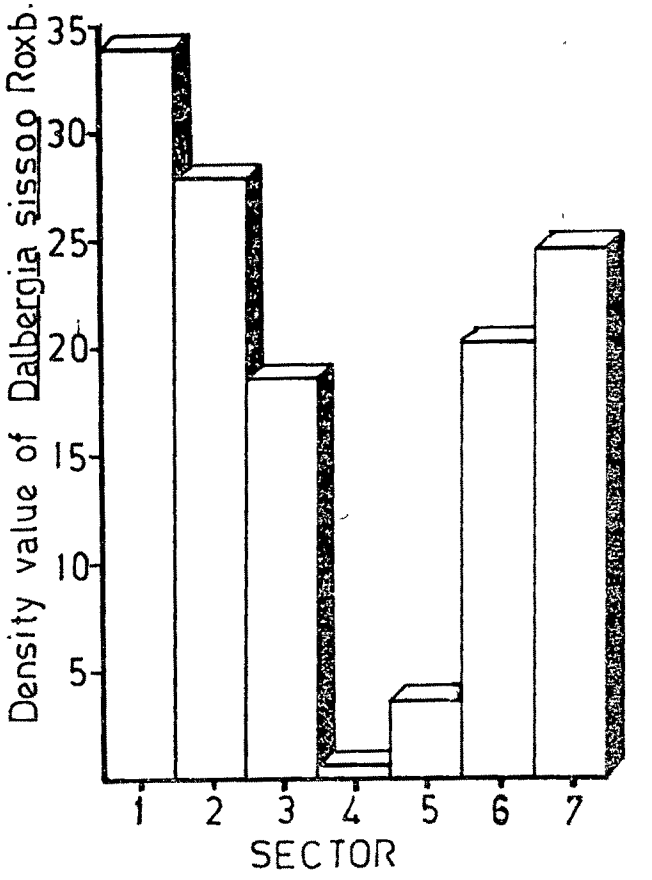
3.1.2.5. Effect on density

The quadrate study on D. sissoo revealed the mean

Fig.3.4.1. Impact Of Air Pollution On Roadside Trees.



*(Mean value of total number of trees in each sector.)



density value per quadrat (30 x 8 mts) decreased drastically in sector 4. In sectors 1, 2 and 3, the density value was 34, 29.7 and 18.7 respectively. In sector 4, it was only 0.33 whereas in remaining sectors i.e. 5, 6 and 7 it was 3.7, 20.3 and 25.7 respectively (Fig.3.4.1.).

The percentage of trees surviving was calculated by comparing with the number of trees planted initially (obtained from the Forest Department). In sectors 1, 2 and 3 it was 27.9%, 23.0% and 28.1% was recorded. In sectors 4 and 5 it was only 0.7% and 5.7% respectively. In sectors 6 and 7 the percentage of trees surviving were 10.8% and 7.6% respectively.

3.1.3. FIELD SURVEY OF FRUIT TREES

3.1.3.1. Effect of industrial air pollution on Mangifera indica L. (mango)

3.1.3.1.1. Effect on morphological parameters: (Table 17)

(i) Height of the tree: Tree height was highly affected at Angadh, where 37.3% reduction was recorded as compared to control. At other stations like *Bajwa, Ranoli, Dhanora, Sankarda and Chhani 13 to 19% reduction was observed. The tree height recorded at Undera and Ankodia was 9% less than control trees. (Fig.4.10.1.)

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* Stations are arranged in decreasing order of damage henceforth in the descriptive part.

Table 17. Effect of industrial air pollution on Mangifera indica L. (Mango)
(Morphological and yield observations)

Parameter		Koyali	Bajwa	Dumad	Angadh	Ranoli	Dhanora
Height (Mts)		9.68	8.62	8.92	6.65	8.84	9.05
	±	0.31	0.46	0.57	0.18	0.23	0.25
Canopy cover (m^2)		152.1	117.6	129.0	106.7	112.5	158.7
	±	16.2	10.3	22.7	11.5	13.2	11.6
Mean leaf area (cm^2)		42.8	40.3	66.7	44.6	48.7	46.3
	±	3.6	1.4	3.5	3.1	2.6	1.4
% leaf area damaged		29.5	34.8	12.4	44.1	36.1	38.6
% Leaflessness		35.0	48.3	10.8	51.3	43.5	45.0
% Flowering		56.0	52.0	80.0	55.0	60.0	70.0
% Fruiting		48.0	40.0	60.0	30.0	42.0	50.0

± Standard deviation.

Table 17. Contd.

Parameter		Ankodia	Undera	Chhani	Sankarda	Ampad	Samiyala (Control)
Height (mts)		9.7	9.65	9.3	8.9	11.6	10.6
	±	0.52	1.01	0.41	0.38	0.51	0.45
Canopy cover (m^2)		138.3	136.1	121.6	162.1	193.0	181.7
	±	9.8	11.5	6.3	13.4	12.2	15.2
Mean leaf area (Cm^2)		68.0	52.9	52.3	56.8	62.1	65.4
	±	3.9	6.3	4.0	2.9	4.1	2.7
% Leaf area damaged		10.2	12.7	14.1	13.3	Nil	Nil
% Leaflessness		NIL	20.0	20.0	26.0	Nil	Nil
% Flowering		80.0	75.0	75.0	80.0	100	100
% Fruiting		65.0	65.0	60.0	60.0	100	100

± Standard deviation.

(ii) Effect on tree canopy cover : Canopy was severely damaged at high pollution zones like Angadh, Bajwa and Ranoli (35 to 42%) as compared to control. At medium polluted stations like Koyali, Dumad, Ankodia, Undera, Sankarda and Chhani the canopy cover decreased 10 to 34%. At Ampad, it was recorded slightly higher than (6.2%) control (Fig.4.10.1.).

(iii) Effect on foliage (mean leaf area, and leaf area damaged) : Maximum reduction (38.4%) in leaf area was recorded at Bajwa. Among the other stations, 25 to 35% reduction in leaf area was observed at Angadh, Koyali, Dhanora and Ranoli. At Chhani, Sankarda and Undera 13 to 20% reduction in leaf area was registered, whereas at remaining stations it was more or less close to control. (Fig.4.10.2).

The photosynthetic leaf area was highly reduced by severe chlorosis and necrosis in the pollution zone. The percentage leaf area damaged was very high (35 to 45%) at highly polluted stations like Angadh, Ranoli, Bajwa and Dhanora. In medium polluted stations like Koyali, Sankarda, Ankodia, Undera, Chhani and Dumad 10 to 30% of leaf area was damaged. At Ampad, no visible foliar damage was observed. (Fig.4.10.2.).

(iv) Effect on defoliation : Trees growing at Angadh exhibited maximum defoliation (51.3%) and at other high

pollution zones i.e. Bajwa, Ranoli and Dhanora 44 to 49% leaflessness was recorded. Among the medium polluted stations, 20 to 35% leaflessness was registered at Koyali, Sankarda, Chhani and Undera. At Ankodia and Ampad no significant defoliation was noticed. (Fig.4.10.2.).

3.1.3.1.2. Effect on fruit yield : Fruit production in mango received a major setback due to pollution stress in the area under investigation. In the pollution zone, the fruit yield was affected at different stages like flowering, fertilization and maturation of fruit. The common symptoms in mango was early senescence of flowers, young and immature fruits. During the course of study it was observed, villagers were removing significant number of unproductive trees in the high pollution zone due to drastic reduction in fruit yield.

Maximum reduction in flowering was observed at Bajwa (48%). At stations like Angadh, Ranoli, Dhanora and Koyali 40 to 45% reduction in flowering was recorded. At all the remaining stations except Ampad, the reduction was 20 to 30%. Flowering was least affected at Ampad. (Fig.4.10.3.).

Fruit yield of mango trees was retarded severely (70%) at Angadh. Among the other stations 50 to 60% reduction in fruit yield was registered at Bajwa, Ranoli, Dhanora and Koyali. At other stations except Ampad, the yield reduction was 30 to 40% than control. At Ampad, the fruit yield was more or less close to the control. (Fig.4.10.3.).

3.1.3.1.3. Effect on biochemical parameters : (Table 18).

(i) Effect on chlorophyll pigments : The chlorophyll pigments, which are primary site of photosynthesis were severely affected. Chlorophyll a pigment was recorded 48 to 55% less than control at Ranoli, Angadh and Bajwa. 33 to 41% reduction in chlorophyll a was observed at Koyali, Dhanora and Sankarda. At all remaining stations except Ampad, chlorophyll a content decreased 14 to 29%, whereas at Ampad, the reduction was 10.1%. (Fig.4.10.4.).

Chlorophyll b pigment also exhibited more or less similar trend of damage pattern. 49 to 53% reduction was observed in trees growing at Angadh, Ranoli and Bajwa. At stations like Dhanora, Koyali, Sankarda, Dumad and Undera the percentage reduction in chlorophyll b pigment ranged from 27 to 39%. At remaining stations 7 to 17% reduction was noticed. (Fig.4.10.4.).

(ii) Effect on foliar protein content : Degradation of protein molecules by air pollutants resulted in its decreased concentration. The percentage reduction in protein content was maximum (42.2%) at Angadh, whereas at stations like Bajwa, Ranoli and Koyali it was 30 to 35% less than control. The protein content reduced 14 to 26% at all remaining stations except Ampad, where minimum reduction (7%) in protein level was recorded. (Fig.4.10.5.).

Table 18. Effect of industrial air pollution on *Mangifera indica* L. (Mango)
(Biochemical observations)

Parameter		Koyali	Bajwa	Dumad	Angadh	Ranoli	Dhanora
Chlorophyll a (mg/g.f.wt.)	±	1.23 0.04	1.06 0.02	1.47 0.29	0.93 0.01	0.95 0.04	1.32 0.07
Chlorophyll b (mg/g.f.wt.)	±	0.88 0.09	0.73 0.05	1.03 0.31	0.67 0.01	0.67 0.01	0.87 0.11
Protein (mg/g.f.wt.)	±	31.0 1.5	28.9 1.4	35.0 2.7	25.6 1.3	30.1 1.2	34.9 1.7
Sulphur (mg/g.d.wt.)	±	3.23 0.01	3.68 0.04	2.61 0.03	3.44 0.02	2.29 0.06	2.46 0.02
Chloride (mg/g.d.wt.)	±	1.30 0.02	1.15 0.07	0.91 0.01	2.82 0.04	5.83 0.01	1.50 0.04
Total soluble sugars (mg/g.d.wt.)	±	40.6 2.2	35.3 3.4	50.2 1.2	30.6 1.8	34.5 2.2	36.1 2.8
Reducing sugars (mg/g.d.wt.)	±	74.0 1.3	92.1 4.8	70.5 4.8	102.1 6.4	81.9 1.2	85.8 2.9

± Standard deviation.

Table 18. Contd.

Parameter		Ankodia	Undera	Chhani	Sankarda	Ampad	Samiyala (Control)
Chlorophyll a (mg/g.f.wt.)	±	1.61 0.02	1.49 0.14	1.78 0.03	1.38 0.05	1.86 0.21	2.07 0.04
Chlorophyll b (mg/g.f.wt.)	±	1.11 0.06	1.03 0.12	1.18 0.11	0.89 0.04	1.32 0.06	1.42 0.07
Protein (mg/g.f.wt.)	±	38.1 3.3	36.9 1.5	35.3 2.0	32.9 1.3	40.1 1.1	44.3 1.2
Sulphur (mg/g.d.wt.)	±	2.06 0.01	2.23 0.02	2.12 0.05	2.39 0.03	0.73 0.01	0.65 0.03
Chloride (mg/g.d.wt.)	±	0.97 0.04	1.03 0.01	0.94 0.06	1.58 0.03	0.64 0.01	0.84 0.05
Total soluble sugars (mg/g.d.wt.)	±	49.7 1.4	43.3 1.1	50.9 2.6	38.8 1.6	50.9 2.3	54.6 1.2
Reducing sugars (mg/g.d.wt.)	±	83.8 4.0	64.6 1.8	77.0 3.1	89.7 2.0	55.9 1.0	52.8 2.7

(iii) Effect on foliar sulphur content : Very high accumulation of sulphur in foliar tissues over control was noticed at Bajwa (5.66 times) and Angadh (5.29 times). Among the other stations, at Dhanora, Dumad and Koyali sulphur content was 3.7 to 5.0 times over control. The sulphur accumulation at remaining stations except Ampad, ranged from 3.1 to 3.7 times over control. At Ampad the increase in sulphur content (1.12 times) was insignificant. (Fig.4.10.6.).

(iv) Effect on foliar chloride content : Mango trees growing at Ranoli exhibited the highest chloride content (6.94 times) over control. Among the other stations at Angadh, 3.36 times increase in chloride level was recorded. At the remaining stations except Ampad, the accumulation of chloride ranged from 1.08 to 1.9 times over control. At Ampad, the foliar chloride level was very close to control. (Fig.4.10.6.).

(v) Effect on total soluble and reducing sugar content : It was observed in the present study, that in the foliar tissues of mango trees growing in pollution zone, the soluble sugar content declined whereas reducing sugar highly increased as compared to control.

At highly polluted stations like Bajwa, Angadh, Ranoli and Dhanora 33 to 44% reduction in total soluble sugar was

registered. 20 to 29% reduction was recorded at Sankarda, Koyali and Undera, whereas at remaining stations the percentage reduction ranged from 6 to 10% as compared to control. (Fig.4.10.5.).

Accumulation of reducing sugars was observed maximum (93.4%) at Angadh. It was 55 to 75% higher than control in the trees growing at Bajwa, Dhanora, Ranoli, Sankarda and Ankodia. In the remaining stations except Ampad, the level of reducing sugars was 22 to 40% higher than control. At Ampad, it was very close to control plants. (Fig.4.10.5.).

3.1.3.2. Effect of industrial air pollution on Manilkara hexandra (Roxb.) Dubard. (rayan)

3.1.3.2.1. Effect on morphological parameters : (Table 19)

(i) Effect on tree height : At high pollution zones like Bajwa, Angadh, Dhanora, Ranoli and Chhani, tree height was 25 to 37% less than control trees. Among the medium polluted stations at Sankarda and Koyali, significant reduction in height (22.7% and 10.2% respectively) was registered. At the remaining stations, tree height was more or less close to control. (Fig.4.10.1.).

(ii) Effect on tree canopy cover : Tree canopy was severely damaged at higher pollution zone. 40 to 57% reduction in tree canopy was observed at Angadh, Bajwa, Dhanora and

Ranoli. Among the medium polluted stations 8 to 20% reduction was registered at Undera, Sankarda, Chhani and Koyali. Tree canopy recorded at Ampad, Ankodia and Dumad were slightly (3 to 8%) higher than control trees. (Fig.4.10.1.).

(iii) Effect on foliage (mean leaf area and leaf area damaged) : The mean leaf area of rayan trees was highly decreased at Angadh (37.3%) and Bajwa (33.3%). At stations like Dhanora, Undera and Ranoli 18 to 28% reduction was recorded as compared to control. At Sankarda and Chhani the percentage reduction was 10.3 and 8.6 respectively, whereas at Ankodia it was more or less close to the control. (Fig.4.10.2.).

Visible foliar damage in rayan was recorded mostly at higher pollution zones only. Maximum percentage of leaf damage (16.7%) was recorded at Angadh followed by Ranoli (13.8), Bajwa (11.2), Dhanora (11.0), Koyali (6.2) and Dumad (2.6). At all the remaining stations no visible foliar symptoms were observed. (Fig.4.10.2.).

(iv) Effect on defoliation : At high pollution zone i.e. Bajwa, Angadh, Ranoli and Dhanora 25 to 35% leaflessness in rayan trees was registered. At medium polluted stations like Sankarda, Chhani, Koyali and Undera the defoliation was 15 to 20%, whereas at the remaining stations there was no significant difference from control trees. (Fig.4.10.2.).

Table 19. Effect of industrial air pollution on Manilkara hexandra (Roxb.) Dubard (rayan)
(Morphological and yield observations)

Parameter		Koyali	Bajwa	Dumad	Angadh	Ranoli	Dhanora
Height (Mts.)		11.1	7.84	12.13	8.38	9.18	9.05
	±	0.5	0.65	0.48	0.16	0.25	0.92
Canopy cover(m^2)		267.1	143.0	121.8	120.8	164.5	151.2
	±	8.0	16.6	13.2	16.2	9.8	14.5
Mean leaf area (Cm^2)		38.3	35.6	39.3	33.5	43.9	40.3
	±	1.8	3.3	1.5	2.6	2.8	4.9
% Leaf area damaged		6.2	12.0	2.6	16.7	13.8	11.0
% Leaflessness		20.0	35.0	Nil	30.0	30.0	25.0
% Flowering		90.0	90.0	90.0	80.0	85.0	80.0
% Fruiting		70.0	50.0	85.0	55.0	58.0	67.0

± Standard deviation.

Table 19. Contd.

Parameter		Ankodia	Undera	Chhani	Sankarda	Ampad	Samiyala (Control)
Height (Mts.)		12.29	11.36	9.04	9.55	12.87	12.36
	±	0.46	0.67	0.89	0.91	1.08	0.31
Canopy cover (m^2)		299.6	232.8	258.9	254.0	305.6	283.2
	±	18.5	12.6	17.6	21.7	18.1	19.8
Mean leaf area (Cm^2)		55.4	43.9	48.8	48.0	57.6	53.4
	±	1.8	2.4	4.1	4.5	3.7	1.5
% Leaf area damaged		Nil	Nil	Nil	Nil	Nil	Nil
% Leaflessness		Nil	15.0	20.0	20.0	Nil	Nil
% Flowering		95.0	100.0	100.0	85.0	100.0	100.0
% Fruting		85.0	90.0	75.0	70.0	100.0	100.00

± Standard deviation.

3.1.3.2.2. Effect on fruit yield

The flowering of rayan was observed less affected even at high air pollution zones. Maximum reduction (20%) in flowering was noticed at Angadh and Dhanora. 10 to 15% reduction was noticed at Ranoli, Bajwa, Sankarda, Koyali and Dumad. At the remaining stations insignificant effect on the flowering was noticed. (Fig.4.10.3.).

The fruit yield was highly affected at Angadh, Bajwa and Ranoli, where 40 to 50% reduction was recorded. Among the other stations 25 to 35% reduction was registered at Dhanora, Koyali, Sankarda and Chhani. At stations like Undera, Ankodia and Dumad the fruit production was 10 to 15% less than control whereas at Ampad it was least affected. (Fig.4.10.3.).

3.1.3.2.3. Effect on biochemical parameters : (Table 20)

(i) Effect on chlorophyll pigments : Maximum damage to chlorophyll a pigment was recorded at Bajwa, where it decreased 31.6% as compared to control. 24 to 29% reduction in chlorophyll a was noticed at Angadh, Ranoli and Koyali. At Dhanora, Sankarda, Chhani and Dumad it was 9 to 17% less than control. At remaining stations chlorophyll a level was more or less close to control plants. (Fig.4.10.4.).

Chlorophyll b pigment also exhibited similar trend of

damage. 22 to 30% reduction was registered at Angadh, Bajwa, Ranoli and Koyali. 12 to 22% reduction was observed at Dhanora, Sankarda and Dumad. At remaining stations the pigment content was more or less close to the control observations. (Fig.4.10.4.).

(ii) Effect on foliar protein content : In rayan, maximum reduction (43.9%) was recorded at Angadh. At Koyali, Bajwa and Dhanora, the percentage of reduction in protein content ranged from 22 to 36%. At remaining stations except Ampad, 12 to 21% reduction was observed, whereas at Ampad it was only 9%. (Fig.4.10.5.).

(iii) Effect on foliar sulphur content : Sulphur content increased over control in the foliar tissues at the pollution zone. Very high accumulation of sulphur over control was recorded at Bajwa (5.76) and Angadh (5.14 times). At Koyali, Dhanora, Ranoli and Sankarda, it was 3 to 3.9 times over control. At all the remaining stations except Ampad, sulphur content ranged from 1.5 to 2.5 times over control. At Ampad, the foliar sulphur content was very close to control. (Fig.4.10.6.).

(iv) Effect on foliar chloride content : Maximum chloride content over control (2.59 times) in rayan leaves was registered at Ranoli. At Angadh it was 1.38 times over control, whereas at stations like Bajwa, Sankarda, Dhanora

Table 20. Effect of industrial air pollution on Manilkara hexandra (Roxb.) Dubard.(rayan)
(Biochemical observations)

Parameter		Koyali	Bajwa	Dumad	Angadh	Ranoli	Dhanora
Chlorophyll a (mg/g.f.wt.)	±	1.09 0.06	1.04 0.08	1.34 0.05	1.11 0.06	1.15 0.19	1.27 0.04
Chlorophyll b (mg/g.f.wt.)	±	0.74 0.02	0.68 0.03	0.83 0.01	0.73 0.02	0.72 0.04	0.80 0.07
Protein (mg/g.f.wt.)	±	38.5 2.1	46.2 2.2	50.3 4.9	33.6 3.8	49.6 5.7	43.1 2.0
Sulphur (mg/g.d.wt.)	±	5.39 0.01	8.12 0.26	3.47 0.02	7.25 0.01	4.40 0.01	4.47 0.05
Chloride (mg/g.d.wt.)	±	2.51 0.01	2.94 0.02	2.46 0.01	3.27 0.04	6.14 0.08	2.63 0.05
Total soluble sugars (mg/g.d.wt.)	±	32.7 3.2	29.5 1.9	42.0 2.7	24.2 1.6	30.3 0.9	31.3 2.4
Reducing sugars (mg/g.d.wt.)	±	72.4 5.4	87.0 3.7	49.6 4.8	78.8 4.5	60.7 5.6	82.9 5.2

± Standard deviation.

Table 20. Contd.

Parameter		Ankodia	Undera	Chhani	Sankarda	Ampad	Samiyala (Control)
Chlorophyll a (mg/g.f.wt.)	±	1.60 0.04	1.46 0.13	1.37 0.09	1.28 0.04	1.46 0.01	1.52 0.06
Chlorophyll b (mg/g.f.wt.)	±	1.00 0.05	0.92 0.06	0.94 0.05	0.76 0.03	1.01 0.02	0.96 0.07
Protein (mg/g.f.wt.)	±	52.30 2.0	50.60 4.1	47.80 1.5	50.30 2.6	54.50 3.4	59.90 3.5
Sulphur (mg/g.d.wt.)	±	2.34 0.01	2.24 0.01	3.43 0.03	4.27 0.04	1.30 0.01	1.41 0.03
Chloride (mg/g.d.wt.)	±	2.54 0.02	2.63 0.03	2.44 0.11	2.82 0.02	2.32 0.04	2.37 0.01
Total soluble sugars (mg/g.d.wt.)	±	41.4 3.4	42.8 5.0	39.2 2.8	30.6 1.7	44.6 2.4	43.9 1.3
Reducing sugars (mg/g.d.wt.)	±	43.6 2.5	56.6 5.8	61.5 4.5	70.0 2.3	45.3 4.0	40.7 3.9

± Standard deviation.

and Undera it ranged from 1.1 to 1.25 times over control. At all remaining stations the chloride level was more or less very close to control. (Fig.4.10.6.).

(v) Effect on foliar total soluble and reducing sugars : In the present study, soluble sugar content declined than control in foliar tissues at pollution zone, whereas reducing sugars exhibited increasing trend at pollution zone over control.

Soluble sugars reduced highly (44.9%) at Angadh and at other highly polluted stations like Bajwa, Dhanora and Ranoli the reduction ranged from 28 to 33%. Among the medium polluted stations, at Sankarda, Koyali and Chhani the soluble sugars decreased 30.3%, 25.5% and 10.7% respectively as compared to control. At all remaining stations the soluble sugar content was close to control. (Fig.4.10.5.).

The reducing sugars increased tremendously in the leaves of rayan growing at pollution zone. At highly polluted stations like Bajwa, Angadh and Dhanora 93 to 114% increase was recorded. Among the medium polluted stations, at Koyali, Sankarda and Chhani 51 to 78% increase over control was registered. At all the remaining stations except Ampad, the percentage increase ranged from 30 to 50%. At Ampad, it was 11.4% higher than control. (Fig.4.10.5.).

3.1.3.3. Effect of industrial air pollution on Syzygium cumini Skeels (Jamun)

3.1.3.3.1. Effect on morphological parameters : (Table 21)

(i) Effect on height of the trees : The height of the trees recorded at Angadh, Ranoli and Bajwa was 18 to 29% less than control trees. The tree height recorded at Chhani, Dhanora, Sankarda was slightly less than control (4 to 8%), whereas it was slightly higher (3 to 8%) at Ampad, Undera, Dumad, Ankodia and Koyali. (Fig.4.10.1.).

(ii) Effect on tree canopy cover : The canopy of jamun trees was maximum affected at Ranoli, where it was 38% less than control. Among other stations, at Angadh, Bajwa and Chhani the percentage reduction was 33.6, 21.1 and 17.9 respectively, whereas at Koyali, Dumad, Dhanora, Ankodia and Sankarda it was 5 to 10% less as compared to control. The canopy cover recorded at Undera and Ampad was slightly higher than the control trees. (Fig.4.10.1.).

(iii) Effect on foliage (mean leaf area and leaf area damaged) : The mean leaf area of jamun was highly reduced at Ranoli (26.8%) and Angadh (16.9%) as compared to control. At Bajwa, Chhani, and Koyali 4 to 11% reduction was recorded, whereas at all the remaining stations the mean leaf area was more or less close to control. (Fig.4.10.2.).

Table 21. Effect of industrial air pollution on Syzygium cumini Skeels (jamun)
(Morphological and yield observations)

Parameter		Koyali	Bajwa	Dumad	Angadh	Ranoli	Dhanora
Height (Mts.)		12.14	10.21	12.55	8.39	9.22	9.43
	±	0.57	0.34	1.13	0.48	0.37	0.19
Canopy cover (m^2)		192.2	168.1	195.2	141.5	132.1	198.9
	±	14.0	10.7	11.4	18.6	12.8	16.8
Mean leaf area (Cm^2)		51.4	48.2	50.8	43.7	39.4	52.6
	±	1.3	3.4	1.5	2.0	2.2	1.8
% Leaf area damaged		4.3	6.3	Nil	18.6	16.5	Nil
% Leaflessness		20.0	20.0	Nil	25.0	35.0	25.0
% Flowering		100.0	70.0	100.0	75.0	75.0	90.0
% Fruiting		75.0	60.0	100.0	50.0	55.0	70.0

± Standard deviation.

Table 21. Contd.

Parameter		Ankodia	Undera	Chhani	Sankarda	Ampad	Samiyala (Control)
Height (Mts.)		12.13	12.28	10.83	11.61	12.70	11.82
	±	1.14	0.73	0.65	0.38	0.67	0.59
Canopy cover (m^2)		200.7	247.6	175.0	119.9	236.8	213.4
	±	21.3	18.1	19.6	22.5	17.0	14.8
Mean leaf area (Cm^2)		52.8	54.0	48.4	53.2	55.1	53.8
	±	2.5	5.3	1.6	3.7	4.5	2.6
% Leaf area damaged		Nil	Nil	Nil	3.6	Nil	Nil
% Leaflessness		Nil	Nil	15.0	15.0	Nil	Nil
% Flowering		100.0	100.0	100.0	100.0	100.0	100.0
% Fruiting		100.0	100.0	85.0	85.0	100.0	100.0

± Standard deviation.

Visible foliar damage was mostly recorded at highly polluted stations. The percentage leaf area damaged was maximum at Angadh (18.6) followed by Ranoli (16.5), Bajwa (6.3), Koyali (4.3) and Sankarda (3.6). At all the remaining stations no significant foliar damage was observed. (Fig.4.10.2.).

(iv) Effect on defoliation : Jamun trees exhibited leaflessness only at high pollution zones i.e. Ranoli, Angadh and Bajwa, where the percentage of leaflessness ranged from 20 to 35%. At all other remaining stations, trees were not exhibiting significant defoliation.(Fig.4.10.2.).

3.1.3.3.2. Effect on fruit yield :

Flowering of jamun was more affected at high pollution zones. 10 to 30% reduction in flowering was registered at Bajwa, Angadh, Ranoli and Dhanora. At the remaining stations, flowering was less affected. (Fig.4.10.3.).

The fruit yield was maximum affected at Angadh, where the reduction was 50% as compared to control. 30 to 45% reduction in fruit production was recorded at Bajwa, Ranoli and Dhanora. Among the medium polluted stations, at Koyali, Sankarda and Chhani 15 to 25% reduction was noticed. At the remaining stations fruit production was close to control. (Fig.4.10.3.).

3.1.3.3.3. Effect on biochemical parameters : (Table 22)

(i) Effect on chlorophyll pigments : Chlorophyll a pigment was highly decreased at Angadh (45.0%) and Ranoli (36.2%) as compared to control. 15 to 30% reduction was registered at Bajwa, Koyali and Dhanora. At the remaining stations chlorophyll a level was more or less close to control. (Fig.4.10.4.).

Similar trend of damage was observed in chlorophyll b pigment content. High reduction was observed at Angadh (44.9%) and Ranoli (35.7%) as compared to control. At Bajwa, Koyali and Dhanora 14 to 30% reduction was recorded. At the remaining stations except Ampad, the chlorophyll b content was very close to control. At Ampad it was slightly higher than (7.1%) control. (Fig.4.10.4.).

(ii) Effect on foliar protein content : It decreased in jamun at polluted zones, as compared to control. 27 to 44% reduction was registered at high pollution zones i.e. Angadh, Ranoli, Bajwa and Dhanora. At the medium polluted stations like Dumad, Koyali, Chhani, Ankodia, Undera and Sankarda, protein content was 11 to 21% less than control. At Ampad minimum (7.6%) reduction in protein content was registered. (Fig.4.10.5.).

(iii) Effect on foliar sulphur content : Very high accumulation of sulphur over control was recorded at Angadh

Table 22. Effect of industrial air pollution on *Syzygium cumini* Skeels (jamun)
(Biochemical observations)

Parameter		Koyali	Bajwa	Dumad	Angadh	Ranoli	Dhanora
Chlorophyll a (mg/g.f.wt.)	±	1.14 0.03	1.05 0.07	1.42 0.04	0.82 0.07	0.95 0.01	1.26 0.08
Chlorophyll b (mg/g.f.wt.)	±	0.77 0.02	0.69 0.03	0.95 0.05	0.54 0.01	0.63 0.04	0.84 0.02
Protein (mg/g.f.wt.)	±	48.7 1.2	42.4 1.5	47.2 3.6	33.4 1.4	36.3 1.9	42.9 5.1
Sulphur (mg/g.d.wt.)	±	2.33 0.04	3.08 0.06	1.84 0.03	3.16 0.03	1.47 0.05	1.68 0.05
Chloride (mg/g.d.wt.)	±	0.72 0.03	0.71 0.01	0.82 0.07	1.75 0.04	3.66 0.08	0.92 0.02
Total soluble sugars (mg/g.d.wt.)	±	47.5 1.4	42.8 3.1	52.1 0.8	36.5 2.7	33.7 1.6	50.4 1.8
Reducing sugars (mg/g.d.wt.)	±	83.4 6.3	104.3 5.1	63.4 2.8	111.7 4.9	90.6 6.7	84.2 4.5

± Standard deviation.

Table 22. Contd.

Parameter		Ankodia	Undera	Chhani	Sankarda	Ampad	Samiyala (Control)
Chlorophyll a (mg/g.f.wt.)	±	1.46 0.02	1.51 0.03	1.42 0.09	1.48 0.06	1.53 0.08	1.49 0.01
Chlorophyll b (mg/g.f.wt.)	±	0.97 0.01	1.01 0.07	0.95 0.01	0.96 0.05	1.05 0.07	0.98 0.03
Protein (mg/g.f.wt.)	±	51.5 3.8	50.6 1.4	48.2 5.6	52.8 3.5	54.7 3.8	59.2 2.9
Sulphur (mg/g.d.wt.)	±	1.34 0.01	1.52 0.04	1.68 0.03	1.61 0.07	1.13 0.06	1.05 0.01
Chloride (mg/g.d.wt.)	±	0.57 0.01	0.72 0.07	0.69 0.04	0.62 0.03	0.51 0.03	0.53 0.01
Total soluble sugars (mg/g.d.wt.)	±	53.7 2.5	51.6 1.8	49.4 4.2	46.9 3.3	54.7 2.4	56.8 1.1
Reducing sugars (mg/g.d.wt.)	±	64.9 3.1	72.8 6.0	85.9 3.8	87.6 5.9	64.6 1.8	60.5 2.7

± Standard deviation.

(3.01 times) followed by Bajwa (2.93), Koyali (2.2 times) and at other stations like Dumad, Dhanora, Chhani, Sankarda and Undera the sulphur accumulation ranged from 1.4 to 1.75 times over control. At Ankodia and Ampad it was 1.28 and 1.08 times over control respectively. (Fig.4.10.6.).

(iv) Effect on foliar chloride content : In jamun, very high chloride content in foliar tissues was recorded at Ranoli (6.91 times) and Angadh (3.30 times) over control. At Dhanora, Dumad, Undera, Bajwa, Koyali and Chhani, the foliar chloride level was 1.3 to 1.8 times over control. At remaining stations it was close to control. (Fig.4.10.6.).

(v) Effect on foliar total soluble and reducing sugars : In jamun, soluble sugar content declined in the pollution zone as compared to control whereas the reducing sugars accumulated higher in the foliar tissues over control.

Maximum reduction (40.7%) in soluble sugar content was registered at Ranoli followed by Angadh (35.7%) and 16 to 25% reduction was recorded at Bajwa, Koyali and Sankarda. At remaining stations except Ampad, the reduction in soluble sugars varied from 5 to 13% whereas it was very close to control at Ampad. (Fig.4.10.5.).

Accumulation of reducing sugars was very high at Angadh (84.6%) and Bajwa (72.4%) than control. 37 to 50% increase over control was noticed at Ranoli, Chhani, Sankarda, Dhanora

and Koyali. At Dumad, Ankodia and Ampad the reducing sugar content was slightly higher than (4 to 8%) control. (Fig.4.10.5.).

3.1.3.4. SOIL STUDY AT DIFFERENT OBSERVATION ZONES : (Table 23)

(i) Soil pH and Conductivity : The soil pH recorded at Angadh, and Dhanora was 5.85 and 6.96 respectively, whereas soil pH at control site was 7.60. At the remaining stations except Ranoli, soil pH ranged from 7.0 to 7.65, at Ranoli it was 7.92.

Electrical conductivity of soil was more at Ranoli (0.565 mS) followed by Chhani (0.416 mS), Bajwa (0.398 mS), Ankodia (0.397 mS), Dumad (0.365 mS), Koyali (0.356 mS) and at all other stations the soil conductivity varied from 0.3 to 0.339 mS.

(ii) Organic matter : Soil organic content recorded at Angadh was 39% more than control, whereas at Bajwa, Dhanora, Dumad and Sankarda it was 10 to 24% higher than control. At stations like Chhani and Undera it was close to control, whereas at remaining stations, organic matter was 9 to 20% less than control.

(iii) Nitrogen content : The nitrogen content recorded at stations like Dumad, Ampad, Sankarda, Ankodia and Undera was 2 to 9% higher than control. At Angadh and Ranoli, the

Table 23. Study on some soil parameters in different observation zones

STATIONS	pH	Conductivity (mS)	% Organic matter	% Nitrogen	% Sulphur	% Chloride
Koyali	7.04	0.356	2.134	0.086	0.0812	0.0076
Bajwa	7.15	0.398	2.679	0.088	0.1248	0.0080
Dumad	7.57	0.365	2.583	0.099	0.1206	0.0094
Angadh	5.85	0.316	2.997	0.075	0.1556	0.0088
Ranoli	7.92	0.565	1.740	0.079	0.1077	0.0189
Dhanora	6.96	0.302	2.568	0.081	0.1003	0.0087
Ankodia	7.65	0.397	1.895	0.094	0.112	0.0070
Undera	7.56	0.314	2.297	0.093	0.0829	0.0053
Chhani	7.35	0.416	2.257	0.087	0.0975	0.0070
Sankarda	7.46	0.315	2.373	0.094	0.0787	0.0060
Ampad	7.62	0.310	1.956	0.096	0.1162	0.0081
Samiyala (Control)	7.60	0.339	2.156	0.091	0.0855	0.0070

nitrogen level was 17.4% and 13.19% less than control respectively. At all remaining stations it was 3 to 11% less as compared to control.

(iv) Sulphur content : The soil sulphur recorded at Angadh was maximum (1.82 times over control). At stations like Bajwa, Dumad, Ankodia and Ampad it was 1.3 to 1.46 times over control. Among other stations, sulphur content recorded at Ranoli, Dhanora and Chhani was slightly higher than control (1.14 to 1.26 times), whereas at Koyali, Undera and Sankarda it was slightly less than control.

(v) Chloride content : The chloride content in soil samples from Ranoli was very high (2.7 times over control). At stations like Dumad, Angadh and Dhanora it was 1.24 to 1.34 times over control. At Ampad, Bajwa and Koyali it ranged from 1.09 to 1.16 times over control, whereas at Chhani and Undera least difference in soil chloride content was noticed. It was slightly less than control at Sankarda and Ankodia.

3.1.3.5. LEAF ANATOMICAL STUDY

Significant variations were observed in epidermal characters between the leaf samples collected from polluted and least polluted region.

3.1.3.5.1. Impact of air pollution on foliar epidermal traits of Mangifera indica L. (mango) :

Stomatal frequency and stomatal index decreased at polluted stations as compared to control. The percentage reduction in stomatal frequency was more at Ranoli (41.4%) and other stations in decreasing order were Angadh (41.3%), Omkarpura (34.6%) and Bajwa (21.6%). Increase in epidermal cell frequency was observed at the polluted zones. There was no significant difference in size of guard cells, whereas the width of the stomatal aperature reduced at Angadh, Ranoli and Omkarpura. Trichome frequency considerably increased at polluted zones. Maximum increase in trichome frequency was recorded at Angadh (5.4 times over control) followed by Omkarpura (4.8), Ranoli (3.7) and Bajwa (3.4 times over control). (Table 24; Fig.3.5.1.).

3.1.3.5.2. Impact of air pollution on foliar epidermal traits of Manilkara hexandra (Roxb.) Dubard.(rayan):

At pollution zones the stomatal frequency and stomatal index were reduced in the leaves as compared to control. The reduction in stomatal frequency was maximum at Omkarpura (13.6%) and at remaining stations the percentage reduction ranged from 4 to 10. Notable increase in epidermal cell frequency was observed at all the polluted sites as compared

to control. There was no significant change in length of the guard cells at pollution zones, but slight reduction in width of the guard cells was noticed. The subsidiary cell complex exhibited least variations at polluted zones. (Table 25; Fig.3.5.1.).

3.1.3.5.3. Impact of air pollution on foliar epidermal traits of Syzygium cumini Skeels (jamun) :

In this species also the stomatal frequency and stomatal index in trees growing in pollution zone was recorded less than control. Stomatal index in control leaves was 35.4% whereas at Omkarpura, Angadh, Ranoli and Bajwa it was 17.8, 18.3, 20.57 and 26.77% respectively. In jamun no significant difference in size of guard cells was observed between control and polluted specimens. The abnormal structures like deformed stomata were noticed. The frequency of deformed stomata was very high at Ranoli (11.6 times over control) and the other stations in decreasing order were Omkarpura (9.27), Angadh (8.73) and Bajwa (5.73 times over control). (Table 26; Fig.3.5.1.).

3.1.3.5.4. Fluorescence study :

Fluorescence of chlorophyll was drastically reduced in mango leaves from pollution zone as compared to control (Fig.3.5.2.). In rayan there was not much difference between

polluted and control specimens in chlorophyll fluorescence (Fig.3.5.3.), whereas a moderate reduction was observed in chlorophyll fluorescence of jamun due to pollution stress (Fig.3.5.4.). The thickness of foliar cuticle slightly increased than the control in all the three species in pollution zone. This was clearly observed by secondary fluorescence of cuticle. (Figs.3.5.2. to3.5.4.).

Table 24. Impact of air pollution on epidermal traits of Mangifera indica L. (mango)

Parameter	Bajwa	Ranoli	Omkarpura	Angadh	University (Control)
Stomatal frequency/0.1 mm^2	97.37 ± 5.70	67.72 6.60	81.14 5.80	72.9 4.30	124.13 9.25
Epidermal cell frequency/0.1 mm^2	344.40 ± 12.80	380.40 12.10	361.30 13.40	348.50 10.80	323.60 8.90
Stomatal index	22.04	15.11	18.37	17.30	27.72
Size of guard cells (μ)					
i) Length	18.30 ± 0.80	18.30 0.62	17.20 0.46	16.40 0.17	18.50 0.60
ii) Width	8.94 ± 0.17	9.25 0.13	9.80 0.20	8.47 0.13	10.35 0.07
Stomatal aperture (μ)					
i) Length	3.14 ± 0.01	3.0 0.21	2.40 0.03	2.11 0.04	3.30 0.03
ii) Width	1.03 ± 0.01	0.54 0.03	0.90 0.02	0.34 0.001	1.24 0.01
Trichome frequency/ 0.1 mm^2	8.15 ± 0.04	9.29 0.16	10.20 0.11	13.50 0.08	2.50 0.04

± Standard deviation.

Table 25. Impact of air pollution on foliar epidermis of Manilkara hexandra (Roxb.) Dubard. (rayan)

Parameter		Bajwa	Ranoli	Omkarpura	Angadh	University
Stomatal frequency/ 0.1 mm^2		42.57	41.82	38.75	40.4	44.87
	±	1.93	1.59	1.60	0.71	1.50
Epidermal cell frequency/0.1 mm^2		253.24	351.68	349.35	325.30	214.40
	±	6.10	9.51	6.30	4.80	5.11
Stomatal index		14.30	10.60	9.90	11.10	17.30
Size of guard cell (μ)						
i) Length		24.72	24.29	23.40	24.15	25.70
	±	0.03	0.08	0.07	0.18	0.04
ii) Width		8.86	10.30	9.22	8.49	11.60
	±	0.01	0.05	0.01	0.04	0.02
Size of stomatal aperture (μ)						
i) Length		6.27	7.23	7.50	6.86	7.90
	±	0.02	0.01	0.02	0.01	0.03
ii) Width		1.395	1.08	1.50	1.14	1.62
	±	0.001	0.01	0.03	0.005	0.02

± Standard deviation.

Table 26. Impact of air pollution on foliar epidermal traits of *Syzygium cumini* Skeels (jamun)

Parameter		Bajwa	Ranoli	Omkarpura	Angadh	University (Control)
Stomatal frequency/ 0.1 mm^2	±	58.20 3.40	46.21 3.02	57.46 1.40	52.40 2.75	61.04 2.30
Epidermal cell frequency/0.1 mm^2	±	136.30 3.56	178.48 6.00	265.40 8.80	234.10 6.10	111.38 3.70
Stomatal index		26.77	20.57	17.80	18.30	35.40
Size of guard cells (μ)						
i) Length	±	26.00 0.01	23.90 0.13	22.50 0.07	24.60 0.03	27.63 0.02
ii) Width	±	9.10 0.02	9.30 0.06	9.70 0.01	9.43 0.01	10.80 0.03
Size of stomatal aperture (μ)						
i) Length	±	6.92 0.02	5.80 0.05	4.90 0.07	5.64 0.01	7.63 0.03
ii) Width	±	1.20 0.01	0.71 0.01	0.875 0.003	0.69 0.007	1.55 0.01
% Deformed Stomata		6.30	12.80	10.20	9.60	1.10

± Standard deviation.

Fig.3.5.1. Leaf epidermal study

A & B : Epidermal structures of Mangifera indica L. leaf from (A) control and (B) pollution zone showing increased trichome density and decreased stomatal frequency in B.

C & D : Epidermal structures of Manilkara hexandra Dubard. (rayan) - leaf from (C) control and (D) pollution zone showing reduced stomatal frequency in D.

G : A enlarged view of a deformed stomata of Syzygium cumini Skeels

H : A enlarged view of a trichome of Mangifera indica L. leaf.

A x 220 ; B x 220 ; C x 910 ; D x 910 ;
E x 910 ; F x 910 ; G x1200 ; H x 512

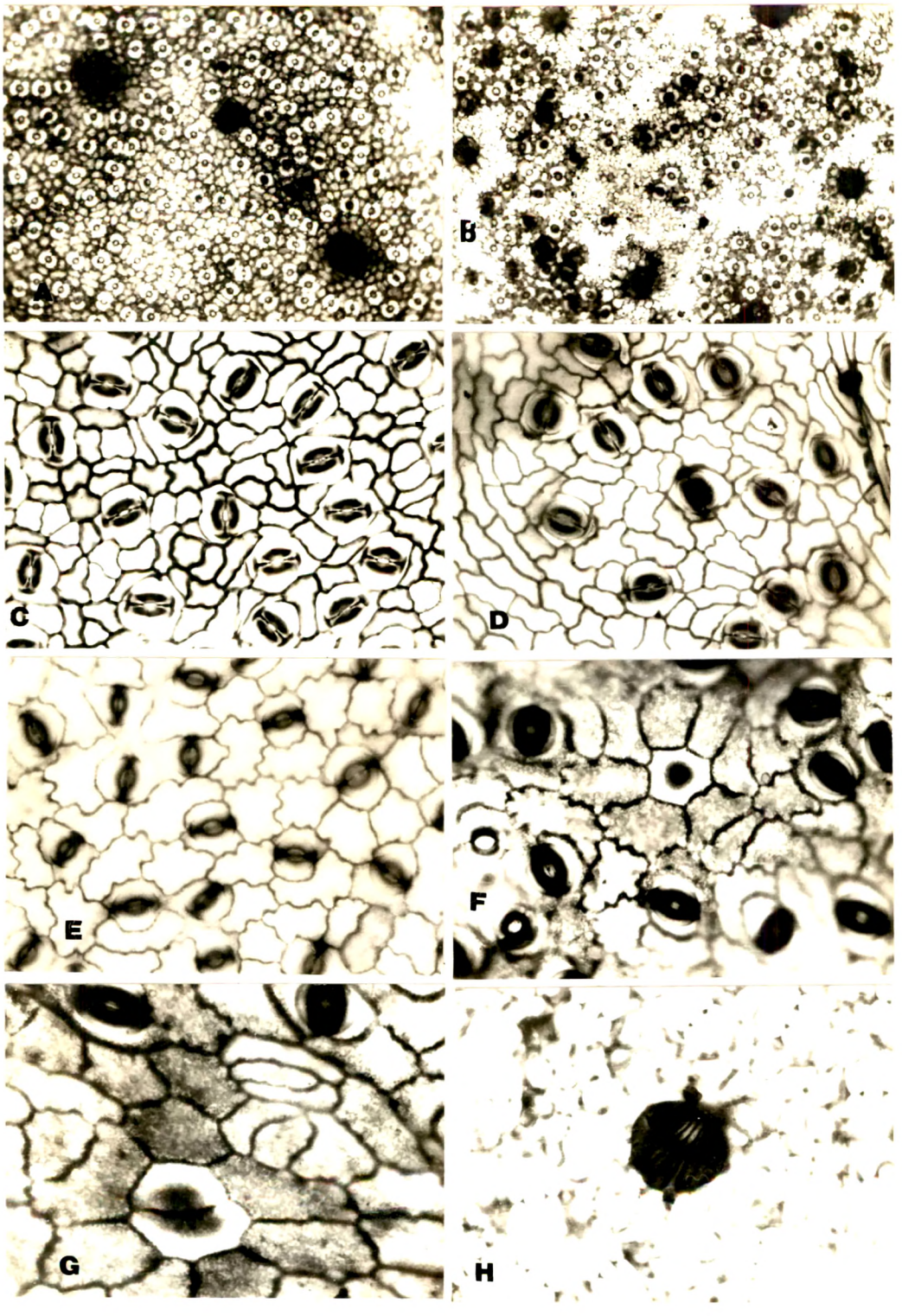

A
B
C
D
E
F
G
H

Fig.3.5.2. Fluorescence study on Mangifera indica L.

A & B : Autofluorescence (reddish) of chlorophyll pigments - leaf from (A) control and (B) pollution zone showing decrease in fluorescence of sample B.

C & D : Induced secondary yellowish fluorescence of cuticle (Cu) with neutral red - leaf from (C) control and (D) pollution zone showing slight increase in cuticular thickness in the sample D.

A x 1120 ; B x 1120 ; C x 448 ; D x 448

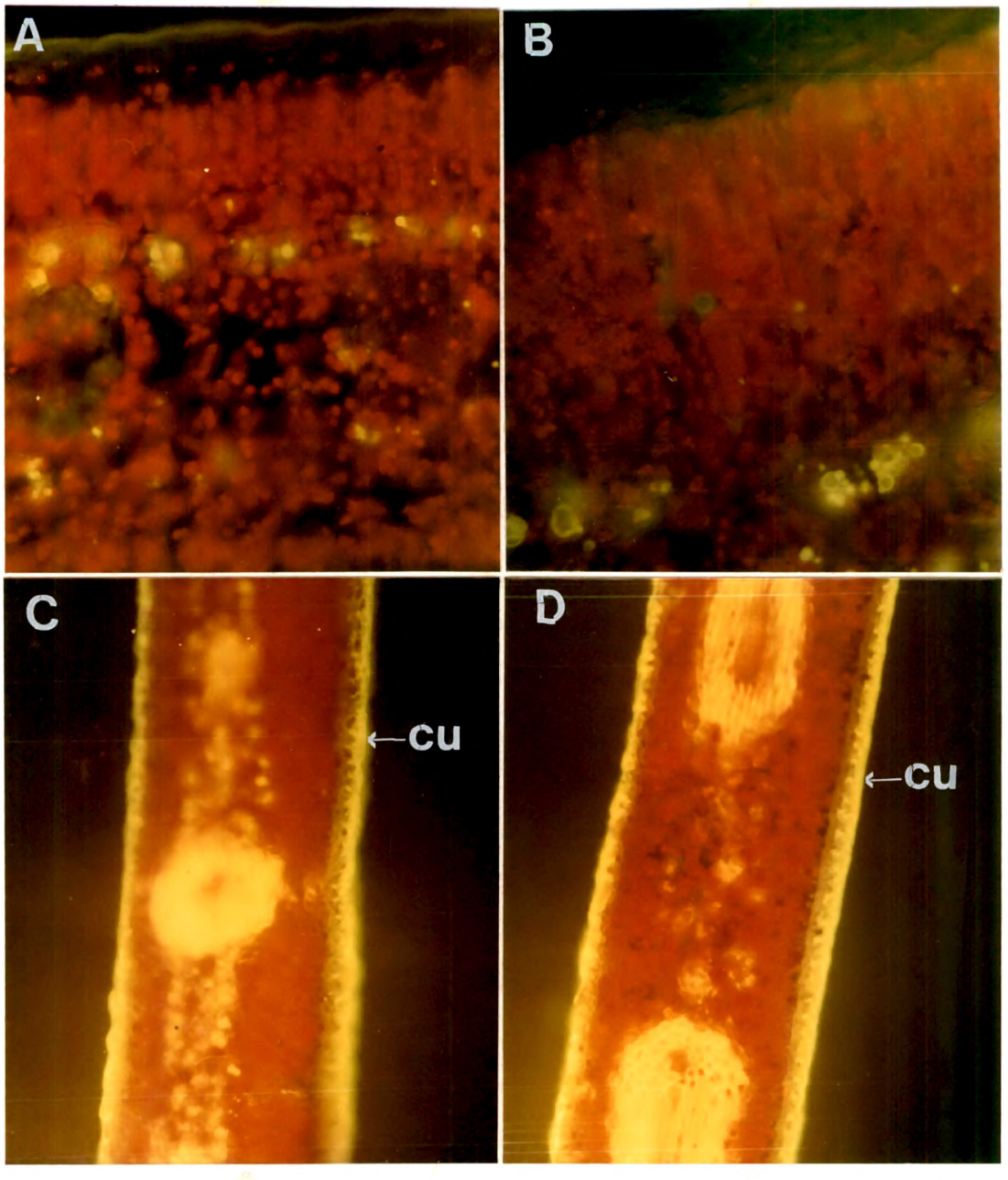

A
B
C
cu
D
cu

Fig.3.5.3. Fluorescence study on Manilkara hexandra Dubard.

A & B : Autofluorescence of chlorophyll pigments (reddish) - leaf fom (A) control and (B) pollution zone showing least difference in fluorescence.

C & D : Induced secondary yellowish fluorescence of cuticle (Cu) with neutral red - leaf from (C) control and (D) pollution zone showing slighst increase in cuticular thickness in the sample D.

A x 1120 ; B x 1120 ; C x 448 ; Dx 448)

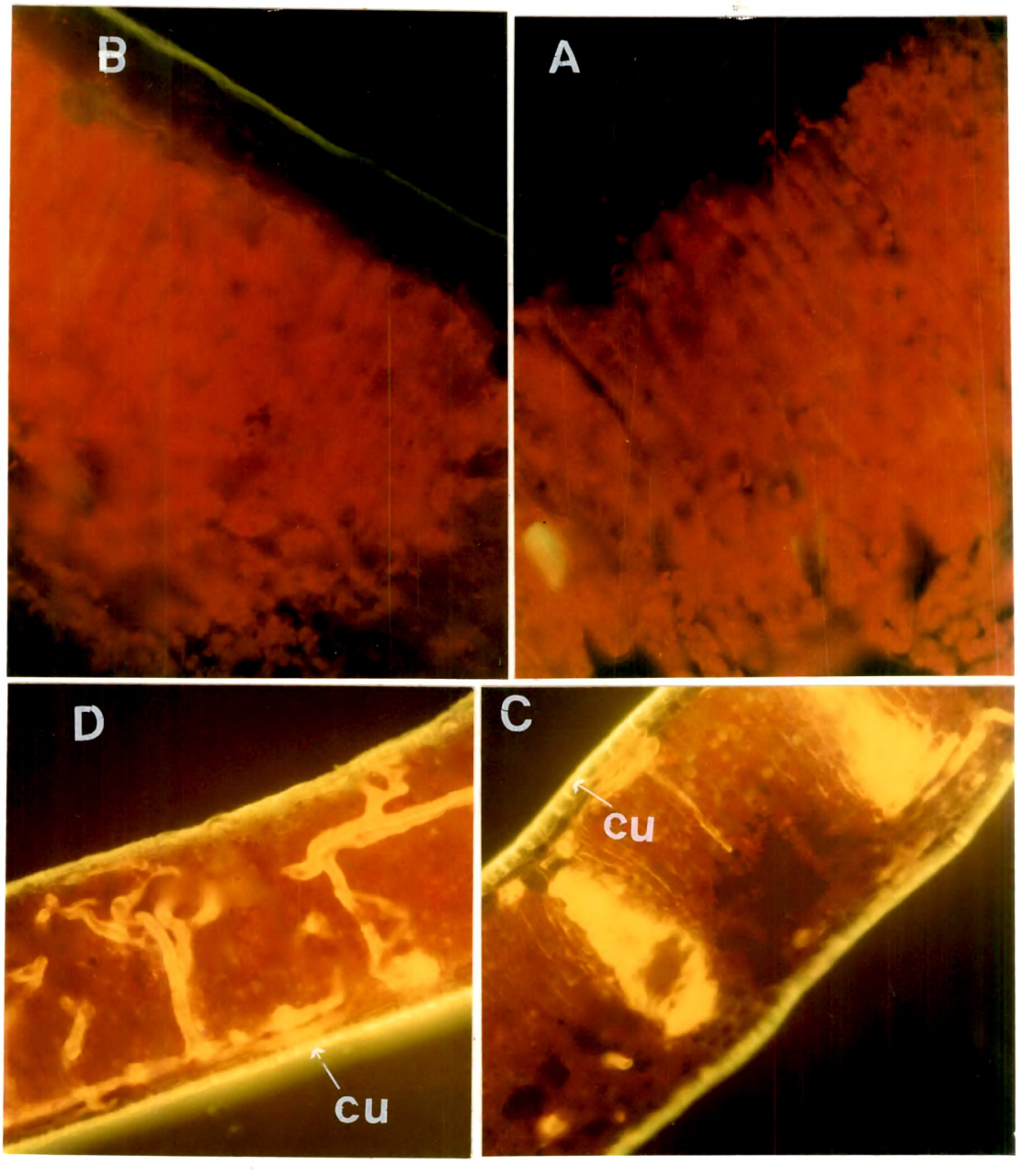
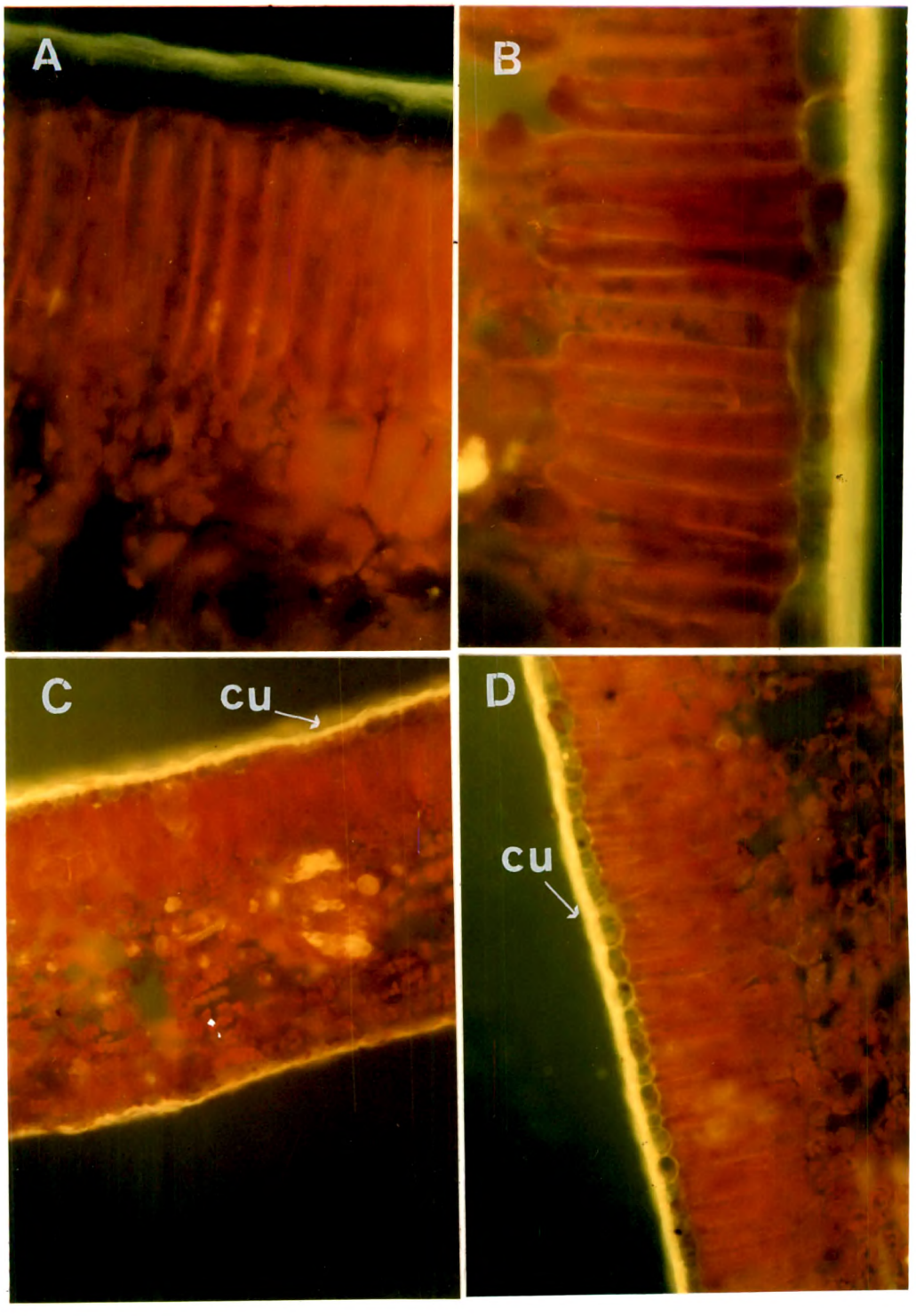

B
A
D
cu
C
cu

Fig. 3.5.4. Fluorescence study on Syzygium cumini Skeels

A & B : Autofluorescence of (reddish) chlorophyll pigments - leaf from (A) control and (B) pollution zone showing moderate reduction in fluorescence in the sample B (Note the thick cuticle (Cu) of the specimen B).

C & D : Induced secondary yellowish fluorescence of cuticle (Cu) with neutral red - leaf from (C) control and (D) pollution zone showing increase in cuticular thickness in the sample from pollution zone.

A x 1120 ; B x 1120 ; C x 448 ; D x 448


A
B
C
cu
D
cu

3.2. FIELD EXPOSURE STUDY

The initial readings of different morphological growth parameters (shoot length, number of leaves/plant, total leaf area etc.) of the tree saplings were not constant, at different experimental stations (Tables 27,30 and 33). The percentage increase or decrease in growth rate was considered for the impact analysis. The growth rate of different growth parameters in control plants was taken as standard for comparison. The difference in initial and final (mean) value of each season in different growth parameters (shoot length, No. of leaves/plant, total leaf area etc.) was compared with growth rate of control, to determine the percentage increase or decrease.

3.2.1. RESPONSE OF FRUIT TREE SAPLINGS TO AIR POLLUTION DURING MONSOON AT DIFFERENT EXPERIMENTAL STATIONS

During monsoon, wind direction was mostly from south or south-west with an average wind speed of 7.3 Km./hr. (Fig. 2.2.4.). The average minimum and maximum temperature was 22.4°C and 34.8°C respectively. The mean relative humidity was 71% (Table 2). The stations Omkarpura, Damapura, Ranoli, Padamla, Fajalpur and Sankarda were on windward direction to the pollution source during most part of the season, whereas Angadh, Bajwa and Koyali were on leeward side.

3.2.1.1. Mangifera indica L. (mango)

3.2.1.1.1. Effect on morphological parameters : (Table 28)

(i) Effect on shoot length : The growth rate of mango saplings growing at Damapura decreased by 74.6% as compared to control.* 45 to 64% reduction was noticed at Angadh, Omkarpura, Ranoli, Padamla and Fajalpur. At remaining stations, the growth rate of shoot reduced 31 to 34% as compared to control. (Fig.4.11.1.).

(ii) Effect on foliage : The rate of increase in number of leaves/plant was also affected at pollution zone. Very high reduction was registered at Ranoli (78.7%) and Omkarpura (71.3%). 44 to 64% reduction was recorded at Damapura, Angadh, Padamla, Fajalpur and Sankarda. At Bajwa and Koyali the percentage reduction was 37.2 and 27.7 respectively (Fig.4.11.1.).

Total leaf area was drastically affected at pollution zone as compared to the control. Maximum reduction of leaf area (92.6%) was recorded at Damapura. At Ranoli, Omkarpura and Angadh 73 to 79% reduction was recorded. At the remaining stations, the percentage reduction ranged from 31 to 53% as compared to control. (Fig.4.11.1.).

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* Stations representing % damage are arranged in decreasing order henceforth in the descriptive part.

Table 27. Field exposure of Mangifera indica L. (Mango) saplings (Initial morphological observations)

STATION		Shoot length (Cm)	No. of leaves/ plant	Total leaf area (Cm^2)
Bajwa		36.4	6.8	413
	±	4.7	2.5	24
Koyali		40.1	9.0	443
	±	3.3	1.8	36
Omkarpura		38.7	8.6	406
	±	2.3	0.8	21
Ranoli		37.3	4.8	241
	±	3.7	1.8	16
Padamla		40.3	7.6	256
	±	1.6	2.1	23
Sankarda		36.1	10.8	428
	±	2.8	2.1	19
Fajalpur		34.6	5.6	255
	±	4.0	1.7	18
Damapura		37.9	6.0	267
	±	2.3	1.8	19
Angadh		37.0	5.8	295
	±	2.5	0.7	21
University (Control)		35.8	8.4	369
	±	3.7	2.5	27

± Standard deviation.

Table 28. Response of Mangifera indica L. (mango) saplings to air pollution

MONSOON - Morphological observations

STATION		Shoot length (Cms.)	No. of leaves/ plant	Total leaf area (Cm^2)	Injury index	% Leaves with symptoms
Bajwa		45.0	12.7	596	1.7	4.0
	±	5.7	1.9	28		
Koyali		48.7	15.8	674	-	-
	±	3.6	2.3	35		
Omkarpura		43.6	11.3	481	8.5	37.5
	±	2.7	2.6	13		
Ranoli		42.5	5.8	316	10.6	77.0
	±	3.6	1.4	17		
Padamla		46.0	12.4	496	3.5	18.3
	±	1.4	1.7	22		
Sankarda		44.5	16.0	573	3.8	12.1
	±	1.4	1.3	34		
Fajalpur		41.5	10.6	464	4.3	16.9
	±	3.8	1.2	17		
Damapura		41.1	9.4	321	18.0	100.0
	±	2.5	0.5	15		
Angadh		41.0	9.2	390	7.6	100.0
	±	3.9	1.7	15		
University (Control)		48.4	17.8	721	-	-
	±	2.1	2.6	35		

± Standard deviation.

During monsoon, highest injury index was registered at Damapura (18.0%) and the other stations in decreasing order were Ranoli (10.6%), Omkarpura (8.5%), Angadh (7.6%), Fajalpur (4.3%), Sankarda (3.8%), Padamla (3.5%) and Bajwa (1.7%). No visible foliar damage was observed at Koyali. (Fig.4.11.2.).

At Damapura and Angadh, all the leaves exhibited foliar symptoms, mostly of tip and margin burning. At Ranoli 77.6% of the leaves showed visible foliar symptoms, whereas at Omkarpura, Padamla, Fajalpur and Sankarda 37.5%, 18.3%, 16.9% and 12.1% of leaves exhibited visible damage respectively. 4% of the leaves exhibited symptoms at Bajwa. (Fig.4.11.2.).

3.2.1.1.2. Effect on biochemical parameters : (Table 29)

(i) Effect on photosynthetic pigments : During monsoon, very high reduction (52 to 62%) in chlorophyll pigments like chlorophyll a, b and total chlorophyll was recorded at Omkarpura and Ranoli.

Among the other stations, high reduction in chlorophyll a and b was noticed at Damapura (48.3% and 46.1% respectively) followed by Angadh (41.4% and 44.7%), Fajalpur (41.9% and 32.2%), Padamla (40.4% and 32.2%), Bajwa (30.1% and 25.7%) and Koyali (21.2% and 19.1% respectively). Almost similar pattern was exhibited at respective stations for total chlorophyll content. (Fig.4.11.3.).

Reduction in carotenoid pigments was 41% at Damapura and 33.3% at Angadh. The percentage reduction was between 15 to 30 at the remaining stations. (Fig.4.11.3.).

(ii) Effect on ascorbic acid : At different stations in pollution zone, ascorbic acid content decreased in the foliar tissues as compared to control. High reduction was recorded at Ranoli (42.1%). 31 to 37% reduction was noticed at Damapura, Omkarpura, Angadh and Sankarda. The percentage reduction ranged from 18 to 29 at Padamla, Bajwa and Koyali. (Fig.4.11.4.).

(iii) Effect on protein and total free aminoacids : Very high reduction in protein content was recorded at Ranoli (47.4%) followed by Damapura (38.9%), Omkarpura (33.7%) and Angadh (30.2%) as compared to control. At other stations the percentage reduction of protein varied from 9 to 25% as compared to control. (Fig.4.11.4.).

Higher accumulation of free aminoacids in foliar tissues over control was recorded in the pollution zone. Maximum accumulation was registered at Damapura (2.5 times over control). 1.9 to 2.2 times increase over control was observed at Omkarpura, Angadh, Ranoli and Bajwa, whereas in the remaining stations it ranged from 1.2 to 1.4 times over control. (Fig.4.11.4.).

Table 29. Response of *Mangifera indica* L. (mango) saplings to air pollution

MONSOON - Biochemical observations

Parameter		Bajwa	Koyali	Omkarpura	Ranoli	Padamla
Chlorophyll a (mg/g.f.wt.)	±	1.42 0.06	1.60 0.05	0.83 0.08	0.90 0.04	1.21 0.11
Chlorophyll b (mg/g.f.wt.)	±	1.13 0.04	1.23 0.08	0.63 0.01	0.65 0.04	1.03 0.06
Total chlorophyll (mg/g.f.wt.)	±	2.84 0.15	3.04 0.11	1.59 0.08	2.03 0.09	2.63 0.13
Carotenoids (mg/g.f.wt.)	±	0.78 0.08	0.82 0.02	0.45 0.04	0.46 0.03	0.68 0.01
Ascorbic acid (mg/g.f.wt.)	±	3.49 0.32	3.97 0.29	3.14 0.18	2.82 0.21	3.04 0.15
Protein (mg/g.f.wt.)	±	58.50 3.40	54.90 2.70	42.60 2.50	33.80 1.90	48.50 3.10
Total free aminoacids (mg/g.d.wt.)	±	31.90 2.40	23.30 3.60	38.00 4.10	34.00 4.70	20.90 2.60
Total soluble sugars (mg.g.d.wt.)	±	41.10 3.40	44.10 2.70	35.00 2.30	36.00 1.90	39.40 5.40
Sulphur (mg/g.d.wt.)	±	1.81 0.07	1.44 0.21	2.99 0.34	2.16 0.17	1.93 0.25

Table 29. Contd.

Parameter		Sankarda	Fajalpur	Damapura	Angadh	University (Control)
Chlorophyll a (mg/g.f.wt.)	±	1.36 0.03	1.18 0.13	1.05 0.01	1.19 0.08	2.03 0.12
Chlorophyll b (mg/g.f.wt.)	±	1.12 0.02	1.13 0.06	0.82 0.06	0.84 0.03	1.52 0.05
Total chlorophyll (mg/g.f.wt.)	±	2.57 0.09	2.49 0.04	2.19 0.10	2.39 0.08	4.16 0.09
Carotenpids (mg/g.f.wt.)	±	0.81 0.07	0.74 0.05	0.57 0.06	0.64 0.08	0.96 0.03
Ascorbic acid (mg/g.f.wt.)	±	3.23 0.13	3.76 0.12	3.07 0.24	3.32 0.19	4.87 0.16
Protein (mg/g.f.w t.)	±	49.70 2.30	57.20 3.90	39.20 1.10	44.80 2.60	64.20 3.70
Total free aminoacids (mg/g.d.wt.)	±	24.00 5.70	22.10 3.90	41.60 1.10	36.00 2.60	17.00 3.70
Total soluble sugars (mg/g.d.wt.)	±	41.40 3.30	39.60 2.80	31.40 1.70	36.20 3.50	43.40 2.70
Sulphur (mg/g.d.wt.)	±	2.16 0.09	2.47 0.13	3.20 0.17	2.78 0.26	1.03 0.08

(iv) Effect on total soluble sugars : It decreased 27.7% at Damapura, whereas at Omkarpura, Ranoli and Angadh the percentage reduction was between 15 to 20 as compared to the control. In the remaining stations except Koyali, reduction in sugar content was 4 to 10% only. At Koyali, sugar content in mango leaves was very close to control. (Fig.4.11.5.).

(v) Effect on sulphur content : Higher accumulation of sulphur in foliar tissues over control was observed at Damapura (3.11 times) and the other stations in decreasing order were Omkarpura (2.9), Angadh (2.7), Fajalpur (2.4), Sankarda and Ranoli (2.1), Padamla (1.87), Bajwa (1.76) and Koyali (1.4 times over control). (Fig.4.11.5.).

3.2.1.2. Manilkara hexandra (Roxb.) Dubard. (rayan)

3.2.1.2.1. Effect on morphological parameters : (Table 31)

(i) Effect on shoot length : During monsoon, the growth rate of shoot highly decreased at Omkarpura (46.0%) followed by Damapura (40.5%), Fajalpur (36.5%) and Ranoli (25.7%). 10 to 20% reduction was recorded at all other stations except Koyali where the growth rate was 8.9% higher than control. (Fig.4.12.1.).

(ii) Effect on foliage : The rate of increase in number of leaves/plant was highly affected at Omkarpura, where the reduction was 52.8% as compared to control. 33 to 45%

Table 30. Field exposure of Manilkara hexandra (Roxb.) Dubard. (rayan) saplings

(Initial morphological observations)

STATION		Shoot length (Cm.)	No. of leaves/ plant	Total leaf area (Cm^2)
Bajwa		5.8	3.6	9.4
	±	1.0	0.8	0.5
Koyali		6.2	3.8	13.2
	±	2.2	1.2	0.4
Omkarpura		6.9	3.1	11.0
	±	1.4	0.5	1.4
Ranoli		5.9	2.6	10.1
	±	1.4	0.5	0.6
Padamla		5.9	3.0	8.5
	±	1.4	0.5	0.2
Sankarda		7.0	4.2	13.5
	±	1.8	0.7	0.8
Fajalpur		5.5	3.1	11.4
	±	1.7	0.6	0.2
Damapura		5.7	3.6	13.5
	±	0.8	0.5	0.5
Angadh		6.8	4.6	11.9
	±	0.2	0.1	0.3
University (Control)		6.8	3.4	10.1
	±	0.5	0.4	0.2

± Standard deviation

Table 31. Response of Manilkara hexandra (Roxb.) Dubard (rayan) saplings to air pollution
MONSOON - Morphological observations

STATION		Shoot length (Cm)	No.of leaves/ plant	Total leaf area (Cm^2)	Injury index	% of leaves with symptoms
Bajwa		12.3	8.9	60.2	-	-
	±	1.6	1.2	4.5		
Koyali		15.0	10.9	74.2	-	-
	±	1.2	1.4	2.6		
Omkarpura		10.9	6.5	41.4	2.5	15.4
	±	1.4	1.1	3.6		
Ranoli		11.4	7.4	46.0	-	-
	±	2.1	1.8	2.5		
Padamla		11.9	8.8	61.9	-	-
	±	1.5	0.9	4.2		
Sankarda		13.6	11.1	92.6	-	-
	±	2.3	1.6	3.1		
Fajalpur		10.2	8.3	45.3	-	-
	±	1.6	1.4	2.9		
Damapura		10.1	7.6	41.0	4.8	23.8
	±	1.8	1.3	4.3		
Angadh		12.8	9.1	63.7	1.7	17.1
	±	1.3	1.8	8.1		
University (Control)		14.6	10.6	86.2	-	-
	±	1.2	1.5	5.3		

± Standrad deviation.

reduction was recorded at Damapura, Angadh and Ranoli. 19 to 28% reduction was registered at Fajalpur, Bajwa and Padamla, whereas the growth rate at Sankarda (4.2%) and Koyali (1.4%) was close to control (Fig.4.12.1.).

50 to 64% reduction in the leaf area was recorded at Damapura, Omkarpura, Fajalpur and Ranoli as compared to control. At Angadh, Bajwa, Padamla and Koyali the reduction ranged from 19 to 34%. (Fig.4.12.2.).

In rayan, visible symptoms were comparatively less. At Damapura 23.8% of the leaves exhibited visible foliar damage and the injury index was 4.8%. At Angadh and Omkarpura 17.1% and 15.4% of the leaves exhibited the injury index of 1.7% and 2.5% respectively. In the remaining stations foliar symptoms were not visible during this season. (Fig.4.12.2.).

3.2.1.2.2. Effect on biochemical parameters : (Table 32)

(i) Effect on photosynthetic pigments : High percentage reduction in chlorophyll a of rayan was recorded at Damapura (51.8) and Omkarpura (44.2). At Angadh and Ranoli reduction was 34.5% and 25.8% respectively, whereas at remaining stations the reduction ranged from 7 to 15% as compared to control. (Fig.4.12.3.).

Maximum reduction in chlorophyll b and total chlorophyll

content was recorded at Damapura (48.0% and 52.7%) followed by Omkarpura (40.2% and 44%), Angadh (32.7% and 40.1%), Ranoli (23.0% and 30.4% respectively) and in the remaining stations reduction varied between 6 to 20%. (Fig.4.12.3.).

At Damapura, carotenoids content in the rayan leaves was 41.0% less than control, whereas at Omkarpura and Angadh it was 36.1 and 28.3% respectively. The percentage reduction at all other stations was 4 to 19% as compared to control.

(ii) Effect on ascorbic acid : Foliar ascorbic acid content was mostly reduced in the plants growing at pollution zone. Maximum reduction was observed at Omkarpura (35.8%) followed by Damapura (30.6%) and Angadh (21.8%). In the remaining stations except Koyali, the percentage reduction in ascorbic acid was 7 to 16% as compared to control. At Koyali slight increase (6%) in ascorbic acid than control was noticed. (Fig.4.12.4.).

(iii) Effect on protein and total free aminoacids : Foliar protein content was 36.7% less than control at Omkarpura, whereas at Damapura, Angadh and Ranoli the reduction ranged between 22 to 31%. At all other stations except Koyali and Sankarda the percentage reduction was 14 to 19%. At Koyali and Sankarda minimum reduction (6 to 8%) was noticed as compared to the control. (Fig.4.12.4.).

Very high accumulation of free aminoacids over control

Table 32. Response of Manilkara hexandra (Roxb.) Dubard.(rayan) saplings to air pollution

MONSOON - Biochemical observations

Parameter		Bajwa	Koyali	Omkarpura	Ranoli	Padamla
Chlorophyll a (mg/g.f.wt.)		1.39	1.50	0.91	1.21	1.41
	±	0.13	0.07	0.18	0.05	0.13
Chlorophyll b (mg/g.f.wt.)		1.03	1.11	0.73	0.94	1.03
	±	0.02	0.08	0.11	0.07	0.12
Total chlorophyll (mg/g.f.wt.)		2.89	3.14	1.97	2.45	2.86
	±	0.12	0.17	0.14	0.22	0.16
Carotenoids (mg/g.f.wt.)		0.96	1.04	0.75	0.96	1.06
	±	0.02	0.08	0.06	0.02	0.03
Ascorbic acid (mg/g.f.wt.)		4.28	4.52	3.09	4.06	4.04
	±	0.42	0.37	0.19	0.13	0.17
Protein (mg/g.f.wt.)		39.90	43.40	29.60	36.40	38.30
	±	2.50	3.80	4.70	6.20	3.40
Total free aminoacids (mg/g.d.wt.)		10.00	9.40	24.80	23.00	21.60
	±	1.70	2.50	6.10	3.50	4.80
Total soluble sugars (mg/g.d.wt.)		47.30	55.70	38.20	40.80	43.30
	±	4.50	3.30	5.70	2.90	6.30
Sulphur (mg/g.d.wt.)		1.86	1.51	2.93	2.33	2.49
	±	0.08	0.11	0.07	0.06	0.09

± Standard deviation.

Table 32 • Contd•

Parameter		Sankarda	Fajalpur	Damapura	Angadh	University (Control)
Chlorophyll a (mg/g•f•wt•)	±	1•50 0•01	1•40 0•03	0•79 0•02	1•07 0•07	1•63 0•09
Chlorophyll b (mg/g•f•wt•)	±	1•14 0•09	1•10 0•04	0•63 0•05	0•82 0•04	1•22 0•15
Total chlotophyll (mg/g•f•wt•)	±	3•21 0•18	2•80 0•12	1•67 0•19	2•11 0•18	3•52 0•11
Carotenoids (mg/g•f•wt•)	±	1•13 0•05	1•06 0•06	0•70 0•04	0•85 0•09	1•18 0•01
Ascorbic acid (mg/g•f•wt•)	±	4•46 0•28	3•34 0•16	3•34 0•13	3•76 0•24	4•81 0•19
Protein (mg•g•f•wt•)	±	43•60 4•50	38•00 6•20	32•00 5•10	35•90 4•80	46•70 3•30
Total free aminoacids (mg/g•d•wt•)	±	13•60 3•60	16•50 2•50	24•50 4•70	17•10 1•60	5•90 0•70
Total soluble sugars (mg/g•d•wt•)	±	46•80 2•80	42•00 6•10	36•50 4•60	43•20 2•70	51•80 3•70
Sulphur (mg/g•d•wt•)	±	1•99 0•05	2•77 0•04	3•43 0•10	2•07 0•11	1•37 0•06

was recorded at Omkarpura and Damapura (4.2 times) followed by Ranoli and Padamla (3.9 and 3.7 times respectively). The other stations in the decreasing order were Angadh (2.9), Fajalpur (2.8), Sankarda (2.3), Bajwa (1.7) and Koyali (1.6 times). (Fig.4.12.4.).

(iv) Effect on total soluble sugars : Maximum reduction in total soluble sugars was recorded at Damapura (29.5%) followed by Omkarpura (26.3%) and Ranoli (21.2%). At the remaining stations except Koyali, the reduction was 8 to 19% whereas at Koyali soluble sugars slightly increased (7.5%) over control. (Fig.4.12.5.).

(v) Effect on foliar sulphur : During monsoon, maximum sulphur accumulation in rayan leaves over control was recorded at Damapura (2.5 times) and the other stations in decreasing order were Omkarpura (2.14), Fajalpur (2.02), S Sankarda (1.82), Ranoli (1.77), Angadh (1.5), Bajwa (1.36) and Koyali (1.1 times). (Fig.4.12.5.).

3.2.1.3. Syzygium cumini Skeels (jamun)

3.2.1.3.1. Effect on morphological parameters : (Table 34).

(i) Effect on shoot length : Maximum reduction in growth rate of shoot (68.7%) was recorded at Damapura followed by Omkarpura (60.7%) and Ranoli (59.3%). 10 to 25% reduction was registered at Angadh, Fajalpur, Padamla and

Sankarda. At Bajwa (5.3%) and Koyali (3.3%) it was slightly less than control. (Fig.4.13.1.).

(ii) Effect on foliage : The rate of increase in the number of leaves/plant was also affected at pollution zone. 42 to 59% reduction was observed at Damapura, Angadh and Omkarpura. At Padamla, Fajalpur, Ranoli and Bajwa 25 to 34% reduction was registered. At remaining stations the percentage reduction ranged from 13 to 19 as compared to control. (Fig.4.13.1.).

In jamun, the leaf area was highly reduced at Ranoli (68.6%) and Damapura (66.0%) as compared to the control. 52 to 57% reduction was noticed at Omkarpura, Angadh, Padamla and Fajalpur. At remaining stations the reduction ranged from 18 to 23%. (Fig.4.13.2.).

During monsoon, injury index was observed maximum at Ranoli (10.5%) followed by Damapura (7.3%), Omkarpura (5.6%), Padamla (4.2%), Angadh (1.8%) and Fajalpur (1.75%). In the remaining stations visible foliar symptoms were not observed. (Fig.4.13.2.).

At Damapura, 12.7% of the leaves exhibited visible damage whereas at Ranoli and Omkarpura it was 9.4% and 8.2% respectively. In the remaining stations like Padamla, Angadh and Fajalpur 3 to 6% of leaves showed symptoms. (Fig.4.13.2.).

Table 33. Field exposure of Syzygium cumini Skeels (jamun) saplings

(Initial morphological observations)

STATION		Shoot length (Cm)	No. of leaves/ plant	Total leaf area (Cm^2)	No. of branches/ plant
Bajwa		29.6	10.9	183	1.1
	±	4.5	3.0	15	0.7
Koyali		33.4	8.9	161	2.2
	±	3.5	2.7	17	1.1
Omkarpura		35.1	9.7	233	1.8
	±	4.3	3.8	41	1.3
Ranoli		33.8	10.5	169	2.5
	±	3.4	3.5	13	0.3
Padamla		28.9	8.6	174	1.3
	±	5.2	4.9	15	1.3
Sankarda		29.3	8.9	191	1.8
	±	5.8	5.2	25	1.5
Fajalpur		25.8	11.4	209	0.9
	±	6.6	4.4	28	0.3
Damapura		26.7	14.5	242	1.1
	±	2.5	3.8	36	0.1
Angadh		31.4	9.9	188	0.6
	±	5.6	5.2	27	0.1
University (Control)		30.1	10.3	221	1.1
	±	6.3	4.1	30	0.8

± Standard deviation.

Table 34. Response of Syzygium cumini Skeels (jamun) saplings to air pollution

MONSOON - Morphological observations.

Parameter		Bajwa	Koyali	Omkarpura	Ranoli	Padamla
Shoot length (Cm)		43.8	47.9	41.0	39.9	41.9
	±	3.1	5.8	3.9	2.8	6.3
No. of leaves/plant		21.6	20.6	18.0	21.3	18.3
	±	2.0	2.8	3.7	3.1	2.6
Total leaf area (Cm^2)		810.0	861.0	601.0	438.0	576.0
	±	37.0	48.0	36.0	40.0	67.0
No. of branches/plant		3.1	4.6	4.1	4.1	3.5
	±	0.4	0.5	0.8	1.1	0.8
Injury index		-	-	5.6	10.5	4.2
% Leaves with symptoms		-	-	8.2	9.4	3.8

± Standard deviation.

Table 34. Contd.

Parameter		Sankarda	Fajalpur	Damapura	Angadh	University (Control)
Shoot length (Cm)		42.7	38.7	31.4	42.8	45.1
	±	3.6	4.8	2.5	2.1	2.6
No. of leaves/plant		21.4	21.5	20.5	18.1	24.8
	±	1.7	3.4	2.7	3.3	1.9
Total leaf area (Cm^2)		885.0	615.0	533.0	559.0	1077.0
	±	69.0	36.0	68.0	44.0	94.0
No. of branches/plant		2.8	3.2	2.1	1.3	2.4
	±	1.5	1.4	0.7	0.2	0.8
Injury index		-	1.75	7.3	1.8	-
% of leaves with symptoms		-	5.4	12.7	5.5	-

± Standard deviation.

3.2.1.3.2. Effect on biochemical parameters : (Table 35)

(i) Effect on photosynthetic pigments : Chlorophyll a and b pigments decreased 50 to 54% at Ranoli and Omkarpura as compared to control, whereas at Damapura it was 48.5% and 53.2% respectively. Among the other stations, maximum percentage reduction in chlorophyll a and b was observed at Angadh (40.8 and 40.5) followed by Fajalpur (29.1 and 34.8), Padamla (25.7 and 25.3), Bajwa (21.6 and 19.2), Koyali (11.7 and 10.3) and Sankarda (10.5 and 8.8 respectively) as compared to control. (Fig.4.13.3.).

Total chlorophyll content in jamun leaves at Omkarpura, Ranoli and Damapura was 46 to 55% less than control. At Angadh and Fajalpur the percentage reduction was 37.8% and 29.5% respectively, whereas at the remaining stations reduction ranged from 11 to 23%. (Fig.4.13.3.).

Maximum percentage reduction in carotenoids content was recorded at Ranoli (50) followed by Omkarpura (43.4). 28 to 38% reduction in carotenoids level was registered at Damapura, Angadh and Fajalpur, whereas at the remaining stations reduction ranged from 5 to 18% as compared to control. (Fig.4.13.3.).

(ii) Effect on foliar ascorbic acid : The jamun saplings growing at Damapura, Omkarpura and Ranoli exhibited 27 to

29% reduction in ascorbic acid content as compared to control. The percentage reduction of ascorbic acid in plants growing at remaining stations varied from 11 to 20%. (Fig.4.13.4.).

(iii) Effect on foliar protein and total free aminoacids : Maximum percentage reduction of protein in jamun leaves was recorded at Damapura (38.4) and other stations in decreasing order were Ranoli (36.7), Omkarpura (31.0), Padamla (24.9), Angadh (19.2), Sankarda (16.4), Koyali (14.9), Fajalpur (14.1) and Bajwa (12.6). (Fig.4.13.4.).

Total free aminoacids content increased at all the stations in the pollution zone. Maximum accumulation over control was recorded at Damapura (1.67 times). Among the other stations, significant increase in aminoacids content (1.3 to 1.6 times over control) was recorded at Omkarpura, Ranoli, Angadh, Padamla and Sankarda. At other stations, the accumulation of free aminoacids in jamun leaves ranged from 1.2 to 1.26 times over control. (Fig.4.13.4.).

(iv) Effect on total soluble sugars : It decreased in the jamun plants growing at pollution zone as compared to control. Higher reduction in soluble sugars was noticed (21 to 29%) at Damapura, Ranoli, Omkarpura and Fajalpur. At the remaining stations the percentage reduction ranged from 12 to 18. (Fig.4.13.5.).

Table 35. Response of Syzygium cumini Skeels (jamun) saplings to air pollution

MONSOON - Biochemical observations

Parameter		Bajwa	Koyali	Omkarpura	Ranoli	Padamla
Chlorophyll a (mg/g.f.wt.)	±	1.62 0.03	1.82 0.05	0.97 0.07	1.00 0.04	1.53 0.05
Chlorophyll b (mg/g.f.wt.)	±	1.28 0.06	1.40 0.10	0.78 0.03	0.73 0.04	1.18 0.05
Total chlorophyll (mg/g.f.wt.)	±	3.19 0.14	3.45 0.17	1.86 0.09	1.90 0.07	3.16 0.11
Carotenoids (mg/g.f.wt.)	±	1.12 0.05	1.21 0.02	0.77 0.06	0.68 0.08	1.17 0.03
Ascorbic acid (mg/g.f.wt.)	±	3.39 0.24	3.43 0.26	2.83 0.15	2.86 0.23	3.51 0.18
Protein (mg/g.f.wt.)	±	47.80 2.40	46.60 3.00	37.70 1.60	34.60 1.90	41.10 2.80
Total free aminoacids (mg/g.d.wt.)	±	54.06 5.70	52.30 6.10	71.00 3.40	66.50 4.80	56.50 2.90
Total soluble sugars (mg/g.d.wt.)	±	48.40 1.50	47.90 2.60	45.60 2.10	42.90 1.70	48.20 1.30
Sulphur (mg/g.d.wt.)	±	1.62 0.13	1.46 0.05	2.27 0.02	2.02 0.16	1.80 0.12

± Standard deviation.

Table 35. Contd.

Parameter		Sankarda	Fajalpur	Damapura	Angadh	University (Control)
Chlorophyll a (mg/g.f.wt.)	±	1.84 0.04	1.46 0.10	1.06 0.08	1.22 0.04	2.06 0.02
Chlorophyll b (mg/g.f.wt.)	±	1.45 0.01	1.03 0.08	0.74 0.04	0.94 0.05	1.59 0.03
Total cholorophyll (mg/g.f.wt.)	±	3.62 0.14	2.89 0.15	2.18 0.09	2.55 0.13	4.10 0.08
Carotenoids (mg/g.f.wt.)	±	1.29 0.04	0.97 0.02	0.85 0.01	0.87 0.03	1.36 0.01
Ascorbic acid (mg/g.f.wt.)	±	3.19 0.16	3.32 0.14	2.82 0.19	3.34 0.12	3.96 0.11
Protein (mg/g.f.wt.)	±	45.70 3.30	47.00 2.60	33.70 1.70	44.20 2.40	54.70 3.10
Total free aminoacids (mg/g.d.wt.)	±	57.20 8.40	51.60 5.30	73.00 7.40	60.30 3.60	43.70 4.20
Total soluble sugars (mg/g.d.wt.)	±	51.40 1.90	46.10 2.40	41.90 2.00	49.20 1.70	58.40 2.50
Sulphur (mg/g.d.wt.)	±	1.63 0.14	2.01 0.11	2.84 0.07	1.88 0.12	1.23 0.04

± Standard deviation.

(v) Effect on foliar sulphur : Total sulphur content in the jamun leaves highly increased over control at Damapura (2.31 times) and the other stations in decreasing order were Omkarpura (1.85), Ranoli (1.64), Fajalpur (1.63), Angadh (1.53), Sankarda (1.33), Bajwa (1.32) and Koyali (1.19 times over control). (Fig.4.13.5.).

3.2.2. RESPONSE OF FRUIT TREE SAPLINGS TO AIR POLLUTION DURING WINTER AT DIFFERENT EXPERIMENTAL STATIONS

During this season, the wind direction was mostly from north or north-east, with an average speed of 3.8 Km./hr. (Fig.2.2.4.). The average atmospheric temperature ranged from 12.1°C to 31.8°C and the mean relative humidity was 58%. During winter, the stations like Angadh, Bajwa and Koyali were in windward direction of the pollution source during most part of the season, whereas all other stations were on leeward side.

3.2.2.1. Mangifera indica L. (mango)

During winter, all the mango saplings were severely damaged and ultimately died at Angadh due to acute exposure to pollution.

3.2.2.1.1. Effect on morphological parameters : (Table 36)

(i) Effect on shoot length : The growth rate of shoot decreased 86.8% at Bajwa and 74.6% at Koyali as compared to control. 56 to 62% reduction was registered at Damapura, Ranoli and Omkarpura. At all other stations the reduction ranged from 21 to 39%. (Fig.4.11.1.).

(ii) Effect on foliage : The rate of increase in number of leaves/plant decreased 62 to 75% at Bajwa, Damapura and Koyali. At all other stations the growth rate was 37 to 53% less than the control. (Fig.4.11.1.).

In mango saplings leaf area was highly affected at Bajwa as compared to control. The percentage reduction was 105% at Bajwa. At Koyali, Damapura and Omkarpura the reduction ranged from 63 to 75%. At the remaining stations, the percentage reduction was 44 to 50%. (Fig.4.11.1.).

High injury index was recorded at Damapura (35.4%) and the other stations in decreasing order were Ranoli (17.5%), Bajwa (14.4%), Koyali and Omkarpura (12.8%), Fajalpur (9.0%), Sankarda (8.5%) and Padamla (7.5%). (Fig.4.11.2.).

Mango leaves of all the saplings growing at Damapura exhibited visible symptoms. At Ranoli, Omkarpura and Bajwa 71%, 47% and 31.6% of leaves showed foliar damage respectively. The percentage of leaves with visible

Table 36. Response of Mangifera indica L. (mango) saplings to air pollution

WINTER - Morphological observations

STATION		Shoot length (Cms)	No.of leaves/ plant	Total leaf area (Cm^2)	Injury index	% of leaves with symptoms
Bajwa		46.5	14.6	568	14.4	31.6
	±	4.2	2.9	26		
Koyali		51.6	18.6	816	6.2	9.3
	±	3.9	1.5	41		
Omkarpura		48.6	15.2	689	12.8	47.0
	±	3.7	1.6	38		
Ranoli		47.5	9.3	554	17.5	71.0
	±	2.8	1.3	27		
Padamla		54.2	15.9	783	7.5	22.0
	±	3.4	1.8	41		
Sankarda		53.5	20.0	874	8.46	14.4
	±	2.8	2.2	37		
Fajalpur		48.5	14.9	780	9.0	16.0
	±	1.6	1.9	39		
Damapura		45.8	11.9	506	35.4	100.0
	±	2.5	2.5	28		
Angadh		All plants ultimately died due to acute exposure to pollution				
University (Control)		59.8	25.2	1285	-	-
	±	3.5	1.7	67		

± Standard deviation.

symptoms varied from 9 to 22 at all the remaining stations. (Fig.4.11.2.).

3.2.2.1.2. Effect on biochemical parameters : (Table 37)

(i) Effect on photosynthetic pigments : Maximum reduction (53 to 60%) in chlorophyll a, b and total chlorophyll pigments was recorded at Bajwa. The percentage reduction in carotenoid pigments was 48.3% at Bajwa as compared to control.

Among the other stations, high damage to chlorophyll a was recorded at Damapura (52.8%). 46 to 48% reduction was noticed at Koyali, Ranoli and Omkarpura, whereas 32 to 39% reduction was at Padamla, Fajalpur and Sankarda.

Reduction in chlorophyll b content was 49.1%, 44.4% and 41.3% at Ranoli, Damapura and Koyali as compared to control. At the remaining stations the chlorophyll b was 25 to 36% less than control.

Higher reduction in carotenoid pigments was registered at Damapura (45.7%) as compared to control. 31 to 38% reduction recorded at Ranoli, Koyali and Omkarpura. At the remaining stations the percentage reduction ranged between 18 to 24. (Fig.4.11.3.).

(ii) Effect on foliar ascorbic acid : Maximum reduction in ascorbic acid content was recorded at Ranoli (40.3%)

followed by Damapura and Bajwa (35%), Omkarpura (33%), Koyali (29.8%), Sankarda (21.5%), Fajalpur and Padamla (19.1%) as compared to control. (Fig.4.11.4.).

(iii) Effect on foliar protein and total free aminoacids : Foliar protein content exhibited high reduction at Ranoli (32.6%). 28 to 30% reduction was recorded at Bajwa, Damapura and Omkarpura, whereas at stations like Koyali, Fajalpur and Padamla 17 to 19% reduction was noticed. Minimum reduction in protein level was at Sankarda (9.4%) during winter. (Fig.4.11.4.).

Total free aminoacids exhibited increasing trend in the foliar tissues at pollution zone as compared to control. The accumulation over control was very high at Damapura (2.4 times), Bajwa (2.0) and Omkarpura (1.8 times). Among the other stations, significant increase was observed at Koyali and Ranoli (1.6 times) whereas at remaining stations it was 1.2 to 1.3 times over control. (Fig.4.11.4.).

(iv) Effect on total soluble sugars : The mango saplings growing at Damapura exhibited maximum reduction in soluble sugars (28.8%) during winter as compared to control. 16 to 22% reduction was registered at Bajwa, Ranoli and Omkarpura. The plants growing at remaining stations showed 5 to 11% reduction in soluble sugars as compared to control. (Fig.4.11.5.).

Table 37. Response of *Mangifera indica* L. (mango) saplings to air pollution

WINTER - Biochemical observations

Parameter		Bajwa	Koyali	Omkarpura	Ranoli	Padamla
Chlorophyll a (mg/g.f.wt.)	±	0.92 0.04	1.21 0.06	1.15 0.11	1.12 0.07	1.29 0.10
Chlorophyll b (mg/g.f.wt.)	±	0.62 0.03	0.78 0.05	0.88 0.02	0.68 0.07	0.99 0.07
Total chlorophyll (mg/g.f.wt.)	±	1.69 0.12	2.54 0.14	2.18 0.09	2.34 0.11	2.71 0.16
Carotenoids (mg/g.f.wt.)	±	0.55 0.01	0.71 0.04	0.73 0.08	0.67 0.05	0.84 0.04
Ascorbic acid (mg/g.f.wt.)	±	3.05 0.28	3.27 0.17	3.12 0.13	2.78 0.11	3.80 0.21
Protein (mg/g.f.wt.)	±	39.70 3.40	45.00 5.10	39.80 2.50	37.30 1.90	45.70 2.70
Total free aminoacids (mg/g.d.wt.)	±	30.60 2.70	24.80 3.50	29.00 2.10	24.80 1.70	19.00 1.30
Total souble sugars (mg/g.d.wt.)	±	30.00 0.90	34.10 2.80	31.70 3.20	29.80 2.60	36.10 1.40
Sulphur (mg/g.d.wt.)	±	3.47 0.09	2.58 0.11	2.95 0.07	2.03 0.08	1.59 0.06

± Standard deviation.

Table 37. Contd.

Parameter		Sankarda	Fajalpur	Damapura	Angadh	University (Control)
Chlorophyll a (mg/g.f.wt.)	±	1.43 0.08	1.29 0.05	1.00 0.07		2.12 0.09
Chlorophyll b (mg/g.f.wt.)	±	0.94 0.05	0.86 0.07	0.74 0.05	All plants ultimately died	1.33 0.09
Total chlorophyll (mg/g.f.wt.)	±	2.78 0.12	2.44 0.08	2.02 0.13		4.22 0.11
Carotenoids (mg/g.f.wt.)	±	0.87 0.03	0.82 0.07	0.58 0.06		1.07 0.05
Ascorbic acid (mg/g.f.wt.)	±	3.64 0.26	3.76 0.18	3.04 0.22		4.66 0.21
Protein (mg/g.f.wt.)	±	50.10 3.60	45.40 4.10	39.70 2.90		55.30 1.80
Total free aminoacids (mg/g.d.wt.)	±	20.20 2.60	22.20 3.70	37.20 4.40		15.50 1.30
Total soluble sugars (mg/g.d.wt.)	±	35.00 4.90	35.30 3.70	27.10 3.40		38.00 2.60
Sulphur (mg/g.d.wt.)	±	2.07 0.10	2.29 0.06	3.60 0.11		1.12 0.03

± Standard deviation.

(v) Effect on foliar sulphur : Sulphur accumulation in mango leaves over control was recorded at Damapura (3.21 times) and the other stations in decreasing order were Bajwa (3.1), Omkarpura (2.63), Koyali (2.3), Fajalpur (2.04), Ranoli (1.81) and Padamla (1.42 times). (Fig.4.11.5.).

3.2.2.2. Manilkara hexandra (Roxb.) Dubard. (rayan)

During winter, rayan saplings growing at Bajwa were severely damaged and ultimately died due to acute exposure to pollution.

3.2.2.2.1. Effect on morphological parameters : (Table 38)

(i) Effect on shoot length : The growth rate of rayan shoot decreased maximum (70.6%) at Angadh as compared to the control. 35 to 55% reduction was registered at Omkarpura, Koyali and Damapura. At Ranoli, Fajalpur and Padamla the reduction ranged from 7 to 18%, whereas at Sankarda the growth rate was 11.8% higher than control. (Fig.4.12.1.).

(ii) Effect on foliage : The rate of increase in number of leaves was also affected in the plants growing at pollution zone. 45 to 59% reduction was observed at Angadh, Omkarpura, Koyali and Damapura. At all the remaining stations the percentage reduction was between 5 to 20% as compared to control. (Fig.4.12.1.).

Table 38. Response of Manilkara hexandra (Roxb.) Dubard. (rayan) saplings to air pollution

WINTER - Morphological observations

STATION		Shoot length (Cm)	No.of leaves/ plant	Total leaf area (Cm^2)	Injury index	% of leaves with symptoms
Bajwa		All plants ultimately died due to acute exposure to air pollution				
Koyali		17.8	13.6	120	-	-
	±	1.3	2.1	18		
Omkarpura		13.2	9.1	79	-	-
	±	1.9	1.4	11		
Ranoli		15.6	11.5	101	-	-
	±	2.0	1.9	13		
Padamla		16.7	13.1	134	-	-
	±	1.8	3.1	24		
Sankarda		19.3	15.9	171	-	-
	±	2.5	1.6	18		
Fajalpur		14.5	12.9	107	-	-
	±	1.6	0.8	17		
Damapura		13.4	10.4	86	6.3	12.4
	±	2.0	1.4	11		
Angadh		14.3	11.2	99	14.5	23.0
	±	1.8	1.5	8		
University (Control)		19.7	15.7	162	-	-
	±	2.0	2.9	15		

± Standard deviation.

In rayan leaf area was highly reduced (53.6%) at Angadh as compared to the control. 40 to 51% reduction was recorded at Omkarpura, Koyali and Damapura. At all other stations except Padamla and Sankarda the reduction was 18 to 28%. At Sankarda and Padamla the growth rate was more or less close to control. (Fig.4.12.2.).

Visible foliar symptoms were observed at Angadh, Damapura and Ranoli. At Angadh, 23% of leaves exhibited an injury index of 14.5%. At Damapura 12.4% of the leaves showed an injury index of 6.3%.(Fig.4.12.2.).

3.2.2.2.2. Effect on biochemical parameters : (Table 39)

(i) Effect on photosynthetic pigments : Maximum reduction in chlorophyll pigments in rayan saplings was recorded at Angadh. Chlorophyll a pigment decreased maximum (48.7%) at Angadh followed by Damapura (32.2%), Omkarpura (26.1%), Koyali (24.1%) and Ranoli (22.4%) as compared to control. At other experimental stations, the percentage ranged between 3 to 11%.

Maximum reduction in chlorophyll b pigment was recorded at Angadh (45.9%), whereas at Koyali, Omkarpura, Ranoli and Damapura the reduction was 19 to 29% as compared to the control. At Padamla, Fajalpur and Sankarda chlorophyll b was close to control. (Fig.4.12.3.).

Total chlorophyll content reduced by 48.2% at Angadh and 40.8% at Damapura as compared to control. At Omkarpura, Ranoli and Koyali the reduction in total chlorophyll was between 29 to 31% whereas at the remaining stations it varied from 6 to 12%.

The carotenoid pigments reduction at Angadh was 35.7% as compared to control. 16 to 28% reduction in carotenoids was registered at Damapura, Koyali, Omkarpura and Ranoli, whereas it was 3 to 11% at the remaining stations. (Fig.4.12.3.).

(ii) Effect on foliar ascorbic acid : In rayan ascorbic acid level decreased by 42.1% at Angadh during winter. At the remaining stations except Sankarda, reduction was from 15 to 26% as compared to control. At Sankarda, foliar ascorbic acid content was very close to control. (Fig.4.12.4.).

(iii) Effect on foliar protein and total free aminoacids : Maximum reduction in protein content was recorded at Angadh (35.2%) as compared to control. At Damapura, Omkarpura, and Koyali, the percentage reduction was between 18 to 23%, whereas at Ranoli, Fajalpur and Padamla it was from 8 to 11%. Foliar protein level was close to control at Sankarda during this season. (Fig.4.12.4.).

Accumulation of free aminoacids in the foliar tissues was observed in the plants growing at pollution zone. Total free aminoacids highly increased over control at Angadh

Table 39. Response of Manilkara hexandra (Roxb.) Dubard.(rayan) saplings to air pollution

WINTER - Biochemical observations

Parameter		Bajwa	Koyali	Omkarpura	Ranoli	Padamla
Chrolophyll a (mg/g.f.wt.)	±	All plants ultimately died	1.19 0.05	1.17 0.04	1.23 0.02	1.41 0.04
Chlorophyll b (mg/g.f.wt.)	±		0.88 0.02	0.86 0.05	0.83 0.09	1.02 0.05
Total chlorophyll (mg/g.f.wt.)	±		2.28 0.16	2.29 0.09	2.26 0.12	2.85 0.15
Carotenoids (mg/g.f.wt.)	±		0.92 0.06	0.92 0.04	0.97 0.07	1.03 0.08
Ascorbic acid (mg/g.f.wt.)	±		3.64 0.29	3.51 0.44	3.76 0.19	3.93 0.14
Protein (mg/g.f.wt.)	±		40.10 6.60	39.90 7.00	47.00 9.20	46.60 8.20
Total free aminoacids (mg/g.d.wt.)	±		22.60 6.10	26.40 1.70	16.80 3.40	14.30 2.10
Total soluble sugars (mg/g.d.wt.)	±		41.40 2.50	45.30 5.20	48.90 5.30	47.20 9.50
Sulphur (mg/g.d.wt.)	±		2.43 0.16	2.54 0.05	1.90 0.06	2.12 0.12

± Standard deviation.

Table 39. Contd.

Parameter		Sankarda	Fajalpur	Damapura	Angadh	University (Control)
Chlorophyll a (mg/g.f.wt.)	±	1.53 0.06	1.46 0.08	1.07 0.14	0.81 0.03	1.58 0.06
Chlorophyll b (mg/g.f.wt.)	±	1.11 0.03	1.05 0.04	0.78 0.09	0.59 0.02	1.09 0.03
Total chlorophyll (mg/g.f.wt.)	±	3.04 0.09	2.90 0.18	1.92 0.13	1.68 0.12	3.24 0.06
Carotenoids (mg/g.f.wt.)	±	1.05 0.07	1.11 0.07	0.84 0.03	0.74 0.09	1.15 0.12
Ascorbic acid (mg/g.f.wt.)	±	4.73 0.13	3.74 0.18	3.44 0.15	2.68 0.16	4.62 0.24
Protein (mg/g.f.wt.)	±	53.20 6.90	45.90 4.10	41.80 5.00	33.20 2.90	51.30 4.10
Total free aminoacids (mg/g.d.wt.)	±	11.30 3.60	19.50 1.80	25.30 4.10	31.40 4.60	7.90 1.20
Total soluble sugars (mg/g.d.wt.)	±	52.70 7.60	49.80 8.30	43.40 9.30	34.00 4.40	54.70 10.20
Sulphur (mg/g.d.wt.)	±	2.17 0.11	2.58 0.16	3.39 0.20	4.41 0.12	1.57 0.04

± Standard deviation.

(4.0 times) followed by Omkarpura (3.3), Damapura (3.2), Koyali (2.9), Fajalpur (2.5) and Ranoli (2.1 times). Accumulation of free amino-acids over control was from 1.4 to 1.6 times at other exposure stations. (Fig.4.12.4.).

(iv) Effect on total soluble sugars : Foliar sugar content decreased maximum at Angadh (37.8%) as compared to control. The percentage reduction in soluble sugars was 17 to 25% at Koyali, Omkarpura and Damapura, whereas it was 3 to 14% at Ranoli, Padamla, Fajalpur and Sankarda. (Fig.4.12.5.).

(v) Effect on foliar sulphur : During winter, highest accumulation of sulphur over control in foliar tissues of rayan was recorded at Angadh (2.81 times). The other stations in decreasing order were Damapura (2.16), Fajalpur (1.64), Omkarpura (1.6), Koyali (1.55), Sankarda (1.38), Padamla (1.35) and Ranoli (1.21 times). (Fig.4.12.5.).

3.2.2.3. Syzygium cumini Skeels (jamun)

3.2.2.3.1. Effect on morphological parameters : (Table 40)

(i) Effect on shoot length : During winter, the growth rate of jamun shoot was highly decreased (48 to 64%) in the plants growing at Angadh, Bajwa, Koyali and Ranoli as compared to the control. At Damapura and Omkarpura the reduction in growth rate was 29.4% and 13.7% respectively. The growth rate was slightly less than control at Padamla

(7.2%) and Fajalpur (3.3%), whereas it was 8.5% higher than control at Sankarda. (Fig.4.13.1.).

(ii) Effect on foliage : In jamun, the growth rate with respect to number of leaves/plant was also highly affected at pollution zone. The reduction was maximum (103.1%) at Angadh followed by Ranoli (70.0%), Bajwa (51.3%) and Damapura (43.1%). The percentage reduction was 10 to 29% at Koyali, Omkarpura and Fajalpur. During winter, jamun saplings at Padamla and Sankarda exhibited slightly higher rate of increase in number of leaves (5.6% and 6.9% respectively) than control plants. (Fig.4.13.1.).

The leaf area was drastically affected at Angadh as compared to the control. The percentage reduction was 114.7 at Angadh, whereas 53 to 70% reduction was registered at Ranoli, Bajwa, Koyali and Omkarpura. 9 to 28% reduction was recorded in plants growing at Omkarpura, Fajalpur and Sankarda. The rate of growth with respect to total leaf area of jamun was very close to control at Padamla. (Fig.4.13.2.).

The injury index was maximum at Angadh (36%) during winter and the other stations in decreasing order were Bajwa (17%), Damapura (13.4%), Ranoli (11.6%) and Koyali (6.4%). Visible foliar damage was not observed at remaining stations during this season. (Fig.4.13.2.).

Table 40. Response of Syzygium cumini Skeels (jamun) saplings to air pollution

WINTER - Morphological observations

Parameter		Bajwa	Koyali	Omkarpura	Ranoli	Padamla
Shoot length (cm)		50.8	55.8	54.2	47.3	56.1
	±	4.2	2.9	4.3	3.6	2.7
No. of leaves/plant		29.4	32.1	31.4	26.1	35.4
	±	3.8	2.6	4.3	3.7	3.2
Total leaf area (cm^2)		974	1046	931	577	1025
	±	38	68	43	40	83
No.of branches/plant		3.6	5.3	4.4	4.3	5.9
	±	1.5	1.7	1.2	1.2	2.4
Injury index		17.0	6.4	-	11.5	-
% of leaves with symptoms		18.6	4.0	2.0	14.8	-

± Standard deviation.

Table 40. Contd.

Parameter		Sankarda	Fajalpur	Damapura	Angadh	University (Control)
Shoot length (cm)		59.3	53.5	42.2	48.4	60.4
	±	3.9	6.2	4.5	3.6	4.9
No.of leaves/plant		38.3	35.9	29.6	17.6	40.8
	±	3.7	4.6	3.3	1.8	3.9
Total leaf area (cm^2)		1299	994	748	492	1534
	±	87	63	53	35	82
No. of branches/plant		2.8	4.3	4.6	3.6	4.3
	±	1.5	1.3	1.9	0.7	1.6
Injury index		-	-	13.4	36.0	-
% leaves with symptoms		-	-	20.6	49.7	-

± Standard deviation.

At Angadh, 50% of the leaves exhibited visible symptoms, in jamun. At Damapura, Bajwa, Ranoli, Koyali and Omkarpura the foliar damage was exhibited by 20.6%, 18.6%, 14.8%, 4.0% and 2.0% of leaves respectively. (Fig.4.13.2.).

3.2.2.3.2. Effect on biochemical parameters : (Table 41)

(i) Effect on photosynthetic pigments : During this season, drastic reduction in chlorophyll pigments was observed at Angadh, Bajwa, Damapura and Ranoli. Chlorophyll a pigment decreased maximum (52.5%) at Angadh, whereas at Bajwa, Damapura and Ranoli it was 40 to 45% less than control. At the remaining stations except Sankarda, the percentage reduction was between 16 to 26%. Chlorophyll a content of jamun leaves at Sankarda was very close to control. More or less similar pattern of damage in total chlorophyll was noticed. (Fig.4.13.3.).

High reduction (43 to 49%) in chlorophyll b pigment was recorded at Angadh, Damapura and Bajwa. At Ranoli the percentage reduction in chlorophyll b was 32.2%, whereas at remaining stations it varied from 14 to 25% as compared to control. (Fig.4.13.3.).

Maximum reduction (40.9%) in carotenoids level was observed at Angadh. Among the other stations, high reduction was observed at Bajwa, Damapura and Ranoli (32.6%, 31.2% and

29% respectively). At the remaining stations, the percentage reduction was between 10 to 16%. (Fig.4.13.3.).

(ii) Effect on foliar ascorbic acid : Ascorbic acid in the foliar tissues of jamun decreased by 41.9%, 39.4%, 37.9% and 20.6% at Angadh, Ranoli, Bajwa and Damapura respectively. The reduction was 10 to 18% at the remaining stations except at Sankarda where it was close to control. (Fig.4.13.4.).

(iii) Effect on foliar protein and total free aminoacids : Foliar protein content diminished maximum at Angadh (46.4%). The other stations in decreasing order were Bajwa (36.6%), Ranoli (28.6%), Damapura (26.7%), Koyali (21.8%) and at the remaining stations it was 12 to 20%, except Sankarda where protein level was slightly higher than control. (Fig.4.13.4.).

Total free aminoacids level increased over control in the plants growing at Angadh (1.67 times), Bajwa (1.56), Damapura (1.38), Ranoli (1.41), Koyali (1.38) and Fajalpur (1.27 times). At the remaining stations the total free aminoacids level was close to control. (Fig.4.13.4.).

(iv) Effect on total soluble sugars : Maximum reduction in soluble sugar content was recorded at Angadh (32.3%) followed by Bajwa (28.3%), Ranoli (26.2%), Koyali (23.1%) and Damapura (18.6%). Among the other stations, 16.3%

Table 41. Response of *Syzygium cumini* Skeels (jamun) saplings to air pollution

WINTER - Biochemical observations

Parameter		Bajwa	Koyali	Omkarpura	Ranoli	Padamla
Chlorophyll a (mg/g.f.wt.)	±	0.91 0.10	1.25 0.04	1.36 0.12	0.97 0.03	1.13 0.06
Chlorophyll b (mg/g.f.wt.)	±	0.67 0.07	0.93 0.04	1.02 0.05	0.80 0.07	0.89 0.03
Total chlorophyll (mg/g.f.wt.)	±	1.86 0.03	2.41 0.06	2.68 0.13	1.97 0.11	2.36 0.08
Carotenoids (mg/g.f.wt.)	±	0.63 0.01	0.80 0.07	0.83 0.04	0.66 0.03	0.82 0.01
Ascorbic acid (mg/g.f.wt.)	±	2.41 0.21	3.17 0.26	3.35 0.14	2.35 0.07	3.48 0.12
Protein (mg/g.f.wt.)	±	33.20 1.40	41.00 1.70	45.60 2.70	37.40 0.90	46.00 1.80
Total free aminoacids (mg/g.d.wt.)	±	63.50 3.20	56.20 2.70	44.00 3.10	57.20 4.90	45.60 1.40
Total soluble sugars (mg/g.d.wt.)	±	36.20 1.60	38.80 1.70	46.10 1.80	37.30 2.40	42.30 1.70
Sulphur (mg/g.d.wt.)	±	3.82 0.07	2.47 0.10	1.95 0.13	1.96 0.05	2.03 0.01

± Standard deviation.

Table 41. Contd.

Parameter		Sankarda	Fajalpur	Damapura	Angadh	University (Control)
Chlorophyll a (mg/g.f.wt.)	±	1.60 0.03	1.19 0.02	0.96 0.01	0.77 0.04	1.62 0.12
Chlorophyll b (mg/g.f.wt.)	±	1.12 0.04	0.90 0.05	0.64 0.03	0.60 0.02	1.18 0.10
Total chlorophyll (mg/g.f.wt.)	±	3.27 0.16	2.40 0.13	1.81 0.09	1.59 0.08	3.38 0.15
Carotenoids (mg/g.f.wt.)	±	0.91 0.02	0.78 0.04	0.64 0.05	0.55 0.07	0.93 0.04
Ascorbic acid (mg/g.f.wt.)	±	3.92 0.16	3.37 0.09	3.08 0.13	2.25 0.08	3.88 0.11
Protein (mg/g.f.wt.)	±	55.10 2.10	42.30 1.60	38.40 2.80	28.10 1.70	52.40 2.50
Total free aminoacids (mg/g.d.wt.)	±	46.00 2.30	51.70 2.60	56.20 3.40	68.00 3.70	40.70 3.40
Total soluble sugars (mg/g.d.wt.)		46.60 1.30	43.40 1.80	41.10 3.10	34.20 2.50	50.50 2.30
Sulphur (mg/g.d.wt.)	±	1.59 0.04	1.80 0.11	2.64 0.02	4.03 0.14	1.43 0.08

± Standard deviation.

reduction was observed at Padamla whereas at the remaining stations reduction was from 8 to 14% as compared to control. (Fig.4.13.5.).

(v) Effect on foliar sulphur content : Very high sulphur accumulation over control in the jamun leaves was recorded at Angadh (2.82 times). The other stations in the decreasing order were Bajwa (2.67), Damapura (1.85), Koyali (1.73), Padamla (1.42), Ranoli (1.37), Omkarpura (1.36), Fajalpur (1.26) and Sankarda (1.21 times over control). (Fig.4.13.5.).

3.2.3. RESPONSE OF FRUIT TREE SAPLINGS TO AIR POLLUTION DURING SUMMER AT DIFFERENT EXPERIMENTAL STATIONS

During this season, wind direction was south or south-west during most of the season with an average speed of 8.0 Km./hr. (Fig.2.2.4.). The mean atmospheric temperature ranged from 19.6°C to 38.1°C and the average relative humidity was 52%. Similar to monsoon season, the stations like Omkarpura, Ranoli and Damapura were on windward direction of the source, whereas Bajwa, Koyali and Angadh were on the leeward side.

3.2.3.1. Mangifera indica L. (mango)

3.2.3.1.1. Effect on morphological parameters : (Table 42)

(i) Effect on shoot length : During summer, growth rate of mango shoots was drastically reduced at pollution zone as compared to the control. 88 to 95% reduction was registered at Ranoli, Omkarpura and Damapura. At Angadh, the shoot growth rate decreased by 75.2%, whereas at Bajwa and Koyali the reduction was 52.9% and 43.1% as compared to the control. (Fig.4.11.1.).

(ii) Effect on foliage : In mango the rate of increase in number of leaves/plant was highly affected at pollution zone. The reduction was very high at Damapura (105.4%) and Omkarpura (101.4%) as compared to control. At all other stations except Koyali, the reduction ranged from 50 to 71%, whereas at Koyali it was 39.2% as compared to control. (Fig.4.11.1.).

During summer, in mango saplings leaf area was observed 75 to 95% less than control at Ranoli, Omkarpura, Damapura and Angadh. At Bajwa and Koyali the percentage reduction was 52.9 and 43.1 respectively. (Fig.4.11.1.).

The injury index was maximum at Damapura (34.1%) during this season and the other stations in the decreasing order

Table 42. Response of Mangifera indica L. (mango) saplings to air pollution

SUMMER - Morphological observations

Parameter		Bajwa	Koyali	Omkarpura	Ranoli	Damapura	Angadh		University (Control)
Shoot length (cm)		48.5	52.6	50.4	49.8	47.7	58.9	(56.8)	65.9
	±	5.1	4.3	3.9	3.1	1.9	1.9	(2.3)	2.4
No.of leaves/plant		18.3	23.1	15.1	11.5	11.5	27.3	(25.2)	30.6
	±	1.7	2.8	1.1	0.8	1.3	2.4	(3.6)	2.8
Total leaf area(Cm^2)		746	1031	727	574	549	1165.0	(1073)	1663.0
	±	31	48	21	36	18	53.0	(41)	78.0
Injury index		16.5	8.5	22.9	29.5	34.1	26.5		-
% Leaves with symptoms		36.6	17.2	83.5	84.1	86.3	72.7		-

± Standard deviation. ( ) Initial observations of new set of plants kept in the beginning of Summer.

were Ranoli (29.5%), Angadh (26.3%), Omkarpura (22.9%), Bajwa (16.5%) and Koyali (8.5%). (Fig.4.11.2.).

In the mango saplings growing at Damapura, Ranoli, Omkarpura and Angadh, 72 to 87% of leaves exhibited visible foliar damage. At Bajwa and Koyali 36.6% and 17.2% of leaves showed damaging symptoms respectively. (Fig.4.11.2.).

3.2.3.1.2. Effect on biochemical parameters : (Table 43)

(i) Effect on photosynthetic pigments : Chlorophyll pigments and carotenoids in mango leaves were significantly damaged at all the exposure stations.

Chlorophyll a pigment reduced 50 to 56% at Omkarpura, Damapura and Ranoli as compared to control. At Angadh, Bajwa and Koyali the percentage reduction was 48.2, 43.1 and 21.7 respectively. (Fig.4.11.3.).

Reduction in chlorophyll b pigment was maximum at Damapura (52.3%). At all the remaining stations except Koyali, the percentage reduction ranged between 38 to 48%, whereas at Koyali it was 27.3%.

Very high reduction in total chlorophyll content was observed at Omkarpura (61.3%), Ranoli (56.1%) and Damapura (53.7%). In the remaining stations except Koyali (22%) reduction was about 44% as compared to control.

Carotenoid pigments were recorded 35 to 46% less than control in mango growing at Damapura, Omkarpura, Ranoli and Angadh. At Bajwa and Koyali the reduction was 27.0% and 18.0% respectively as compared to control. (Fig. 4.11.3.).

(ii) Effect on foliar ascorbic acid : Ascorbic acid decreased in the foliar tissues of mango growing at pollution zone as compared to control. Maximum reduction was at Omkarpura (39.7%), whereas 34 to 38% reduction was registered at Ranoli, Damapura and Angadh. At Koyali and Bajwa, the foliar ascorbic acid content was 26.2% and 21.9% less than control respectively. (Fig.4.11.4.).

(iii) Effect on foliar protein and total free aminoacids : Maximum reduction in protein content was noticed at Omkarpura (32.1%) followed by Damapura (30.9%), Ranoli (25.2%), Angadh (23.8%) and Bajwa (16.1%) as compared to control. At Koyali foliar protein level was very close to control (Fig.4.11.4.).

Total free aminoacids level increased significantly over control at all the stations in the pollution zone. It was very high at Damapura (2.6 times) and Omkarpura (2.4 times over control). At stations like Bajwa, Ranoli and Angadh the accumulation was 2.1 to 2.2 times over control, whereas at Koyali it was only 1.5 times over control. (Fig.4.11.4.).

Table 43. Response of Mangifera indica L. (mango) saplings to air pollution

SUMMER - Biochemical observations

Parameter		Bajwa	Koyali	Omkarpura	Ranoli	Damapura	Angadh	University (Control)
Chlorophyll a (mg/g.f.wt.)	±	1.08 0.03	1.48 0.09	0.84 0.06	0.95 0.02	0.85 0.04	0.98 0.05	1.89 0.07
Chlorophyll b (mg/g.f.wt.)	±	0.82 0.07	0.96 0.03	0.68 0.05	0.69 0.04	0.63 0.06	0.69 0.02	1.32 0.11
Total chlorophyll (mg/g.f.wt.)	±	2.18 0.02	3.02 0.05	1.51 0.08	1.71 0.05	1.80 0.04	2.17 0.06	3.89 0.17
Carotenoids (mg/g.f.wt.)	±	0.82 0.06	0.92 0.04	0.64 0.07	0.66 0.05	0.61 0.08	0.72 0.07	1.12 0.09
Ascorbic acid (mg/g.f.wt.)	±	2.63 0.23	2.85 0.18	2.34 0.14	2.41 0.07	2.46 0.21	2.54 0.03	3.86 0.15
Protein (mg/g.f.wt.)	±	40.60 1.90	45.20 2.60	32.90 0.50	36.20 3.10	33.40 2.70	36.90 2.40	48.40 1.90
Total free amino-acids (mg/g.d.wt.)	±	34.30 3.20	24.50 2.90	38.40 4.70	32.70 5.10	41.60 6.20	33.00 3.90	15.90 2.70
Total soluble sugars (mg/g.d.wt.)	±	34.00 0.90	35.50 2.40	29.90 2.70	28.60 0.70	26.60 1.80	30.40 1.10	38.80 2.40
Sulphur (mg/g.d.wt.)	±	2.67 0.05	2.13 0.06	2.92 0.04	1.90 0.07	3.05 0.02	2.80 0.11	0.98 0.05

± Standard deviation.

(iv) Effect on total soluble sugars : High reduction (31.1%) in soluble sugar content was recorded at Damapura. 21 to 24% reduction in foliar sugar content was recorded at Ranoli, Omkarpura and Angadh. At Bajwa and Koyali the percentage reduction was 12.3% and 9.4% respectively as compared to control. (Fig.4.11.5.).

(v) Effect on foliar sulphur : Maximum sulphur accumulation over control in mango leaves was recorded at Damapura (3.11 times). The other stations in decreasing order were Omkarpura (2.98), Angadh (2.86), Bajwa (2.72), Koyali (2.71) and Ranoli (1.94 times). (Fig.4.11.5.).

3.2.3.2. Manilkara hexandra (Roxb.) Dubard. (rayan)

3.2.3.2.1. Effect on morphological parameters : (Table 44)

(i) Effect on shoot length : During summer, the growth rate of rayan shoots decreased by 46 to 56% at Omkarpura, Damapura and Bajwa as compared to control. At Angadh and Ranoli the reduction was 38.4% and 35.2% whereas at Koyali it was 13.8% respectively (Fig.4.12.1.).

(ii) Effect on foliage : The rate of increase in number of leaves/plant was maximum affected at Damapura followed by Omkarpura, where it was reduced by 53.7% and 51.2% as compared to control respectively. 34 to 44% reduction was recorded at Angadh, Bajwa and Ranoli. At Koyali, the

Table 44. Response of Manilkara hexandra (Roxb.) Dubard.(rayan) saplings to air pollution

SUMMER - Morphological observations

Parameter		Bajwa		Koyali	Omkarpura	Ranoli	Damapura	Angadh	University (Control)
Shoot length (cm)		20.1	(17.2)	22.4	15.6	19.1	16.3	17.6	25.1
	±	2.3	(1.5)	2.0	1.7	2.2	1.4	2.1	1.8
No. of leaves/ plant		15.1	(12.6)	16.7	11.1	14.2	12.3	13.5	19.8
	±	2.3	(0.9)	1.4	0.8	1.1	1.1	0.9	1.6
Total leaf area (Cm^2)		134.0	(118)	153	94.0	115	95.0	121	204
	±	11.0	(16)	15	11.0	10	8.0	15	19
Injury index		1.6		-	8.4	3.5	11.3	4.2	-
% Leaves with symptoms		12.8		-	27.2	11.5	28.0	23.3	-

± Standard deviation. ( ) Initial observations of new set of plants kept in the beginning of Summer.

percentage reduction in growth rate was 24.4 as compared to control. (Fig.4.12.1.).

The total leaf area in the saplings was observed less than control in the plants growing at pollution zone. Maximum reduction (78.8%) was recorded at Damapura. 61 to 67% reduction was noticed at Ranoli, Omkarpura and Bajwa. At Angadh and Koyali, the reduction in growth rate was 47.6% and 21.4% as compared to the control. (Fig.4.12.2.).

During summer, the visible foliar damage was mostly observed at all the stations (except Koyali) under investigation in the pollution zone. Injury index was maximum (11.3%) at Damapura followed by Omkarpura (8.4%), whereas at other stations injury index was from 1.6 to 5%. (Fig.4.12.2.).

In rayan, saplings growing at Damapura, Omkarpura and Angadh 23 to 28% of the total leaves exhibited visible foliar symptoms. At Bajwa and Ranoli 12.8% and 11.5% of the leaves showed visible damaging symptoms respectively. (Fig.4.12.2.).

3.2.3.2.2. Effect on biochemical parameters : (Table 45)

(i) Effect on photosynthetic pigments : During summer severe damage to chlorophyll pigments was noticed in rayan at Damapura and Omkarpura. Chlorophyll a pigment was

reduced 48.9% and 45.6% respectively at these stations as compared to control. At the remaining stations except Koyali, the chlorophyll a content was 23 to 30% less than control. At Koyali the percentage reduction was 11.4. More or less similar pattern of damage was observed in total chlorophyll content.

Maximum reduction in chlorophyll b pigment was registered at Damapura (46.3%). Among the other stations, at Omkarpura and Angadh 44.3% and 30.1% reduction was noticed, whereas at the remaining stations chlorophyll b level was 8 to 22% less than control.

Carotenoid pigments decreased by 45.2% at Damapura, 37.6% at Omkarpura and 21.2% at Angadh. Among the other stations, only at Koyali the percentage reduction was 7, whereas at the remaining stations it was 15 to 20 as compared to control. (Fig.4.12.3.).

(ii) Effect on foliar ascorbic acid : Maximum reduction in ascorbic acid content was recorded at Damapura (34.8%). The other stations in decreasing order were Omkarpura (29.4%), Angadh (24.1%), Bajwa (19.1%) and Ranoli (18.4%). At Koyali it was 8.9% higher than control. (Fig.4.12.4.).

(iii) Effect on foliar protein and total free aminoacids : During summer, foliar protein content decreased at all the stations under investigation. Maximum reduction

Table 45 • Response of Manilkara hexandra (Roxb.) Dubard.(rayan) saplings to air pollution

SUMMER - Biochemical observations

Parameter		Bajwa	Koyali	Omkarpura	Ranoli	Damapura	Angadh	University (Control)
Chlorophyll a (mg/g•f•wt.)	±	1•22 0•07	1•40 0•06	0•86 0•05	1•21 0•09	0•81 0•16	1•11 0•10	1•58 0•13
Chlorophyll b (mg/g•f•wt.)	±	0•89 0•06	1•04 0•15	0•63 0•19	0•98 0•09	0•61 0•12	0•79 0•03	1•13 0•15
Total chlorophyll (mg/g•f•wt)	±	2•45 0•21	2•98 0•19	1•75 0•08	2•19 0•15	1•73 0•03	2•45 0•07	3•32 0•04
Carotenoids (mg/g•f•wt.)	±	0•88 0•05	0•98 0•10	0•66 0•11	0•86 0•13	0•58 0•06	0•83 0•09	1•05 0•08
Ascorbic acid (mg/g•f•wt.)	±	3•13 0•29	3•52 0•14	2•73 0•13	3•15 0•16	2•52 0•07	2•93 0•12	3•86 0•18
Protein (mg/g•f•wt.)	±	37•20 2•50	43•00 5•80	28•90 7•50	33•80 6•40	30•70 6•70	35•20 2•40	47•60 7•10
Total free aminoacids (mg/g•d•wt.)	±	21•20 4•10	18•70 2•90	41•20 4•10	34•40 3•50	37•40 5•70	22•50 4•0	8•40 1•50
Total soluble Sugars (mg/g•d•wt.)	±	37•70 3•80	40•30 8•10	30•80 3•60	31•60 8•20	28•90 4•30	31•90 5•40	44•10 4•60
Sulphur (mg/g•d•wt.)	±	3•01 0•07	2•32 0•11	4•44 0•13	3•04 0•08	5•21 0•15	4•55 0•10	1•68 0•09

± Standard deviation.

was recorded at Omkarpura (39.3%) followed by Damapura (35.5%). At the remaining stations except Koyali (9.7%) the percentage reduction was between 20 to 30% as compared to control. (Fig.4.12.4.).

Very high accumulation of free aminoacids over control was recorded in the plants growing at pollution zone. At Omkarpura, Damapura and Ranoli the aminoacids content varied from 4.1 to 4.9 times over control. At the remaining stations, increase in free aminoacids level was 2.2 to 2.7 times over control. (Fig.4.12.4.).

(iv) Effect on total soluble sugars : Soluble sugar content decreased at all the stations except Koyali as compared to control. Maximum reduction registered at Damapura was 34.8%. The percentage reduction ranged from 14 to 30% at all the remaining stations except Koyali where it was close to control. (Fig.4.12.5.).

(v) Effect on foliar sulphur : During summer, maximum accumulation of sulphur in the foliar tissues of rayan saplings was recorded at Damapura (3.1 times over control). The other stations in the decreasing order were Angadh (2.71), Omkarpura (2.64), Ranoli (1.81), Bajwa (1.79) and Koyali (1.38 times over control). (Fig.4.12.5.).

3.2.3.3. Syzygium cumini Skeels (jamun)

3.2.3.3.1. Effect on morphological parameters : (Table 46)

(i) Effect on shoot length : During summer, the growth rate of jamun shoot of plants growing at Omkarpura was highly decreased (75.9%) as compared to the control. At Ranoli and Damapura the percentage reduction was 65.5 and 60.2 respectively. At all other stations the reduction varied from 32 to 40% as compared to the control. (Fig.4.13.1.).

(ii) Effect on foliage : The rate of increase in number of leaves/plant was also reduced in the plants growing at pollution zone as compared to control. Maximum reduction (50.5%) was registered at Damapura followed by Omkarpura (49.3%). At Bajwa, Angadh and Ranoli the reduction ranged from 14 to 29%, whereas at Koyali growth rate slightly decreased (6.0%) as compared to control. (Fig.4.13.1.).

During summer, in jamun saplings leaf area was 68.6% and 62.8% less than control at Ranoli and Omkarpura. At all other stations except Koyali, the reduction ranged from 35 to 55%. At Koyali, total leaf area was slightly higher (7.2%) than control plants. (Fig.4.13.2.).

Injury index was recorded maximum in jamun saplings growing at Damapura (38.4%) followed by Angadh (29.1%), Omkarpura (18.7%), Ranoli (15.3%), Bajwa (9.3%) and Koyali (2.6%). (Fig.4.13.2.).

Table 46. Response of Syzygium cumini Skeels (jamun) saplings to air pollution

SUMMER - Morphological observations

Parameter		Bajwa	Koyali	Omkarpura	Ranoli	Damapura	Angadh	University (Control)
Shoot length (cm)		62.4	68.7	58.8	53.9	49.8	60.3	79.5
	±	5.1	3.8	2.1	4.1	3.7	4.2	4.8
No. of leaves/plant		39.0	44.7	39.4	37.8	36.2	28.4	54.2
	±	3.5	4.7	3.9	4.1	2.9	2.9	3.1
Total leaf area (cm^2)		1234	1493	1086	708	938	761	1951
	±	62	84	73	62	51	75	106
No. of branches/plant		4.1	6.3	4.9	4.7	4.6	3.8	5.3
	±	1.2	1.4	0.8	1.6	0.9	1.2	1.4
Injury index		9.3	2.6	18.7	15.3	38.4	29.1	-
% leaves with symptoms		11.3	4.1	29.1	46.1	58.7	32.4	-

± Standard deviation.

The saplings exposed at Damapura and Ranoli exhibited visible foliar symptoms in 58.7% and 46.1% of the leaves respectively. At Angadh and Omkarpura 32.4% and 29.1% of the total leaves showed foliar damage. Comparatively lesser number of leaves exhibited visible damage at Bajwa (11.3%) and Koyali (4.1%). (Fig.4.13.2.).

3.2.3.3.2. Effect on biochemical parameters : (Table 47)

(i) Effect on photosynthetic pigments : The chlorophyll a content of jamun saplings exposed at Damapura exhibited maximum damage i.e. it was 50.6% less than the control plants. 40 to 47% reduction was recorded at Angadh, Ranoli and Damapura. At Bajwa and Koyali the percentage reduction was 26.5 and 15.7 respectively. More or less similar pattern of damage in total chlorophyll content was noticed at the above exposure stations.

Maximum reduction in chlorophyll b pigment was recorded at Damapura (54.9%), at Ranoli, Angadh and Omkarpura it decreased from 39 to 47% as compared to the control. At Bajwa and Koyali, the percentage reduction in chlorophyll b was 23.3 and 10.9 respectively.

Carotenoid pigments decreased 34 to 44% at Damapura, Ranoli, Angadh and Omkarpura as compared to control. At Bajwa and Koyali carotenoids level was 17.5% and 8.2% less than control respectively. (Fig.4.13.3.).

Table 47. Response of *Syzygium cumini* Skeels (jamun) saplings to air pollution

SUMMER - Biochemical observations

Parameter		Bajwa	Koyali	Omkarpura	Ranoli	Damapura	Angadh	University (Control)
Chlorophyll a (mg/g.f.wt.)	±	1.16 0.04	1.33 0.08	0.94 0.02	0.85 0.10	0.78 0.06	0.84 0.03	1.58 0.05
Chlorophyll b (mg/g.f.wt.)	±	0.87 0.05	1.01 0.09	0.69 0.04	0.60 0.08	0.51 0.04	0.62 0.07	1.13 0.06
Total chlorophyll (mg/g.f.wt.)	±	2.44 0.13	2.69 0.25	1.78 0.16	1.65 0.09	1.48 0.11	1.69 0.17	3.21 0.15
Carotenoids (mg/g.f.wt.)	±	0.77 0.08	0.85 0.11	0.62 0.07	0.58 0.04	0.52 0.09	0.59 0.03	0.93 0.02
Ascorbic acid (mg/g.f.wt.)	±	2.96 0.31	3.46 0.18	2.45 0.14	2.30 0.07	2.35 0.32	2.58 0.21	3.61 0.23
Protein (mg/g.f.wt.)	±	39.60 1.90	45.50 2.70	30.10 1.80	33.90 2.60	26.60 2.40	32.20 1.70	47.50 3.10
Total free amino acid (mg/g.d.wt.)	±	47.70 2.80	43.10 4.30	66.50 3.90	53.30 3.20	68.50 3.60	54.40 2.80	38.90 5.60
Total soluble sugars (mg/g.d.wt.)	±	38.80 2.40	42.40 2.60	34.10 3.50	32.20 2.40	29.00 3.20	34.10 4.30	45.80 3.70
Sulphur (mg/g.d.wt.)	±	1.51 0.07	1.38 0.02	1.96 0.07	1.73 0.05	2.69 0.11	2.07 0.13	1.03 0.04

± Standard deviation.

(ii) Effect on foliar ascorbic acid : During summer, the foliar ascorbic acid in jamun plants exposed at Damapura was 34.9% less than the control. The reduction at other stations in decreasing order was 32.2% at Omkarpura, 30.9% at Ranoli, 28.6% at Angadh and 18.0% at Bajwa. At Koyali ascorbic acid content was very close to control. (Fig. 4.13.4.).

(iii) Effect on foliar protein and total free aminoacids : The foliar protein content at Damapura was 44.1% less than control. Among other stations, reduction was 29 to 37% at Omkarpura, Angadh and Ranoli whereas at Bajwa it was 16.7% as compared to control. At Koyali it was very close to control. (Fig.4.13.4.).

Significant accumulation (1.4 to 1.8 times) of free aminoacids over control was noted at all the stations, except Bajwa and Koyali where it was 1.2 and 1.1 times over control. (Fig.4.13.4.).

(iv) Effect on total soluble sugars : Soluble sugar content was 36.8% less in jamun plants growing at Damapura as compared to control. At Ranoli, Angadh and Omkarpura it decreased from 25 to 30%. There was comparatively less (7.5%) reduction in sugar content at Koyali. (Fig.4.13.5.).

(v) Effect on foliar sulphur : Sulphur accumulation in foliar tissues was recorded maximum at Damapura (2.6 times over control). The other stations in decreasing order were Angadh (2.01), Omkarpura (1.96), Ranoli (1.61), Bajwa (1.47) and Koyali (1.34 times over control). (Fig.4.13.5.).

3.3. ARTIFICIAL FUMIGATION STUDY

To determine the effect of SO_2 on three tree species under investigation, unexposed, ascorbic acid untreated plants (C_1) were compared with SO_2 exposed and ascorbic acid untreated (C_2) plants.

The SO_2 effect on ascorbic acid treated plants (T_1 and T_2) was also determined by comparing with C_1.

The amelioration of SO_2 effect by ascorbic acid was determined by comparing T_1 and T_2 plants with C_2.

3.3.1. MANGIFERA INDICA L. (MANGO)

3.3.1.1. Effect of sulphur dioxide

(i) Effect on foliage : Visible foliar tip burning symptoms were observed in C_2 plants at 90 days in 17.39% of the leaves. At 120 days, 33.85% of the leaves exhibited an injury index of 6.49%. At 150 days, 56.7% of the leaves showed visible foliar damage and the injury index was 25.6%. At 180 days, the injury index was 38.9% and the leaves with symptoms were 88.9%.

In the T_1 plants visible symptoms were recorded at 150 days in 16.5% leaves and the injury index was 1.14%. At

180 days, 20.38% of the leaves exhibited symptoms and the injury index was 5.49%.

In T_2 plants, foliar symptoms were recorded at 90 days in 6.45% of the leaves. At 120 days, 13.9% of the leaves exhibited injury index of 5.71%. At 150 days, the injury index was 16.3% in 33.0% of leaves. At 180 days, 66.2% of leaves showed visible damage and the injury index was 30.2%.

(ii) Effect on chlorophyll a : Gradual reduction in chlorophyll a pigment was observed in C_2 plants with increasing exposures of SO_2. At 60 and 120 days chlorophyll a content in C_2 plants was 11.96% and 26.0% less than C_1 respectively. At 180 days, i.e. exposure of 60 $ppmh^{-1}$ accumulative dose of SO_2, chlorophyll a reduced 43.5% in C_2 plants as compared to C_1.

In T_1 plants, at 30 days chlorophyll a was close to C_1. At 60 and 120 days it decreased 5.02% and 13.4% respectively. At 180 days reduction was 15.67% as compared to C_1.

In T_2 plants at 30 days, chlorophyll a level was close (1.95% higher) to C_1, but in subsequent exposures it decreased gradually. At 120 and 180 days, the reduction was 20.4% and 39.8% as compared to C_1. (Fig.3.6.1.).

(iii) Effect on chlorophyll b : In C_2 plants it was 7.1% less than C_1 after exposing to 10 $ppmh^{-1}$ accumulative SO_2 dose. The degradation of chlorophyll b increased with number of

Fig.3.6.1. Effect of SO_2 fumigation on photosynthetic pigments of Mangifera indica L. (mango)

C_1 : Neither exposed to SO_2 nor treated with ascorbic acid (AA)

C_2 : Exposed to SO_2 but not treated with AA

T_1 : Exposed to SO_2 and treated with 10 µmoles of AA.

T_2 : Exposed to SO_2 and treated with 100 µmoles of AA.

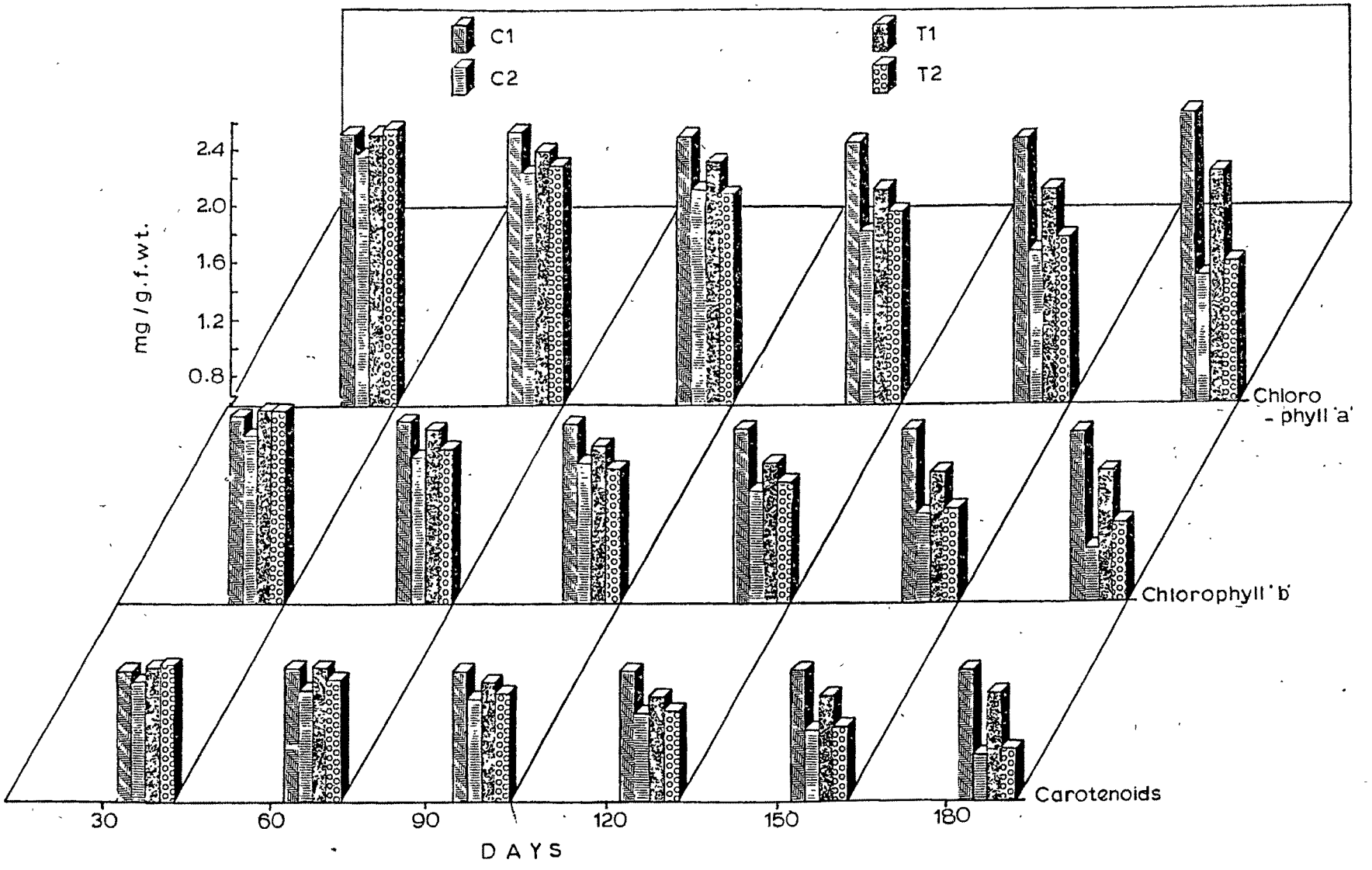

C1
C2
T1
T2
2.4
2.0
1.6
1.2
0.8
mg / g.f.wt.
Chloro - phyll 'a'
Chlorophyll 'b'
Carotenoids
30
60
90
120
150
180
DAYS

Fig. 3.6.1.

SO_2 exposures. At 120 and 180 days, it was 24.1% and 46.1% less in C_2 plants than in C_1 respectively.

In T_1 plants, at 30 days chlorophyll b level was close to C_1, but in subsequent exposures it decreased rapidly. At 60 and 120 days, it was 3.73 and 12.38% less than C_1. At 180 days reduction was 15.98% as compared to C_1.

In T_2 also at 30 days chlorophyll b was least affected. At 60 and 120 days the reduction was 10.76% and 21.5% respectively. At 180 days, the percentage reduction was 35.9 as compared to C_1 (Fig.3.6.1.).

(iv) Effect on carotenoids : The carotenoid pigments content in C_2 plants diminished with increasing number of SO_2 exposures. At 60, 120 and 180 days carotenoid pigments content in C_2 plants was 10.97%, 20.07% and 38.57% less than C_1 respectively.

In T_1 even after exposing to 20 $ppmh^{-1}$ accumulative SO_2 dose carotenoids were least affected. At 90 and 150 days it was 5.1% and 12.8% less than C_1 respectively. The reduction was 10.6% at 180 days as compared to C_1.

In T_2 plants, at 30 days carotenoids content was slightly higher than C_1, but with subsequent exposures it decreased rapidly. At 60, 120 and 180 days the carotenoids level was 6.0%, 18.4% and 37.1% less than C_1. (Fig.3.6.1.).

(v) Effect on ascorbic acid : Not much change in ascorbic acid content of C_2 was observed upto 10 $ppmh^{-1}$ SO_2 exposure. In subsequent SO_2 exposures it decreased sharply. At 60, 120 and 180 days foliar ascorbic acid content in C_2 plants decreased by 6.4%, 19.6% and 29.76% as compared to C_1 respectively.

In T_1 plants slight increase (2.3%) over C_1 was observed at 30 days, but at 60, 120 and 180 days it was 4.4%, 14.5% and 11.6% less than C_1 respectively.

In T_2 plants also at 30 days slight increase (4.5%) over C_1 was observed, but it decreased sharply with further exposures. At 120 and 180 days ascorbic acid content in T_2 was 18.1% and 26.03% less than C_1 respectively. (Fig.3.6.2.).

(vi) Effect on foliar protein : In C_2 plants protein content declined due to SO_2 exposures. At 60 and 120 days it decreased 6.86% and 18.9% as compared to C_1. At 180 days sharp reduction (34.5%) was noticed in C_2 plants.

At 30 days in T_1 plants, the foliar protein content was slightly higher (2.4%) than C_1, but at 60 days it was 5.3% less than C_1. Maximum reduction in T_1 plants (18.6%) was recorded at 180 days.

Initial increase in protein content (5.9%) was noticed in T_2 plants at 30 days, but in subsequent exposures it exhibited

Fig.3.6.2. Effect of SO_2 fumigation on foliar ascorbic acid content of Mangifera indica L.

C_1 : Neither exposed to SO_2 nor treated with ascorbic acid (AA)

C_2 : Exposed to SO_2 but not treated with AA

T_1 : Exposed to SO_2 and treated with 10 µmoles of AA

T_2 : Exposed to SO_2 and treated with 100 µmoles of AA

(Vertical bars represent standard deviation)

Fig. 3.6.2.

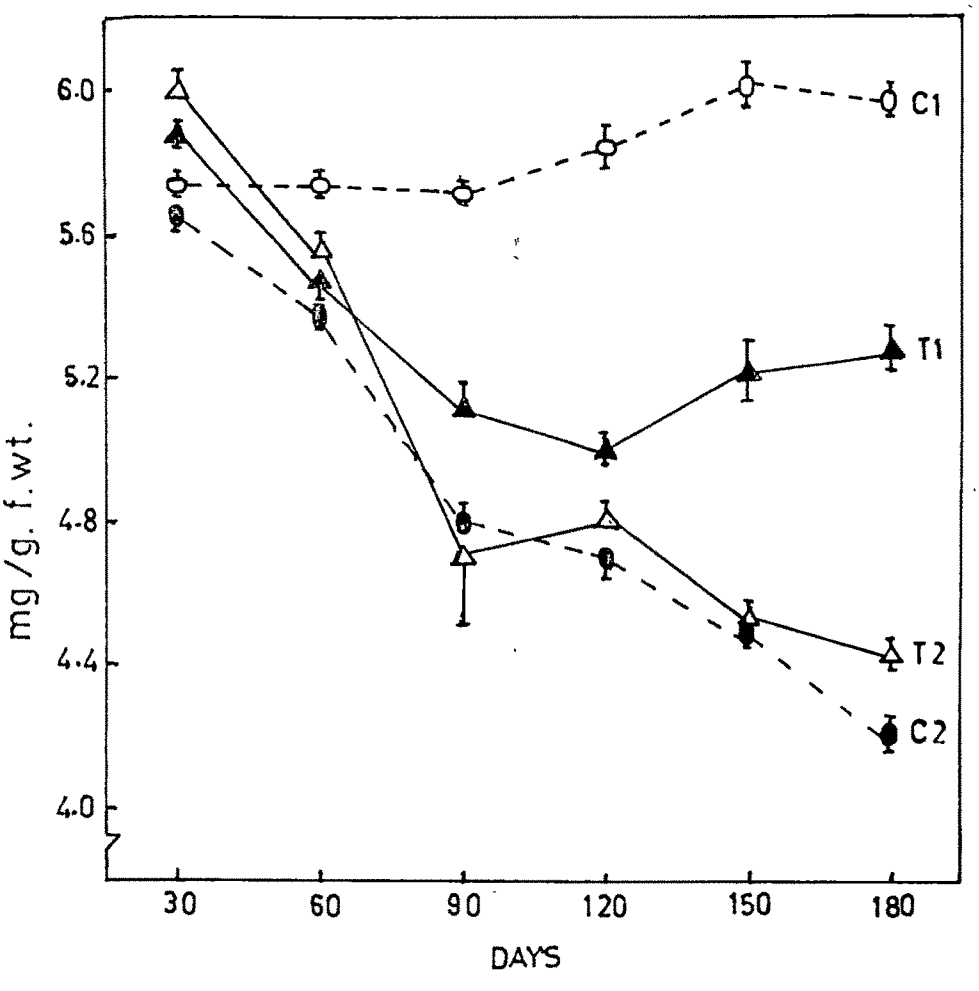


Fig.3.6.3. Effect of SO_2 fumigation on (A) foliar protein and (B) total free aminoacid content of Mangifera indica L.

C_1 : Neither exposed to SO_2 nor treated with ascorbic acid (AA)

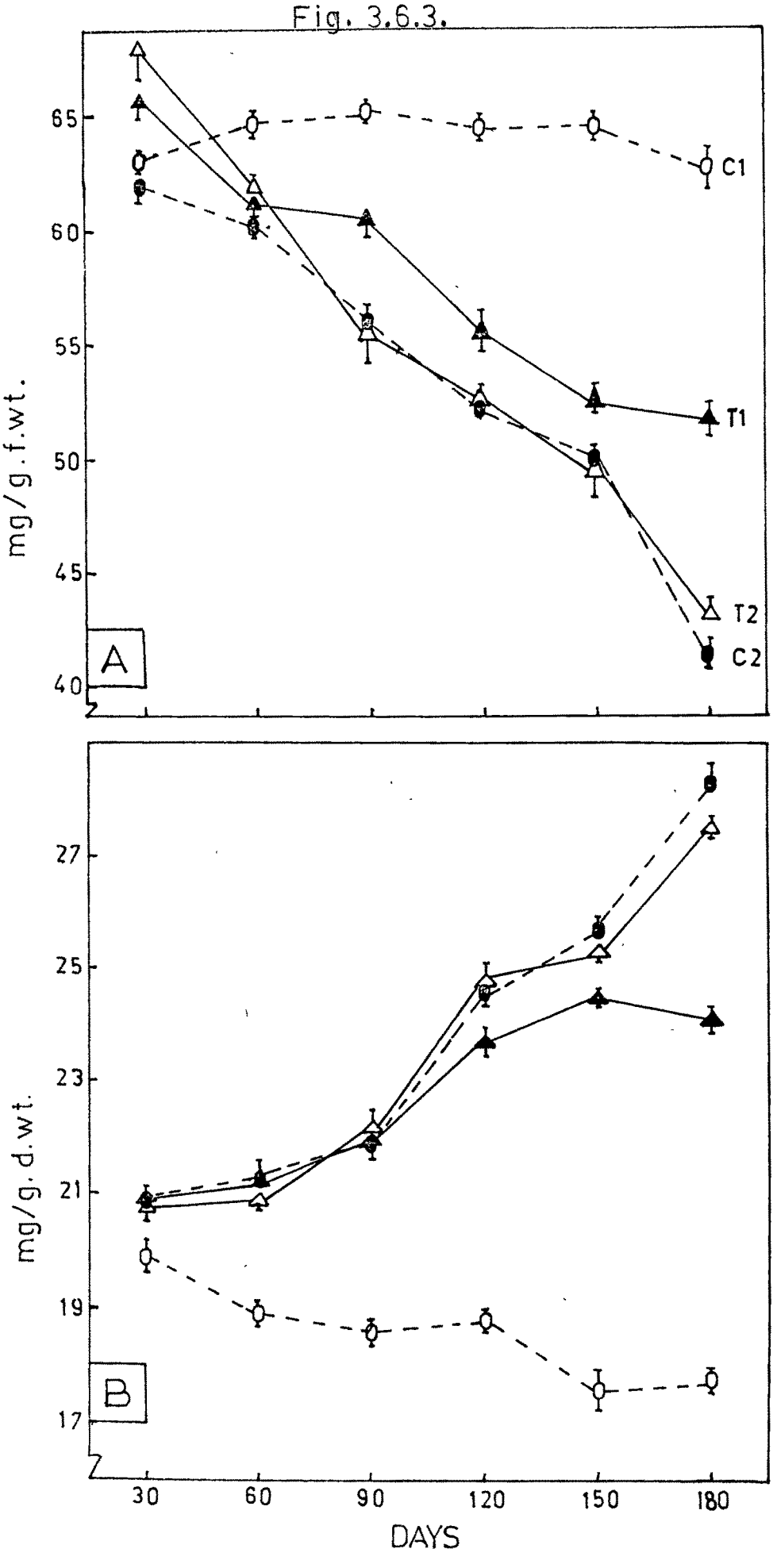
C_2 : Exposed to SO_2 but not treated with AA

T_1 : Exposed to SO_2 and treated with 10 µmoles of AA

T_2 : Exposed to SO_2 and treated with 100 µmoles of AA

(Vertical bars represent standard deviation)

Fig. 3.6.3.


65
60
55
50
45
40
mg/g.f.wt.
A
C1
T1
T2
C2
27
25
23
21
19
17
mg/g.d.wt.
B
30
60
90
120
150
180
DAYS

decreasing trend. At 60, 120 and 180 days reduction was 4.3%, 18.3% and 32.5% as compared to C_1 respectively. (Fig.3.6.3A.).

(vii) Effect on total free aminoacids : SO_2 exposures increased the total free aminoacid content in the foliar tissues of C_2 plants. At 60, 120 and 180 days in C_2 plants, it was 12.6%, 30.5% and 58.8% higher than C_1 respectively.

In T_1 plants also SO_2 exposure increased the free aminoacids. At 60 and 120 days it was 13.6% and 25.7% higher than C_1 respectively. Maximum percentage of accumulation (39.5%) was recorded at 150 days. At 180 days it was 35.4% higher than C_1.

In T_2 plants, free aminoacid content always showed increasing trend. At 60, 120 and 180 days, it was 10.1%, 31.5% and 54.5% higher than C_1 respectively. (Fig.3.6.3B.).

(viii) Effect on total soluble sugars : At 30 days, the soluble sugar content in C_2 plants was close to C_1. At 60, 120 and 180 days 4.6%, 16.0% and 31.6% reduction was recorded as compared to C_1.

Initial increase (5.5%) in soluble sugars was observed in T_1 plants at 30 days, but with further exposures it decreased. Maximum reduction (20.1%) was recorded at 150 days. At 180 days, it was 18.6% less than C_1.

In T_2 plants, 6.7% increase over C_1 was recorded at 30 days. At 60 days sugar content was close to C_1, but in subsequent exposures it was reduced in T_2 plants. At 120 and 180 days soluble sugar content in T_2 was 18.5% and 28.1% less than C_1 (Fig.3.6.4.A.).

(ix) Effect on sulphur content : Gradual increase in foliar sulphur content was recorded corresponding with the increasing SO_2 exposures. In C_2 plants, foliar sulphur content was 13.5%, 28.7% and 46.5% higher than C_1, at 90, 120 and 180 days respectively.

T_1 plants also exhibited increasing trend in sulphur accumulation. At 60, 120 and 180 days it was 6.0%, 21.3% and 30.4% higher than C_1.

SO_2 exposure increased the foliar sulphur in T_2 plants. 26.5% and 45.6% increase over C_1 was recorded at 120 and 180 days. (Fig.3.6.4.B.).

3.3.1.2. Amelioration of SO_2 effect by ascorbic acid treatments :

In mango, among the two concentrations of ascorbic acid employed, 10 µmoles treatment (T_1) mitigated the SO_2 effect more than 100 µmoles treatment (T_2).

Fig.3.6.4. Effect of SO_2 fumigation on (A) foliar total soluble sugars and (B) sulphur content of Mangifera indica L.

C_1 : Neither exposed to SO_2 nor treated with ascorbicacid (AA)

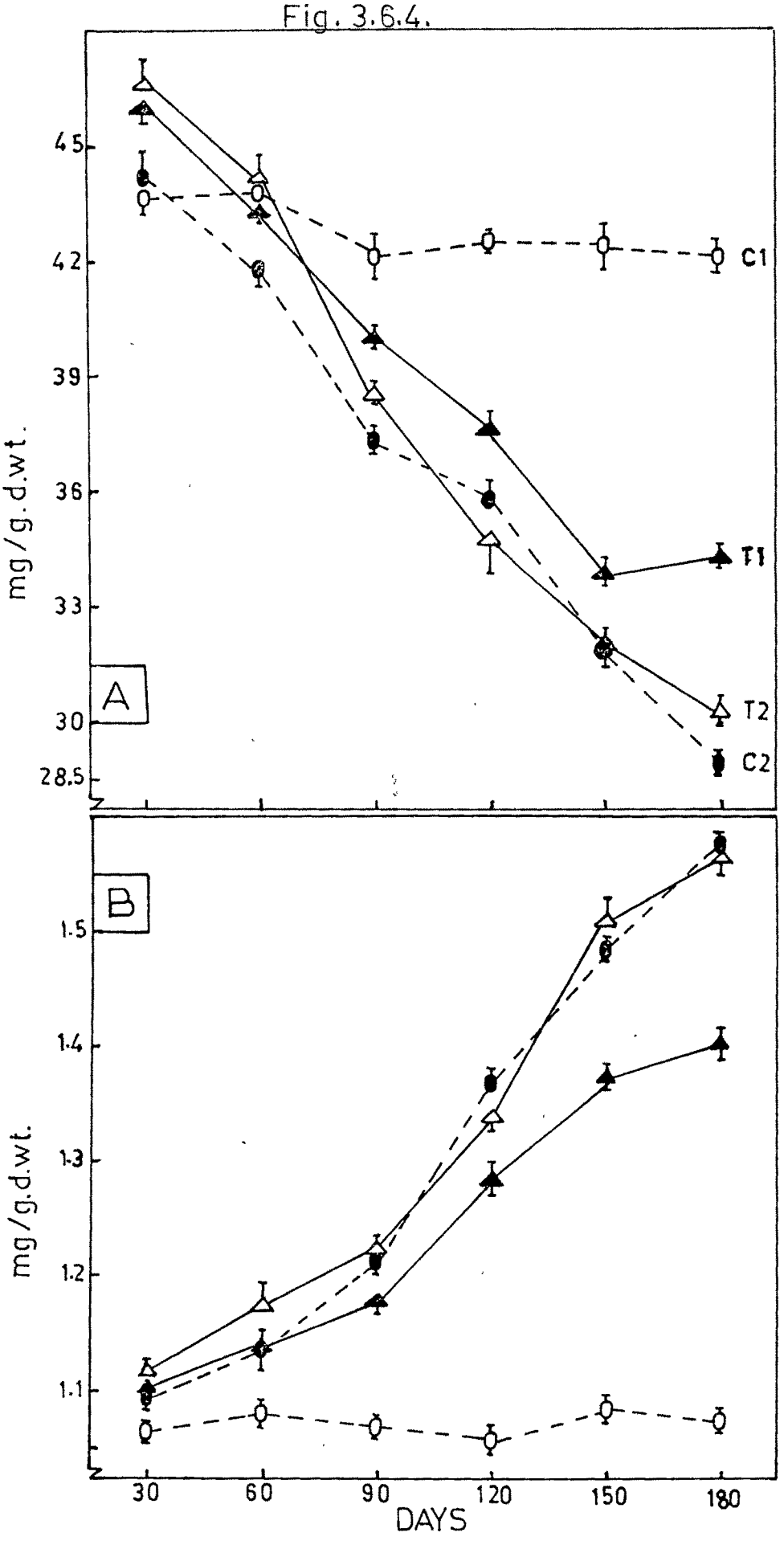
C_2 : Exposed to SO_2 but not treated with ascorbic acid

T_1 : Exposed to SO_2 and treated with 10 µmoles of AA

T_2 : Exposed to SO_2 and treated with 100 µmoles of AA.

(Vertical bars represent standard deviation)

Fig. 3.6.4.


45
42
39
36
33
30
28.5
mg/g.d.wt.
A
C1
T1
T2
C2
B
1.5
1.4
1.3
1.2
1.1
mg/g.d.wt.
30
60
90
120
150
180
DAYS

(i) Effect on chlorophyll a : Chlorophyll a pigment was always higher than C_2 plants in the ascorbic acid treated plants (T_1 and T_2). In T_1, at 60, 120 and 180 days the amelioration effect was well reflected by 6.86%, 17.0% and 49.3% increase over C_2 respectively.

In T_2, at 30 days 8.45% increase over C_2 was recorded. At 120 and 180 days the chlorophyll a level in T_2 was 7.6% and 6.6% higher than C_2 respectively. (Fig.3.6.1.).

(ii) Effect on chlorophyll b : In T_1 plants chlorophyll b pigment was 11.6%, 15.4% and 55.9% higher than C_2 at 60, 120 and 180 days.

In T_2 plants, at 30 days chlorophyll b was 9.33% higher than C_2, whereas at 120 and 180 days the percentage increase was 3.3% and 18.9% over C_2 respectively. (Fig.3.6.1.).

(iii) Effect on carotenoids : In T_1, this pigment also exhibited increasing trend over C_2. At 60, 120 and 180 days it was 11.1%, 8.1% and 45.9% higher than C_2 respectively.

In T_2 plants, at 30 days carotenoids level was 8.75% higher than C_2. The carotenoids content in T_2 plants was more or less close to C_2 at 120 and 180 days. (Fig.3.6.1.).

(iv) Effect on ascorbic acid : In T_1 at 30 days it was slightly higher (3.69%) than C_2 plants. At 120, 150 and 180 days it was 6.33%, 16.1% and 25.8% higher than C_2 respectively.

In T_2 plants foliar ascorbic acid content showed slight increase over C_2 at 30 and 60 days (5.91 and 3.62% respectively). At 120 days it was close to C_2, but at 180 days ascorbic acid content was 5.3% higher than C_2. (Fig.3.6.2.).

(v) Effect on foliar protein : In T_1 plants, at 30 days protein content was 5.96% higher than C_2. At 120 and 180 days the percentage increase was 6.4 and 25.0 respectively.

In T_2 plants also at 30 days, protein content increased significantly (9.58%) over C_2. The protein content in T_2 plants was very close to C_2 plants at 120 and 150 days. At 180 days it was slightly (4.1%) higher than C_2. (Fig.3.6.3.A.).

(vi) Effect on total free aminoacids : In T_1, the free aminoacid content was very close to C_2 plants upto 90 days. The mitigating effect was reflected by reducing the accumulation of free aminoacids in T_1. It was 3.68%, 4.59% and 14.7% less than C_2 plants at 120, 150 and 180 days respectively.

In T_2 plants free aminoacids level was close to C_2 upto 120 days. At 150 and 180 days it was slightly (2.3 and 2.8% respectively) less than C_2. (Fig.3.6.3.B.).

(vii) Effect on total soluble sugars : In T_1 soluble sugar content was observed always higher than C_2. At 60, 120 and 180 days it was 3.77%, 5.72% and 18.5% higher than C_2 respectively.

In T_2, at 30 and 60 days it was 5.33% and 5.98% higher than C_2. At 120 and 150 days sugar content was close to C_2. At 180 days, it was 4.8% higher than C_2. (Fig.3.6.4.A).

(viii) Effect on foliar sulphur : The sulphur content in T_1 was close to C_2 at 30 and 60 days. It decreased by 5.98% and 11.0% at 120 and 180 days respectively as compared to C_2.

In T_2 plants foliar sulphur content was observed close to C_2 plants. At 180 days it was slightly (4.1%) less than C_2 plants. (Fig.3.6.4B).

3.3.2. MANILKARA HEXANDRA (ROXB.) DUBARD. (RAYAN)

3.3.2.1. Effect of sulphur dioxide

(i) Effect on foliage : In rayan, no visible symptoms were observed in the leaves of SO_2 exposed plants, upto 60 $ppmh^{-1}$ accumulative SO_2 exposure.

(ii) Effect on chlorophyll a : In C_2 plants, at 30 days it was slightly (2.6%) less than C_1. At 120 and 180 days chlorophyll a content decreased by 15.8% and 26.5% as compared to C_1 respectively.

In T_1 plants, the chlorophyll a content was less affected after exposing to 10 $ppmh^{-1}$ accumulative SO_2 dose, but with

subsequent exposures it gradually decreased. It was 14.6% and 23.5% less than C_1 at 120 and 180 days respectively.

In T_2 plants initial increase (4.1%) recorded at 30 days, but at 60 days chlorophyll a was slightly less than C_1. At 120 and 180 days it was 13.8% and 27.3% less than C_1 respectively. (Fig.3.7.1.).

(iii) Effect on chlorophyll b : In C_2 saplings, the content of chlorophyll b pigment also declined gradually with increasing SO_2 exposures. At 60, 120 and 180 days, it was reduced by 4.2%, 13.8% and 27.3% as compared to C_1 respectively.

In T_1 plants, chlorophyll b level was more or less close to C_1 at 30 and 60 days. At 120 and 180 days it was 14.1% and 24.5% less than C_1 respectively.

At 30 days, slight increase in chlorophyll b content (3.8%) over C_1 was observed in T_2, but it decreased with subsequent exposures. At 120 and 180 days, it was 12.4% and 12.2% less than C_1 respectively. (Fig.3.7.1.).

(iv) Effect on carotenoids : In C_2 plants it decreased by 9.4%, 18.4% and 29.0% at 60, 120 and 180 days as compared to C_1 respectively.

In T_1, carotenoid pigments were less affected even after exposing to 20 $ppmh^{-1}$ accumulative SO_2 dose. At 120 and 180 days it was 11.4% and 21.4% less than C_1 respectively.

Fig. 3.7.1. Effect of SO_2 fumigation on photosynthetic pigments of *Manilkara hexandra* Dubard. (rayan)

C_1 : Neither exposed to SO_2 nor treated with ascorbic acid (AA)

C_2 : Exposed to SO_2 but not treated with AA

T_1 : Exposed to SO_2 and treated with 10 µmoles of AA

T_2 : Exposed to SO_2 and treated with 100 µmoles of AA

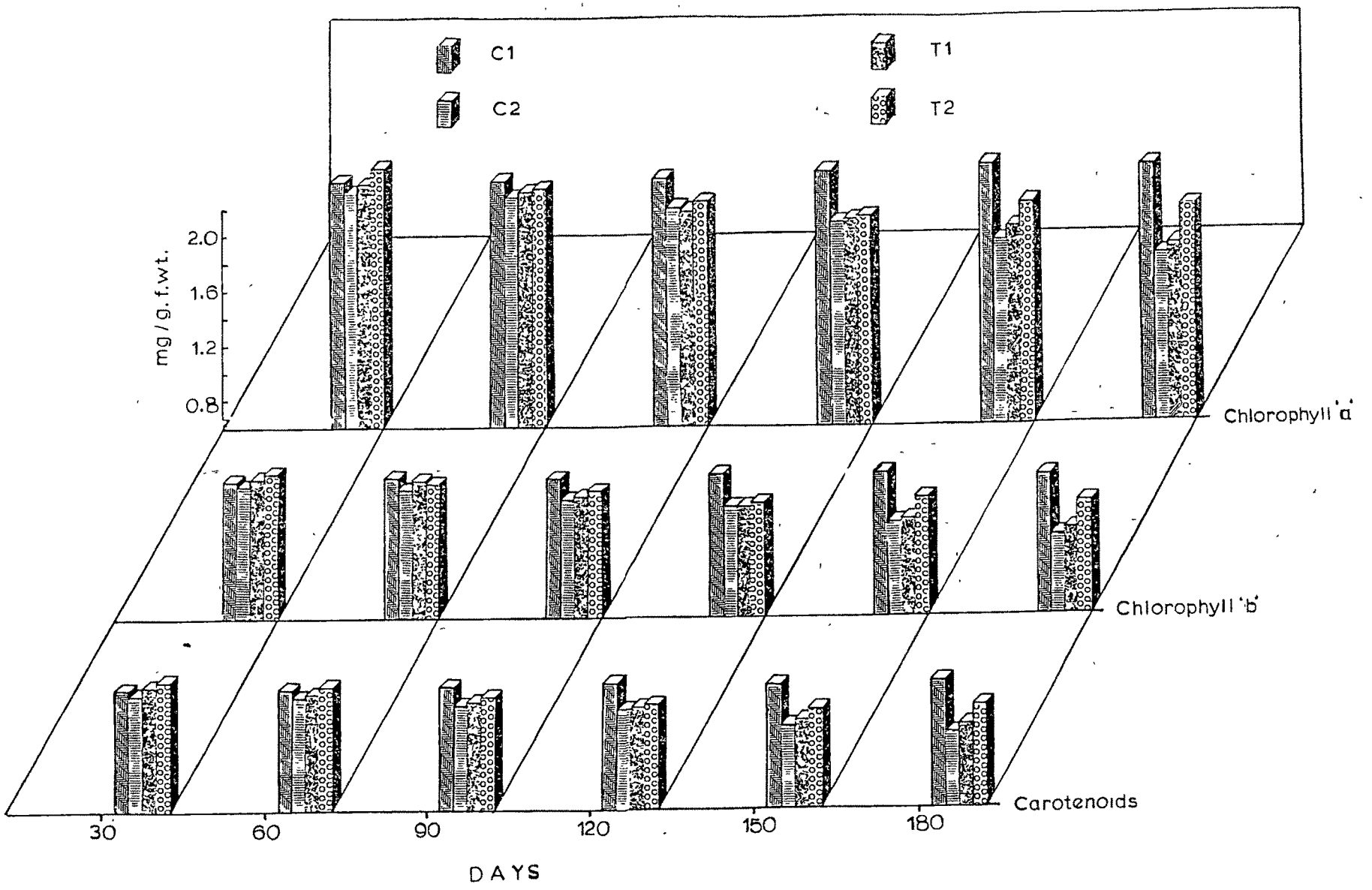

C1
C2
T1
T2
mg/g.f.wt.
2.0
1.6
1.2
0.8
Chlorophyll 'a'
Chlorophyll 'b'
Carotenoids
30
60
90
120
150
180
DAYS

Fig. 3.7.1.

In T_2, at 30 days the carotenoids content was slightly higher (3.1%) than C_1 and at 60 days it was very close to C_1. At 120 and 180 days it was 9.3% and 11.3% reduced as compared to C_1 respectively. (Fig.3.7.1.).

(v) Effect on ascorbic acid : Reduction in foliar ascorbic acid was observed in C_2 plants due to SO_2 exposure. At 90 and 180 days, ascorbic acid recorded in C_2 was 12.8% and 29.0% less than C_1.

In T_1 plants, ascorbic acid content exhibited decreasing trend with increasing SO_2 exposures. At 60, 120 and 180 days the percentage reduction was 8.1%, 19.3% and 26.1% as compared to C_1 respectively.

In T_2, ascorbic acid content was close to C_1 at 30 days, but in subsequent exposures it showed decreasing trend. At 120 and 180 days, the percentage reduction was 12.1 and 16.3 as compared to C_1 respectively. (Fig.3.7.2.).

(vi) Effect on foliar protein : In C_2, protein content decreased 5.1% than C_1 after exposing to 10 $ppmh^{-1}$ accumulative SO_2 dose. At 120 and 180 days it was 13.9% and 24.5% less than C_1 respectively.

In T_1 plants at 60 days protein content was reduced by 7.4%. Maximum percentage reduction (17.3%) was recorded at 150 days, whereas at 180 days it was 16.9% as compared to C_1.

Fig.3.7.2. Effect of SO_2 fumigation on foliar ascorbic acid content of Manilkara hexandra Dubard. (rayan)

C_1 : Neither exposed to SO_2 nor treated with ascorbic acid (AA)

C_2 : Exposed to SO_2 but not treated with AA

T_1 : Exposed to SO_2 and treated with 10 µmoles of AA

T_2 : Exposed to SO_2 and treated with 100 µmoles of AA.

(Vertical bars represent standard deviation)

Fig. 3.7.2.

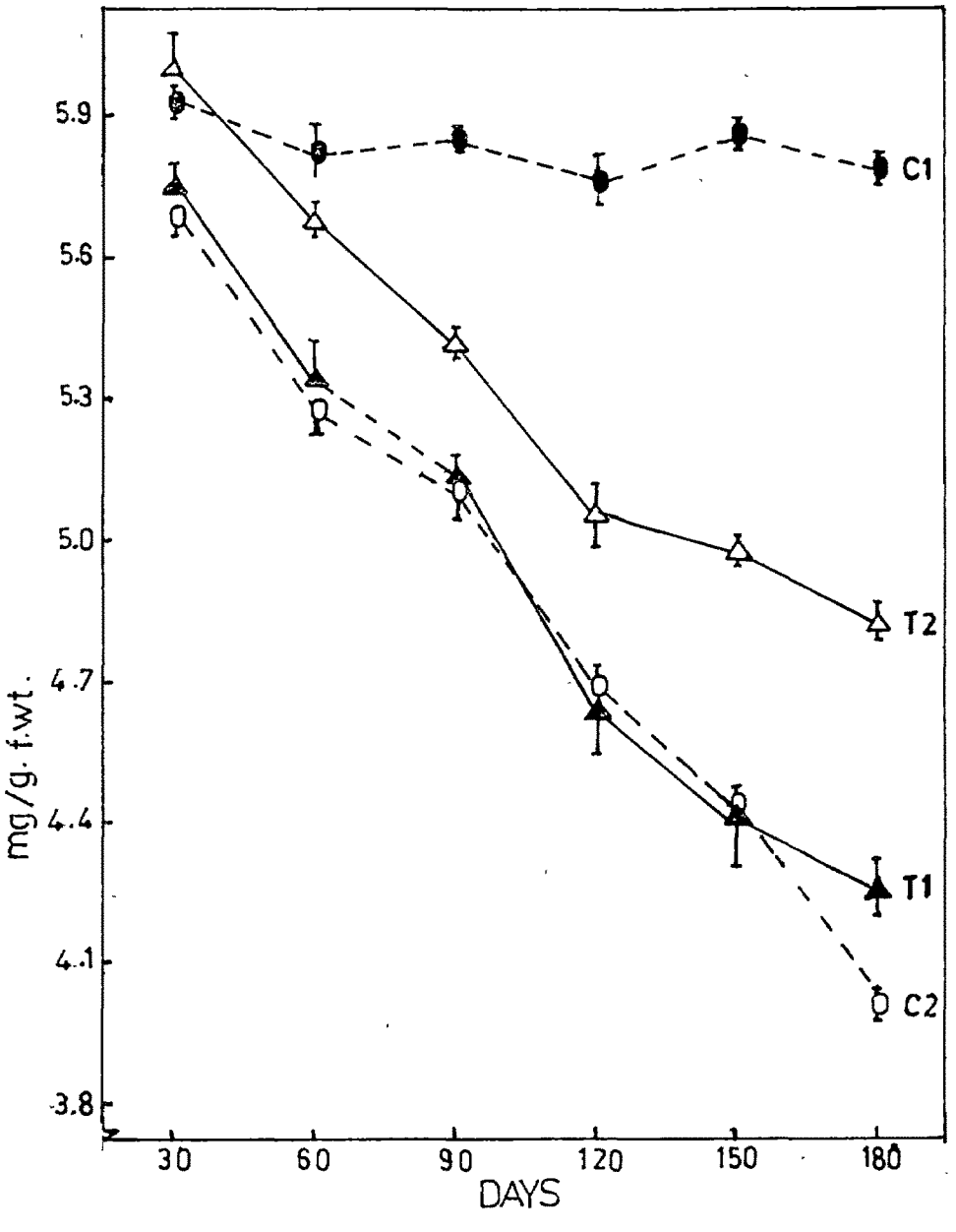


Fig.3.7.3. Effect of SO_2 fumigation on (A) foliar protein and (B) total free aminoacid content of Manilkara hexandra Dubard. (rayan)

C_1 : Neither exposed to SO_2 nor treated with ascorbic acid (AA)

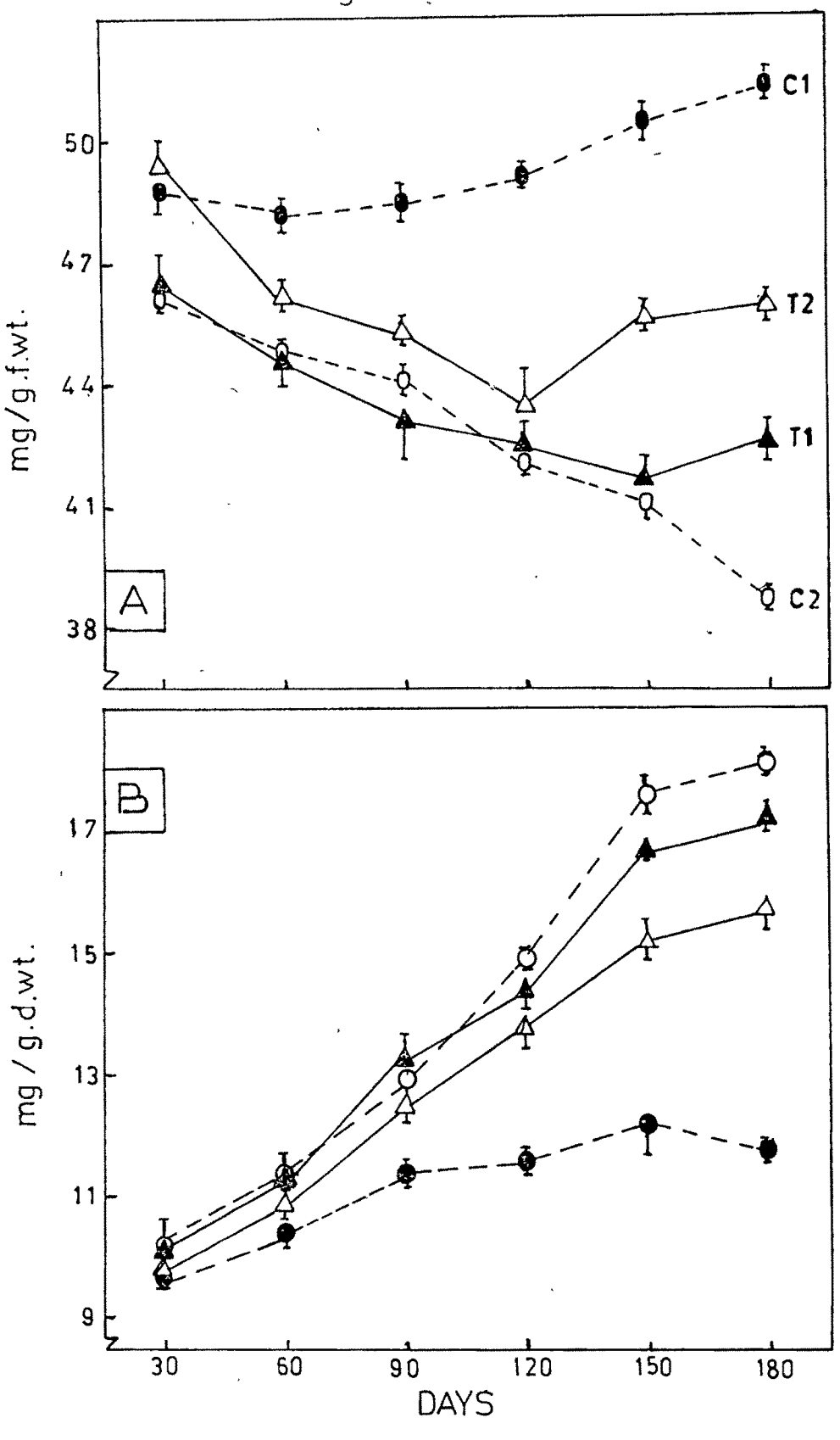
C_2 : Exposed to SO_2 but not treated with AA

T_1 : Exposed to SO_2 and treated with 10 µmoles of AA

T_2 : Exposed to SO_2 and treated with 100 µmoles of AA

(Vertical bars represent standard deviation)

Fig. 3.7.3.


C1
T2
T1
C2
A
B
mg/g.f.wt.
mg / g.d.wt.
50
47
44
41
38
17
15
13
11
9
30
60
90
120
150
180
DAYS

In T_2 plants, the foliar protein content was less affected with 10 $ppmh^{-1}$ SO_2 exposure. At 60, 120 and 180 days protein content was 6.5%, 11.3% and 10.3% less than C_1 respectively. (Fig.3.7.3.A.).

(vii) Effect on total free aminoacids : SO_2 exposure increased the total free aminoacids in the foliar tissues of C_2 plants. At 60, 120 and 180 days it was 8.3%, 28.5% and 52.5% higher than C_1 respectively.

In T_1 also, the total free aminoacids showed increasing trend with increasing SO_2 exposures. The percentage increase was 9.1, 23.5 and 45.2 as compared to C_1 at 60, 120 and 180 days respectively.

In T_2, it was very close to C_1 at 30 days, but it accumulated more than C_1 with further exposures. At 120 and 180 days free aminoacid content was 18.1% and 33.1% higher than C_1. (Fig.3.7.3B).

(viii) Effect on total soluble sugars : In C_2 plants it reduced sharply with increasing SO_2 exposures. At 60, 120 and 180 days the percentage reduction was 5.6, 14.5 and 27.4 as compared to C_1 respectively.

In T_1 plants, soluble sugars were reduced by 4.3%, 13.5% and 26.8% at 60, 120 and 180 days respectively when compared to C_1.

In T_2, at 30 days slight increase over C_1 was recorded in soluble sugar content. In subsequent exposures it reduced significantly. At 120, 150 and 180 days the percentage reduction was 10.5, 14.4 and 12.1 as compared to C_1 respectively. (Fig.3.7.4A.).

(ix) Effect on foliar sulphur : Increase in foliar sulphur content in SO_2 exposed plants was proportionate to the increasing number of exposures. In C_2 plants, it increased by 6.5%, 21.9% and 39.2% over C_1 at 60, 120 and 180 days respectively.

In T_1 plants, at 60, 120 and 180 days the foliar sulphur content was 7.2%, 19.4% and 35.7% higher than C_1 respectively.

In T_2 plants, the percentage increase in sulphur accumulation was 5.9 , 15.1 and 20.6 respectively at 60, 120 and 180 days. (Fig.3.7.4B.).

3.3.2.2. Amelioration of SO_2 effect by ascorbic acid treatments :

In rayan, 100 µmoles ascorbic acid treatment (T_2) showed significant mitigating effect than 10 µmoles ascorbic acid treatment (T_1).

(i) Effect on chlorophyll a : In T_1 plants chlorophyll a content was slightly higher (2.42%, 4.6% and 4.1%) at 60, 120 and 180 days than C_2 plants.

Fig.3.7.4. Effect of SO_2 fumigation on (A) total soluble sugars and (B) sulphur content of Manilkara hexandra Dubard. (rayan)

C_1 : Neither exposed to SO_2 nor treated with ascorbic acid (AA)

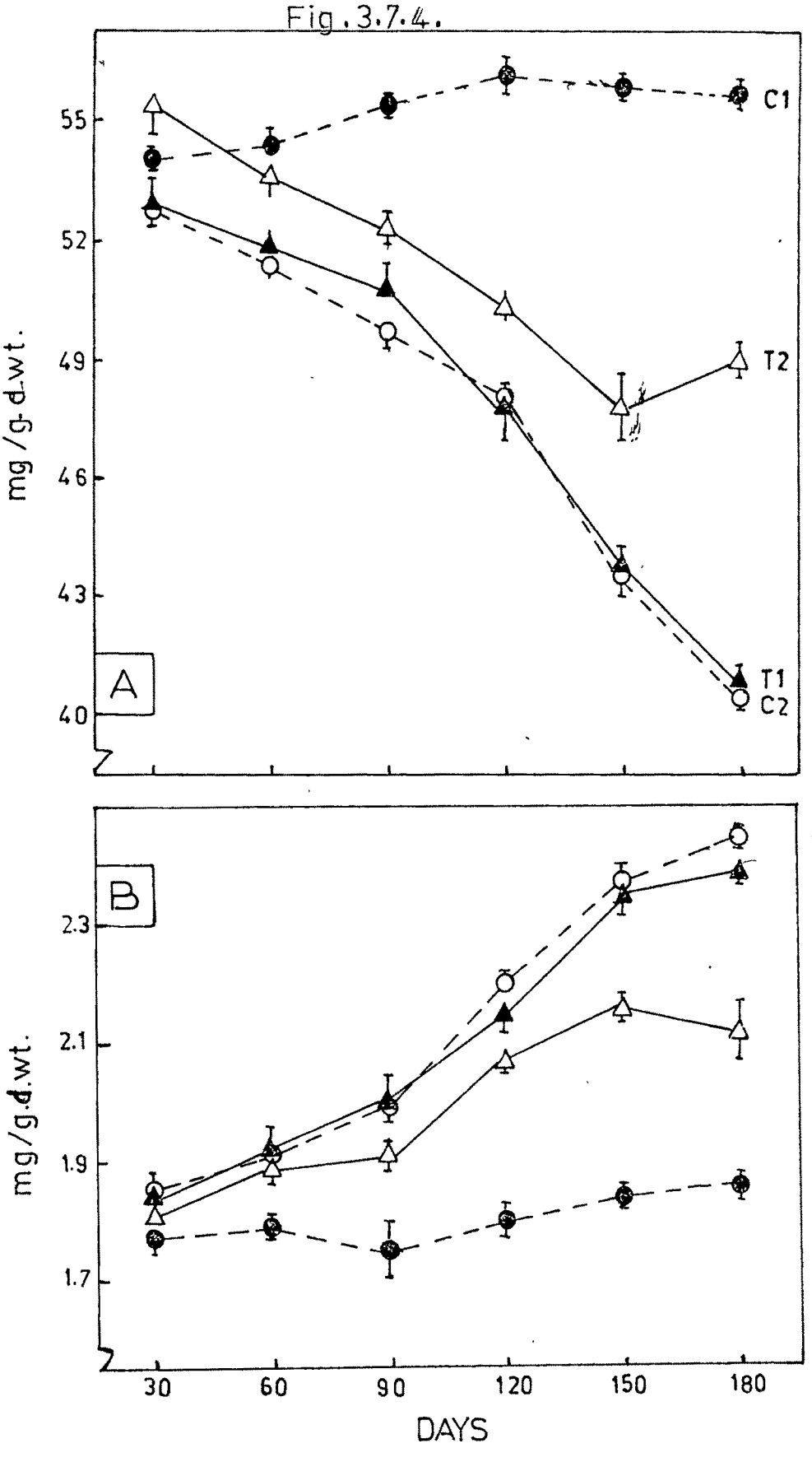
C_2 : Exposed to SO_2 but not treated with AA

T_1 : Exposed to SO_2 and treated with 10 µmoles of AA

T_2 : Exposed to SO_2 and treated with 100 µmoles of AA.

(Vertical bars represent standard deviation)

Fig. 3.7.4.


55
52
49
46
43
40
mg/g d.wt.
A
C1
T2
T1
C2
B
2.3
2.1
1.9
1.7
mg/g.d.wt.
30
60
90
120
150
180
DAYS

In T_2, 7.39% increase over C_2 was observed at 30 days. At 150 and 180 days, chlorophyll a content was 14.4% and 19.2% higher than C_2 respectively. (Fig.3.7.1.).

(ii) Effect on chlorophyll b : In T_1, at 30 days slight increase (3.69%) over C_2 was noticed, but at 120 and 150 days chlorophyll b level was very close to C_2. At 180 days it was slightly higher (3.9%) than C_2.

In T_2 plants, 6.24% increase over C_2 was observed at 30 days. At 150 and 180 days chlorophyll b content was significantly higher (14.5% and 20.8% respectively) than C_2 plants. (Fig.3.7.1.).

(iii) Effect on carotenoid pigments : At 30 days, it was 4.4% higher than C_2 in T_1 plants, but it was close to C_2 at 120 days. At 180 days carotenoids content was slightly higher (3.8%) than C_2.

In T_2, the carotenoids content recorded at 60, 120 and 180 days was 5.46%, 4.05% and 17.2% higher than C_2 respectively. (Fig.3.7.1.).

(iv) Effect on foliar ascorbic acid : In T_1 plants ascorbic acid content was observed more or less close to C_2 plants. At 180 days, it was 4.1% higher than C_2 plants.

In T_2, ascorbic acid content was always recorded higher

than C_2. At 60, 120 and 180 days, it was 7.84%, 7.72% and 17.9% higher than C_2 respectively. (Fig.3.7.2.).

(v) Effect on foliar protein : In T_1, protein content was close to C_2 upto 90 days. Amelioration effect was significantly reflected at 180 days, i.e. it was 10.1% higher than C_2 in T_1 plants.

In T_2, protein content was recorded higher than C_2. At 30 days it was 6.75% higher than C_2. At 120 and 180 days the percentage increase was 11.04 and 18.8 respectively. (Fig.3.7.3A.).

(vi) Effect on total free aminoacids : In T_1 plants total free aminoacid content was close to C_2 upto 60 days. The accumulation of free aminoacids slightly decreased (3.89% and 4.8% respectively) at 120 and 180 days as compared to C_2.

In T_2, the accumulation of free aminoacids decreased by 3.79%, 7.78% and 12.7% at 60, 120 and 180 days as compared to C_2 respectively. (Fig.3.7.3B.).

(vii) Effect on total soluble sugars : In T_1 plants, the soluble sugar content was recorded always close to C_2 plants.

In T_2, soluble sugar content was higher than C_2. At 90, 150 and 180 days, the percentage increase over C_2 was 5.02, 9.88 and 21.1 respectively. (Fig.3.7.4A.).

(viii) Effect on foliar sulphur : In T_1 plants the sulphur accumulation was very close to C_2 upto 90 days. At 120 and 180 days it was slightly less than C_2.

In T_2 plants, sulphur accumulation was reduced by 4.63%, 8.28% and 13.36% at 90, 150 and 180 days as compared to C_2 respectively. (Fig.3.7.4B.).

3.3.3. SYZYGIUM CUMINI SKEELS (JAMUN)

3.3.3.1. Effect of sulphur dioxide

(i) Effect on foliage : In jamun, no visible symptoms were observed upto 60 $ppmh^{-1}$ of accumulative SO_2 exposure.

(ii) Effect on chlorophyll a : The chlorophyll a pigment gradually decreased in the C_2 plants with increasing number of SO_2 exposures. At 60, 120 and 180 days, it was reduced by 6.6%, 13.3% and 23.7% as compared to C_1 respectively.

In T_1 plants, reduction in chlorophyll a was 7.1%, 12.4% and 23.7% at 60, 120 and 180 days as compared to C_1 respectively.

In T_2 plants, initial increase in chlorophyll a content (3.3%) was noticed at 30 days, but in subsequent exposures it decreased, as compared to C_1. At 120 and 180 days, the reduction was 8.26% and 11.4% respectively. (Fig.3.8.1.).

Fig.3.8.1. Effect of SO_2 fumigation on photosynthetic pigments of *Syzygium cumini* Skeels (jamun)

C_1 : Neither exposed to SO_2 nor treated with ascorbic acid (AA)

C_2 : Exposed to SO_2 but not treated with AA

T_1 : Exposed to SO_2 and treated with 10 µmoles of AA

T_2 : Exposed to SO_2 and treated with 100 µmoles of AA

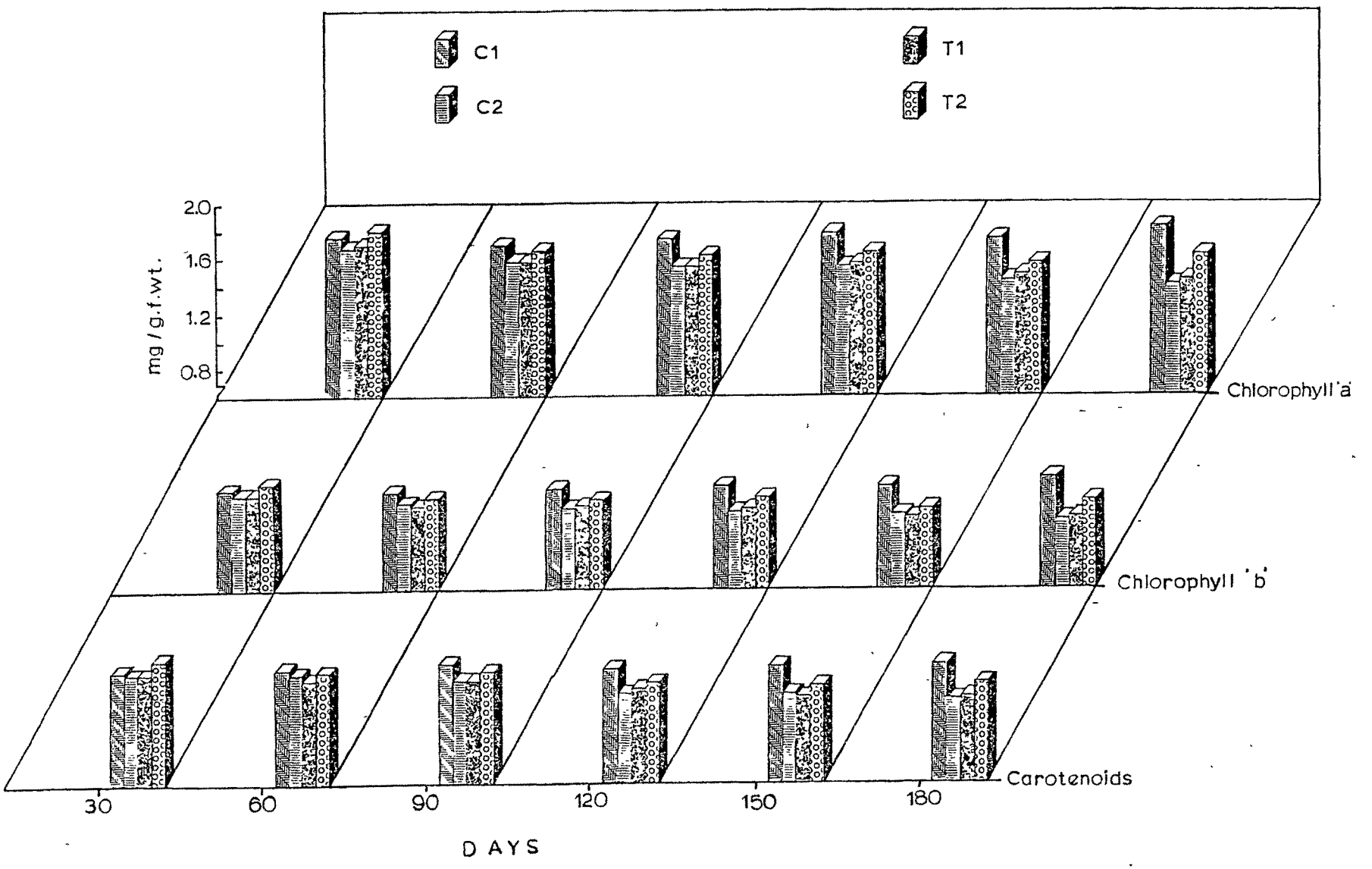

C1
C2
T1
T2
2.0
1.6
1.2
0.8
mg / g.f.wt.
Chlorophyll 'a'
Chlorophyll 'b'
Carotenoids
30
60
90
120
150
180
DAYS

Fig. 3.8.1.

(iii) Effect on chlorophyll b : At 60, 120 and 180 days, chlorophyll b content in C_2 plants was 5.1%, 13.9% and 30.9% less than C_1.

In T_1 plants, chlorophyll b content was reduced by 6.6%, 11.4% and 20.7% as compared to C_1 at 60, 120 and 180 days respectively.

In T_2, slight increase (3.7%) over C_1 was recorded at 30 days, but it declined with further exposures. Maximum reduction (11.5%) recorded at 180 days. (Fig.3.8.1.).

(iv) Effect on carotenoids : This pigment was comparatively less affected by SO_2 exposures in C_2 plants. After exposure of 20 $ppmh^{-1}$ accumulative SO_2 dose, it decreased 3.1% in C_2 plants as compared to C_1. At 120 and 180 days it was 12.1% and 18.04% less than C_1 respectively. (Fig.3.8.1.).

In T_1 plants, percentage reduction in carotenoids was 3.0, 9.4 and 16.1 at 60, 120 and 180 days as compared to C_1 respectively.

In T_2 plants, at 30 days, 4.8% increase over C_1 was recorded and at 60 days it was close to C_1. The carotenoids level declined by 6.1% and 9.1% at 120 and 180 days respectively. (Fig.3.8.1.).

(v) Effect on ascorbic acid : SO_2 exposures decreased the ascorbic acid level in C_2 plants. It decreased 7.2%, 17.7%

Fig.3.8.2. Effect of SO_2 fumigation on foliar ascorbic acid content of *Syzygium cumini* Skeels (jamun)

C_1 : Neither exposed to SO_2 nor treated with ascorbic acid (AA)

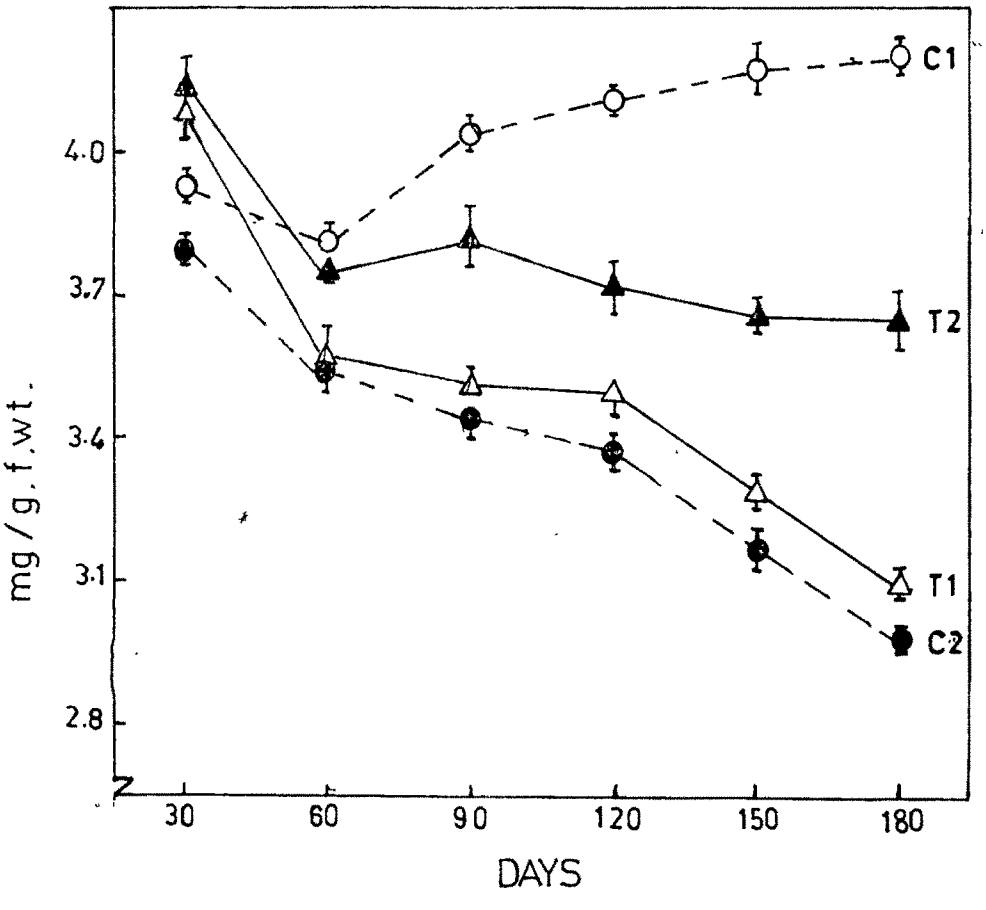
C_2 : Exposed to SO_2 but not treated with AA

T_1 : Exposed to SO_2 and treated with 10 µmoles of AA

T_2 : Exposed to SO_2 and treated with 100 µmoles of AA

(Vertical bars represent standard deviation)

Fig. 3.8.2.



and 29.3% in C_2 plants, after exposing to 20, 40 and 60 $ppmh^{-1}$ accumulative SO_2 dose respectively.

Increase in ascorbic acid was (4.0%) recorded at 30 days in T_1 plants, but it sharply decreased with subsequent exposures. At 60, 120 and 180 days it was 6.9%, 15.0% and 26.6% less than C_1 respectively.

In T_2, at 30 days 5.2% increase over C_1 was recorded and at 60 days ascorbic acid content was close to C_1. At 120 and 180 days, the reduction was 9.37% and 13.1% as compared to C_1 respectively. (Fig.3.8.2.).

(vi) Effect on foliar protein : Foliar protein content decreased sharply with increasing SO_2 exposures in C_2 plants. At 60, 120 and 180 days the percentage reduction was 8.0, 20.16 and 27.6 respectively.

In T_1 also degradation of protein due to SO_2 exposure was evident. The percentage reduction was 7.9%, 21.3 and 22.9 at 60, 120 and 180 days respectively.

In T_2, slight increase in foliar protein (3.0%) was noticed at 30 days, but due to the increase in SO_2 exposures it decreased gradually. Maximum percentage reduction (13.7%) was recorded at 150 days, whereas at 180 days it was 12.76% as compared to C_1 (Fig.3.8.3.A.).

(vii) Effect on total free aminoacids : Significant increase in free aminoacid content was recorded in C_2 due to SO_2 exposures. At 60, 120 and 180 days the accumulation was 11.0%, 23.4% and 42.5% higher than C_1 plants respectively.

In T_1 plants, the total free aminoacids increased 10.7%, 26.2% and 38.9% over C_1 at 60, 120 and 180 days respectively.

In T_2, the percentage increase in free aminoacid content at 60, 120 and 180 days was 7.5, 18.4 and 24.2 respectively. (Fig.3.8.3B.).

(viii) Effect on total soluble sugars : At 30 days, there was not much change in soluble sugar content in C_2 plants as compared to C_1, but it decreased with further SO_2 exposures. 11.3% and 22.17% reduction was recorded in C_2 at 120 and 180 days respectively.

In T_1 plants, at 30 days soluble sugars slightly increased over C_1, but it showed decreasing trend due to further exposures. At 90, 150 and 180 days it was 8.5%, 16.5% and 18.8% less than C_1 respectively.

In T_2, soluble sugar content was less affected upto 60 days. At 120 and 180 days it was 8.7% and 7.4% less than C_1 respectively. (Fig.3.8.4A.).

Fig.3.8.3. Effect of SO_2 fumigation on (A) foliar protein and (B) total free aminoacid content of Syzygium cumini Skeels (jamun)

C_1 : Neither exposed to SO_2 nor treated with ascorbic acid (AA)

C_2 : Exposed to SO_2 but not treated with AA

T_1 : Exposed to SO_2 and treated with 10 µmoles of AA

T_2 : Exposed to SO_2 and treated with 100 µmoles of AA.

(Vertical bars represent standard deviation)

Fig. 3.8.3.

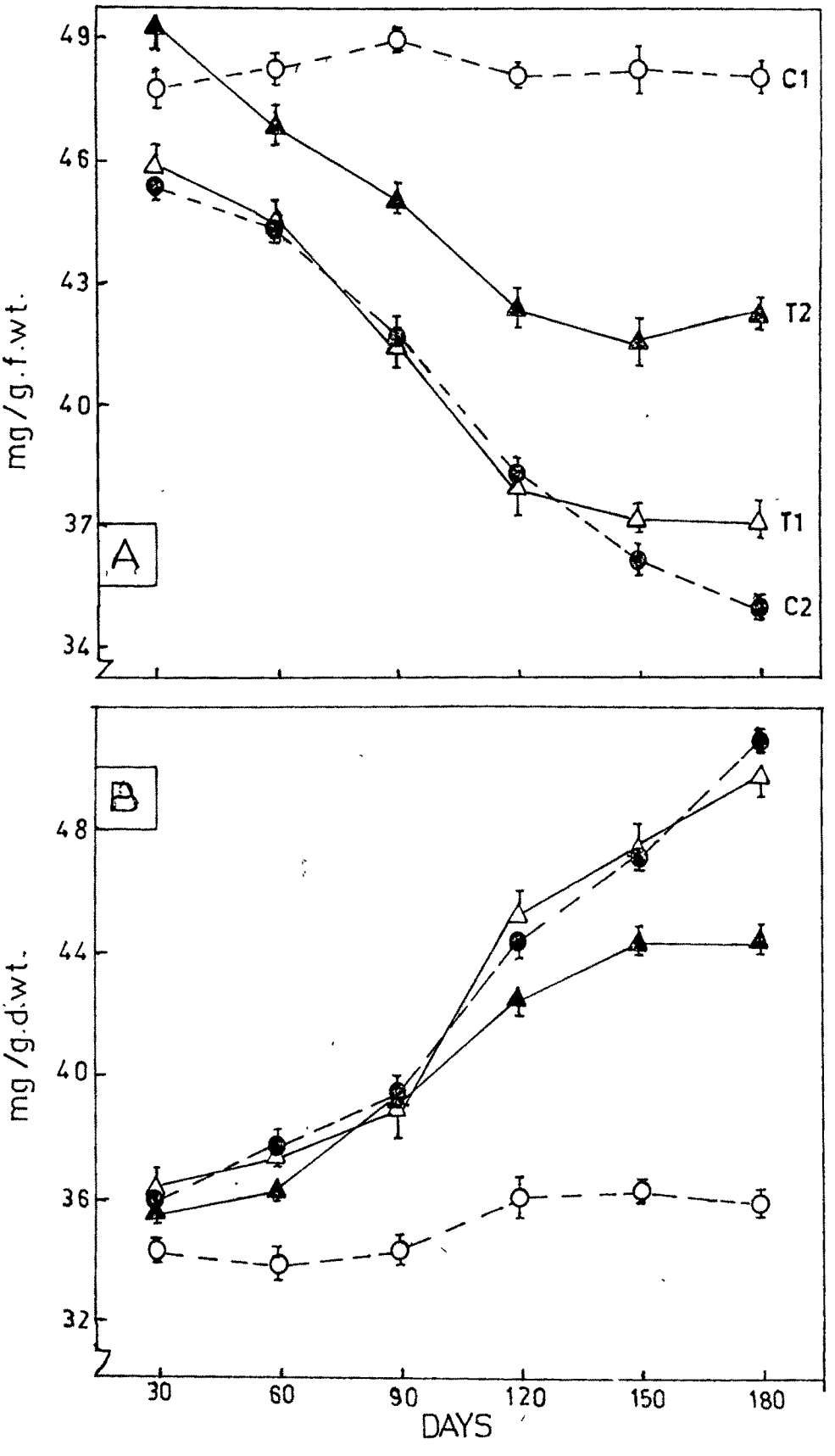

49
46
43
40
37
34
mg/g.f.wt.
A
C1
T2
T1
C2
B
48
44
40
36
32
mg/g.d.wt.
30
60
90
120
150
180
DAYS

Fig.3.8.4. Effect of SO_2 fumigation on (A) total soluble sugars and (B) sulphur content of *Syzygium cumini* Skeels (jamun)

C_1 : Neither exposed to SO_2 nor treated with ascorbic acid (AA)

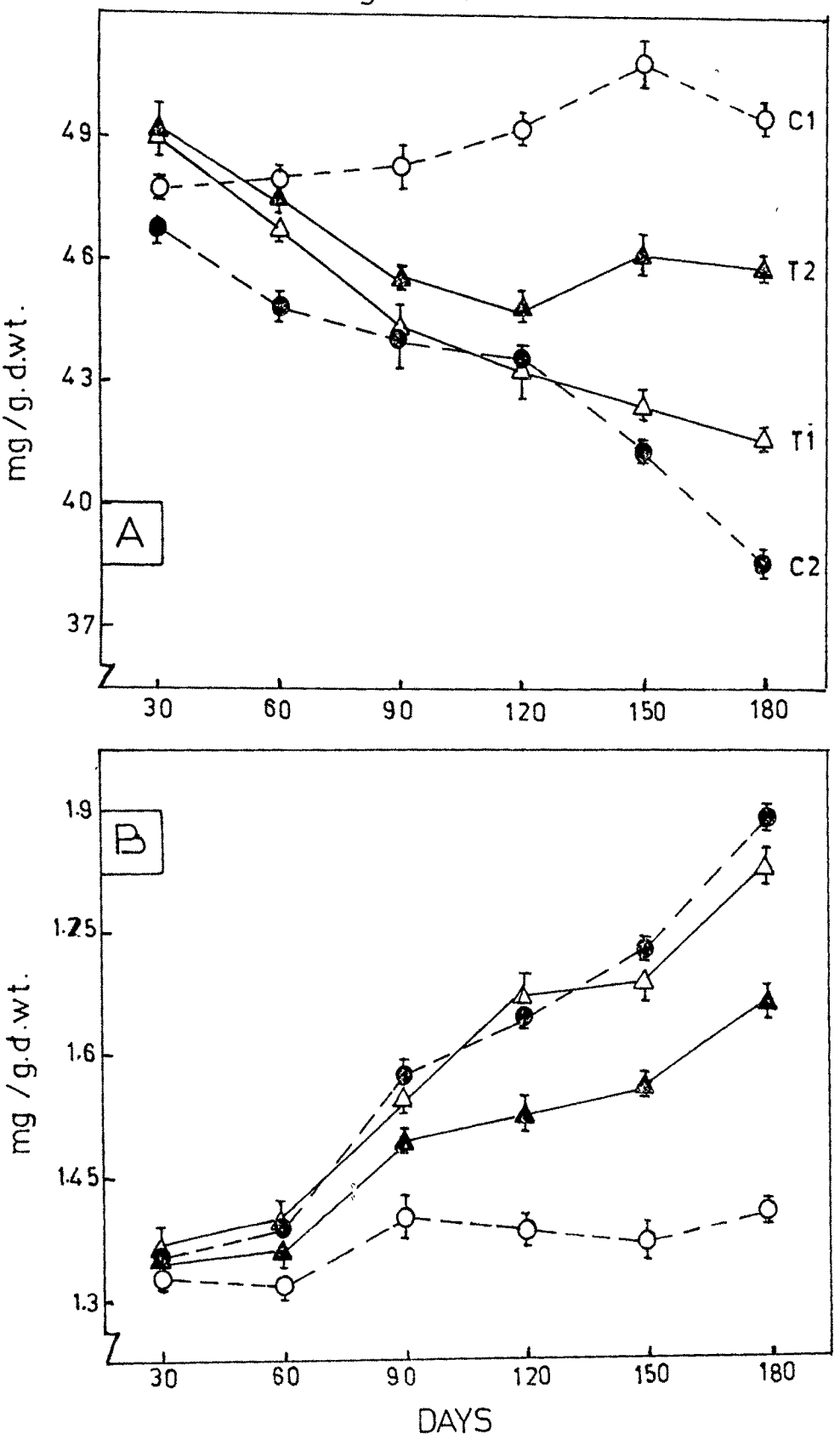
C_2 : Exposed to SO_2 but not treated withAA

T_1 : Exposed to SO_2 and treated with 10 µmoles of AA

T_2 : Exposed to SO_2 and treated with 100 µmoles of AA.

(Vertical bars represent standard deviation)

Fig. 3.8.4.


mg/g.d.wt.
49
46
43
40
37
A
C1
T2
T1
C2
30
60
90
120
150
180
B
1.9
1.25
1.6
1.45
1.3
mg/g.d.wt.
DAYS

(ix) Effect on sulphur content : Foliar sulphur content increased in C_2 plants with increasing number of SO_2 exposures. At 120 and 180 days, sulphur content in C_2 was 19.0% and 34.5% higher than C_1 respectively.

In T_1, it was close to C_1 at 30 days. The sulphur accumulation increased by 11.1%, 23.9% and 30.3% over C_1 at 90, 150 and 180 days respectively.

In T_2 plants, foliar sulphur content was 7.6%, 14.5% and 18.7% over C_1 at 90, 150 and 180 days respectively. (Fig.3.8.4.B.).

3.3.3.2. Amelioration of SO_2 effect by ascorbic acid treatments :

In jamun, SO_2 effect was mitigated more by 100 µmoles ascorbic acid concentration (T_2) than 10 µmoles treatment (T_1).

(i) Effect on chlorophyll a :In T_1 plants chlorophyll a content was recorded more or less close to C_2 upto 90 days. At 150 and 180 days it was slightly higher (2.6% and 3.4% respectively) than C_2.

In T_2, chlorophyll a content recorded was always higher than C_2 at all the ages. At 60, 120 and 180 days it was 4.9%, 5.8% and 16.0% more than C_2 respectively. (Fig.3.8.1.).

(ii) Effect on chlorophyll b : In T_1, this pigment also exhibited similar trend as chlorophyll a. At 120 and 180 days it showed slight increase (2.9% and 2.4% respectively) over C_2.

In T_2, it increased by 3.2%, 8.8% and 11.8% over C_2 at 60, 120 and 180 days respectively. (Fig.3.8.1.).

(iii) Effect on carotenoids : In T_1 plants, it was very close to C_2 plants upto 60 days. At 120 and 180 days the carotenoids content were recorded slightly higher than (3.6%, 2.4% respectively) C_2 plants.

In T_2 plants it was 7.3% higher than C_2 at 30 days, whereas at 120 and 180 days the percentage increase was 6.8 and 10.9 respectively. (Fig.3.8.1.).

(iv) Effect on ascorbic acid : In T_1 plants, 7.9% increase over C_2 was noticed at 30 days, whereas at 120 and 180 days it was 3.2% and 3.8% respectively.

In T_2, ascorbic acid content recorded was always higher than C_2. At 60, 120 and 180 days the percentage increase over C_2 was 6.4, 10.2 and 22.9 respectively.(Fig.3.8.2.).

(v) Effect on protein : In T_1 plants protein content recorded was more or less close to C_2 plants upto 120 days. At 150 and 180 days it was 3.0%, and 6.5% higher than C_2 respectively.

In T_2 plants, foliar protein content increased by 5.6%, 10.5% and 21.1% over C_2 at 60, 120 and 180 days respectively. (Fig.3.8.3A.).

(vi) Effect on total free aminoacids : In T_1 plants, the accumulation of free aminoacids was observed close to C_2 plants. At 120 and 180 days it was slightly less (2.9% and 2.5% respectively) than C_2.

In T_2 plants, mitigating effect was reflected by decreased accumulation of free aminoacids. At 120, 150 and 180 days the percentage reduction in free amino acid content was 4.1, 6.0 and 12.8 respectively than C_2. (Fig.3.8.3B.).

(vii) Effect on total soluble sugars : In T_1, soluble sugar content increased by 5.2% and 4.3% at 30 and 60 days respectively, but at 120 days it was close to C_2. At 180 days, it was 4.24% higher than C_2.

In T_2, at 30 days it increased by 5.0% over C_2. At 90, 150 and 180 days, the percentage increase was 3.4, 11.5 and 18.9 respectively. (Fig.3.8.4A.).

(viii) Effect on sulphur : In T_1 plants foliar sulphur content recorded was more or less close to the C_2 plants upto 120 days. It decreased slightly (2.3% and 3.1% respectively), at 150 and 180 days as compared to C_2.

In T_2 plants, accumulation of sulphur was close to C_2 upto 60 days. At 120 and 180 days it decreased by 7.5% and 11.8% respectively. (Fig.3.8.4B.).