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Assessment of losses caused by major insect-pests and diseases of mango (*Mangifera indica* L) under humid tropics

J.K. BANA[1,2]*, HEMANT SHARMA[3], S.M. CHAVAN [1]*, D.K. SHARMA[1] and S.J. PATIL[4]

[1] Agriculture Experimental Station, Navsari Agricultural University, Paria, Dist. Valsad, 396 145, Gujarat
[2] Department of Entomology, Sri Karan Narendra College of Agriculture, Sri Karan Narendra Agriculture University, Jobner-303 329, Rajasthan
[3] ASPEE College of Horticulture, Navsari Agricultural University, Navsari, 396 450, Gujarat
[4] N.M. College of Agriculture, Navsari Agricultural University, Navsari, 396 450, Gujarat
***E-mail:** sachinento@gmail.com, jugalbana@gmail.com

ABSTRACT: A study spanning five consecutive years (2016-20) was conducted to evaluate the damages inflicted on mango crops in humid tropical regions by primary insect pests and diseases. The findings revealed that hoppers, thrips, and fruit flies were the primary pests, while powdery mildew, anthracnose (pre and post-harvest), and stem end rot (SER) were the dominant diseases affecting mango trees. Notably, the population of hoppers and thrips remained significantly lower in orchards with protective measures (1.84 hoppers/panicle and 1.73 thrips/panicle/tap, respectively) compared to those without protection (11.58 and 8.84, respectively). Similarly, the incidence of pre-harvest diseases such as powdery mildew (2.28%) and anthracnose (5.24%), as well as post-harvest diseases like anthracnose (3.00%) and SER (3.75%), was notably reduced in protected orchards compared to unprotected ones (7.28, 14.30, 7.25, and 8.50, respectively). On average, % yield loss of 47.33 was documented in unprotected orchards compared to protected ones. This assessment holds the potential for enhancing the management of major insect pests and mango diseases, offering valuable insights for agricultural advisory services to aid farmers effectively.

Keywords: Anthracnose, mango hopper, stem end rot, thrips, unprotected orchard, yield loss

INTRODUCTION

Mango, *Mangifera indica* L. (Family: Anacardiaceae) is known for its delicious taste, attractive colour, savoring flavor, and high nutritional value of vitamins A and C, mineral and fiber content. The area under mango cultivation in India is 2.20 million hectares, with a total production of 18.64 million tonnes, sharing 40 percent of the total mango production of the world (NHB, 2015). Among Indian states, Gujarat covers 150 thousand hectares area with a total of 1.24 million tonnes of output with 8.10 tonnes/ha productivity (NHB, 2015). Various biotic (insect, disease, and weeds) and abiotic (temperature, humidity, wind, etc.) factors limit the potential productivity of mango in India. Crop loss assessment is the quantification of the impact of pests and diseases on crop yield. Among insects, more than 492 species of insect species are reported as pests on mangoes, of which 188 are reported from India (Tandon and Verghese, 1985). Hoppers, thrips, and fruit flies are recorded as a serious pest of mango in south Gujarat at flowering to fruiting harvesting stages and cause significant yield losses (Rahman and Kuldeep, 2007; Kumar *et al.,* 2014; Gundappa *et al.,* 2014; Mouly *et al.,* 2017; Bana *et al.,* 2017, Bana *et al.,* 2018; Bana *et al.,* 2021). Fruit fly incidence reduces the yield and quality and restricts the export of fruits to many countries (Patel *et al.,* 2013). In the highly humid and heavy rainfall zone of south Gujarat, direct damage is caused by fruit flies to fruits of mango and sapota to 16-40 and 2-4 percent, respectively (Patel and Patel, 2005).

Mango also suffers from several diseases, among them anthracnose, powdery mildew, and stem end rot (SER), which are recorded major from new flush to harvesting and storage conditions (Bana *et al.,* 2020; Nelson, 2008a, Karunanayake and Adikaram, 2020). Anthracnose is the major pre and post-harvest mango disease caused by *Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc. About 25 to 30% of fruit loss in total mango production has been reported under humid conditions due to the incidence of anthracnose and SER (Uddin *et al.,* 2018). Powdery mildew, *Oidium mangiferae* Berthet, is a significant, serious, and widespread disease in India and causes up to 90 percent flower panicle damage when observed in the epidemic (Misra *et al.,* 2016; Nelson, 2008b; Prakash and Srivastava, 1987). Symptoms of this disease can be noticed on leaves, inflorescences, and young fruits (Nelson, 2008b and Bana *et al.,* 2020). The southern part of Gujarat is considered a major production hub of the delicious Kesar variety of mango in western India.

Estimating yield losses in mango orchards is a major predicament in the economical production of high-quality quantities of mango over the entire region. Database of loss estimates related to crops and pests are essential prerequisites for economic management of pests and evaluating the efficacy of recommended crop protection practices. Pest and disease activity changes over time with respect to changing climate scenarios. In recent years, we have witnessed major climate changes, ultimately leading to changes in the status of pests. Therefore, quantification of yield losses with respect to changes in insect-pests status is very important for economic pest management. Strategies for using limited resources for management may be developed to optimize productivity and sustainability of production. Therefore, keeping in mind the above facts, the present experiment was carried out to estimate the yield losses of mangoes concerning major insect pests and diseases for developing cost-effective and ecologically benign pest management strategies under humid climatic conditions of south Gujarat.

MATERIALS AND METHODS

Experimentation and data observations

The study was conducted at the Agriculture Experimental Station, Navsari Agricultural University, Paria, India, on 20-year-old mango trees of *cv*. Kesar during five consecutive years (2016-20). Plant-to-plant and row-to-row distances were 8×8 and 10×10 m. The experiments were conducted by paired ‘t’ tests with two treatments (fully protected and unprotected plots). For insect pests, the first spray was applied of acephate 75 SP (0.04%) at the panicle emergence stage, followed by a second spray (need basis) with spinosad 45 SC (0.0112%) and a third need-based spray of thiamethoxam 25 G (0.008%) and first spray of carbendazim 50 WP (1gm/l) at appearance of disease on newly emerge flushes followed by hexaconazole 5 EC (1ml/l) at panicle stage for diseases. Weekly observations of major insect pests and diseases were recorded on ten panicles or inflorescence per tree from twenty randomly selected trees (10 sprayed and unsprayed trees) per the NICRA manual (NICRA, 2011). Fruit fly incidence was observed in 5 fruits per tree at 60 days after fruit set and harvest stage in plucked fruits from protected and unprotected orchards. Fruit fly infestation (dropped fruits) was observed 60, 75, and 85 days after the fruit set. Protection against insect pests and diseases in protected treatments was given according to the recommended package and practices of the plant protection sub-committee of Navsari Agricultural University, Navsari, Gujarat (Anonymous, 2014; 2016).

Percent Disease Index (PDI) was recorded by scoring all the individual ten panicles on each plant on a 0-5 rating scale (0= inflorescence healthy, or no disease, 1=<20% inflorescence covered by disease in panicles, 2=21-40% of the inflorescence covered by disease in panicles, 3=41-60% of the inflorescence covered by diseases in panicles, 4=61-80% of the inflorescence covered by disease in panicles and 5=81-100% of the inflorescence covered by disease). Anthracnose PDI was recorded by scoring all the individual ten leaves or twigs on each plant on a 0-5 rating scale (0=no visible symptoms, 1=1 % leaf area affected, 2=1.1 to 10 % leaf area affected, 3=10.1 to 25 % leaf area affected, 4=25.1 to 50 % leaf area affected, 5=More than 50 % leaf area affected by the disease). Further, the PDI was calculated using the McKinney formula (1923).

$$\text{PDI (\%)} = \frac{\text{Sum of all the disease ratings } (\Sigma N) \quad \times 100}{\text{No. of panicles observed x Maximum disease rating}}$$

Post-harvest diseases were observed on 100 plucked fruits in both treatments (protected and unprotected). Freshly harvested fruits at physiological maturity were stored at room temperature for 15 days to observe post-harvest diseases. The disease incidence (%) was calculated as the number of fruit infected (n) with post-harvest diseases out of the total number of fruits (N) observed.

$$\text{Disease incidence (\%)} = \frac{n}{N} \times 100$$

The avoidable crop loss and economics loss were calculated for each treatment by using the following formula,

$$\text{Avoidable loss (\%)} = \frac{\text{Yield in treated plot (kg ha}^{-1}\text{) - Yield in control plot (kg ha}^{-1}\text{)} \times 100}{\text{Yield in treated plot (kg ha}^{-1}\text{)}}$$

$$\text{Avoidable economic loss (\%)} = \frac{\text{Income in treated plot (kg ha}^{-}\text{)- Income in control plot (kg ha}^{-}\text{)} \times 100}{\text{Income in treated plot (kg ha}^{-}\text{)}}$$

Statistical analyses and data interpretation

Major pests (hopper, thrips, and fruit flies) and diseases (powdery mildew, anthracnose, and stem end rot) were recorded for five consecutive years (2016-20) in protected and unprotected orchards. Significant differences among the data were calculated using the paired ‘t’ test. Avoidable losses were calculated in protected and unprotected orchards.

RESULTS AND DISCUSSION

Incidence of major insect-pests and diseases were observed during the study periods. Significant difference was observed among the imposed treatments in protected and unprotected orchards.

Incidence of major insect-pests in protected and unprotected orchards

The results presented in Table 1 showed that the

Table 1. Incidence of mango hopper in protected and unprotected plot

		Hopper population/ panicle											
Year (s)		**2015-16**		**2016-17**		**2017-18**		**2018-19**		**2019-20**		**Pooled**	
Treatment details		UP	P	UP	P	UP	P	UP	P	UP	P	UP	P
BS	BS***	6.84	7.72	6.03	6.46	6.42	5.76	7.32	8.26	6.47	6.56	6.62	6.95
	SD****	1.76	2.43	1.08	1.66	1.84	1.62	2.29	1.96	2.25	2.01	0.70	0.81
	T-Statistic	0.936^{NS}		0.75^{NS}		0.93^{NS}		1.12^{NS}		0.09^{NS}		1.38^{NS}	
Ist spray	7 DAS	8.46	1.16	7.12	2.07	7.39	2.23	8.19	1.95	7.92	1.78	7.82	1.84
	SD	2.17	0.70	1.41	1.17	1.42	0.79	2.27	0.70	1.52	0.54	0.57	0.33
	T-Statistic	12.80**		11.87**		12.29**		11.05**		10.15**		33.51**	
	14 DAS	10.13	3.19	8.52	2.78	9.17	2.12	9.47	3.40	8.95	2.98	9.25	2.89
	SD	2.19	1.56	1.52	0.69	1.57	1.00	1.62	0.79	1.74	1.12	0.93	0.49
	T-Statistic	8.49**		14.00**		13.16**		11.12**		11.46**		22.35**	
IInd spray	7 DAS	12.07	0.67	9.84	1.10	10.08	1.34	10.96	0.86	11.02	0.55	10.79	0.90
	SD	2.95	0.49	1.68	0.59	1.34	0.83	1.74	0.41	2.04	0.48	0.75	0.33
	T-Statistic	12.71**		13.31**		15.96**		20.71**		15.91**		40.26**	
	14 DAS	13.18	1.73	11.23	1.14	10.67	0.91	13.41	1.46	12.95	0.82	12.29	1.21
	SD	2.35	0.77	1.88	0.67	1.99	0.53	2.15	0.80	2.13	0.36	1.01	0.30
	T-Statistic	14.17**		14.13**		13.75**		14.89**		17.18**		29.32**	
IIIrd spray	7 DAS	14.13	0.94	11.42	0.73	-	-	13.89	1.23	12.85	1.06	13.07	0.99
	SD	3.12	0.63	1.94	0.48	-	-	2.48	1.04	2.56	0.67	0.90	0.38
	T-Statistic	14.06**		15.91**				13.26**		12.90**		39.90**	
	14 DAS	13.92	1.21	12.18	0.92	-	-	14.87	1.60	15.20	1.89	14.04	1.41
	SD	2.03	0.68	2.05	0.65	-	-	2.27	1.18	2.31	0.95	0.86	0.37
	T-Statistic	18.52**		14.15**				14.64**		15.26**		35.84**	
Pooled	7 DAS	11.55	0.92	9.46	1.30	8.74	1.79	11.01	1.35	10.60	1.13	10.27	1.30
	SD	1.79	0.30	0.91	0.56	1.25	0.55	1.26	1.35	1.77	0.38	0.47	0.21
	T-Statistic	20.21**		23.18**		16.82**		23.22**		15.05**		57.92**	
	14 DAS	12.41	2.04	10.64	1.61	9.92	1.52	12.58	2.15	12.37	1.90	11.58	1.84
	SD	0.98	0.58	1.23	0.57	1.47	0.45	1.24	0.48	1.76	0.70	0.72	0.29
	T-Statistic	27.79**		17.29**		17.95**		20.95**		16.62**		35.37**	

Significant at 0.01 level; NS, Non-significant; UP, Unprotected; P, Protected; BS*, Before spray; SD****, Standard deviation

population of mango hoppers remained non-significant in both orchards (protected and unprotected) before the imposition of sprays. Based on the four-year consecutive study (irrespective of different post-spray intervals), the hopper population was found to be significantly lower in protected (1.30 & 1.84 hoppers /panicle) as compared to unprotected orchards (10.27 & 11.58 hoppers/panicle) after 7 and 14 days of sprays, respectively ($P<0.01$).

During the study periods, the thrips population was recorded in 2016- 17, and results revealed that populations were found to be non-significant before the imposition of sprays. The lowest thrips population was recorded in protected trees (1.23 and 1.73 thrips /panicle/ tap) over to unprotected trees after 7 and 14 DAS (8.19 and 8.84 thrips/panicle/tap), respectively (Table 2). Both treatments were found to be non-significant in fruit fly infestation in plucked fruits during study periods, while a significant difference was observed in dropped fruits (Table 3). In dropped fruits, the significantly lowest fruit fly incidence was observed in the protected plots (5.27%) over to the unprotected plots (15.22%). Similarly, more or less trends were recorded during the study periods. Based on the pooled results, both treatments were significant in fruit fly infestation ($P<0.01$).

The Integrated Pest Management module comprised the first spray of acephate 75 SP (0.04%) at the panicle emergence stage, followed by spinosad 45 SC (0.004%) after 21 days. A third need-based spray was the most effective treatment in reducing the mango hopper and thrips population reported by Bana *et al.* (2015a) and Bana *et al.* (2015b). The maximum number of fruits at the marble stage (425.63 fruits/100panicles) was recorded with the treatment over to control (153.50 fruits/100panicles). Verghese *et al.* (2006) reported that pre-harvest IPM combination of male annihilation technique (using methyl eugenol as a lure) + sanitation brought down fruit flies infestation to 5.00% from an infestation ranging from 17–66% in control. The untreated fruits, which were also exposed to gravid females, showed 30% and 5.5% infestations in 2004 and 2005 at IIHR, Bengaluru.

Incidence of pre-and post-harvest disease in protected and unprotected orchards

After 15 days of spray, powdery mildew and anthracnose intensity were significantly lower in the protected plot (3.80 and 8.80%) than in the unprotected plot (12.20 and 20.40%). Similar trends were observed during succeeding years. Based on pooled results, minimum severity was recorded in protected plots (2.28 and 5.24 %) over in unprotected plots (7.28 and 14.30 %), respectively. Sayiprathap *et al.* (2018) surveyed ten districts of Karnataka. They reported that the highest percent disease index (PDI) was observed in Srinivas

Table 2. Incidence of mango thrips in protected and unprotected plot during 2016-17#

Treatment details	Thrips population/panicle/tap																	
			Ist Spray				IInd Spray				IIIrd Spray				Pooled			
	BS		7 DAS		14 DAS		7 DAS		14 DAS		7 DAS		14 DAS		7 DAS		14 DAS	
	UP	P	UP	P	UP	P	UP	P	UP	P	UP	P	UP	P	UP	P	UP	P
Mean	5.11	4.32	5.47	2.26	6.32	3.10	8.86	0.59	9.51	0.92	10.24	0.84	10.69	1.17	8.19	1.23	8.84	1.73
SD	1.11	0.69	1.40	1.05	1.82	0.80	2.20	0.35	1.76	0.48	1.55	0.56	1.20	0.81	0.96	0.45	1.02	0.41
T-Statistic	1.73^{NS}		4.92**		5.18**		11.24**		13.97**		19.62**		21.18**		24.17**		22.19**	

** Significant at 0.01 level; NS, Non-significant

#Thrips population was recorded in 2016-17, rest years incidence low or negligible in plot.

Table 3. Fruit fly incidence in plucked and dropped fruits on protected and unprotected plot

Treatment details	Plucked fruits (% Fruit fly infestation)*											
	2015-16		2016-17		2017-18		2018-19		2019-20		Pooled	
	UP	P	UP	P	UP	P	UP	P	UP	P	UP	P
Mean	13.00	6.00	8.00	3.00	9.00	5.00	10.00	2.00	9.00	4.00	9.80	4.00
SD	11.59	8.43	6.32	4.83	7.38	5.27	11.54	4.21	7.38	6.99	3.71	2.49
T-Statistic	1.12^{NS}		1.86^{NS}		1.80^{NS}		2.22^{NS}		1.34^{NS}		4.11**	
	Dropped fruits (%Fruit fly infestation)*#											
Mean	15.22	5.27	13.14	6.84	17.58	4.02	16.65	4.32	21.58	6.89	10.42	2.70
SD	6.20	1.98	4.71	5.77	5.86	2.50	5.24	3.47	4.46	2.70	2.83	1.07
T-Statistic	5.15**		2.92**		6.47**		6.67**		9.97**		7.48**	

** Significant at 0.01 level; NS, Non-significant

Hopper population on twigs, sooty mold symtoms on panicles and thrips infested pea sized fruits

Thrips damage on leves, and infested and dropped fruits by fruit fly

purtaluka (33.60 %) of Kolar district with a mean PDI of 32.40, followed by Chikkaballapur district with a mean PDI of 31.62. Dembele *et al.* (2019) reported that anthracnose disease incidence and severity varied from locality to locality in dry and rainy seasons. Disease intensity was higher in the rainy season than in the dry season.

Anthracnose and SER rot were reported as major devastating post-harvest diseases during the study periods. The results (Table 4 and Figure 3) showed that the minimum incidence of anthracnose and SER was reported in collected fruits from protected plots (3 and 2%) over to unprotected plots (11 and 6%), respectively. Subsequently, anthracnose and stem end rot post-harvest disease losses reached up to 4 and 6% in protected fruits, compared to un-protected plot collected fruit (9 and 13%). In pooled results, the incidence of anthracnose and SER were observed at 3& 3.75% in protected and 7.25 and 8.50% in unprotected fruits, respectively. Prusky *et al.* (2009) reported that postharvest diseases of mango reduce fruit quality and cause severe losses, resulting in entirely unmarketable fruits and increases during the ripening stage due to physiological changes. The disease was also more severe on fruits than on leaves (Dembele *et al*., 2019). Terao *et al.* (2018) reported that SER is a severe threat to the mango industry in Brazil and caused significant losses during transportation and storage. Pre- and post-harvest anthracnose correlated significantly, indicating that infection was initiated in the field and remained latent until fruit repining. In Israel, SER causes a 30–40% loss of harvested mango fruit (Diskin *et al.,* 2017). In Sri Lanka, postharvest losses of mangoes exceed 30 - 40% due to extensive rotting of harvested fruits.

Yield and economic losses

Results presented in Tables 5 & 6 showed that the significantly highest mango yield (73.60 kg /tree) was recorded in the protected plots compared to the unprotected plots (46.30 kg/tree) during 2015-16. Subsequently, the maximum yield was obtained in the protected plot (69.90 kg/tree) over to the unprotected plot (35.60 kg/tree). A similar trend was observed during consecutive years; the highest yield was recorded in the protected plots (62.43, 60.43, and 65.25 kg/tree) as compared to unprotected plots (29.65, 25.18, and 18.30 kg /tree) during 2017-18 to 2019-20, respectively. In pooled results, the maximum yield was recorded in the protected plot (66.32 kg /tree) compared to the unprotected plot (31.01kg/tree). The maximum net return was recorded in the protected plot compared to the unprotected plot (Rs. 1205943 over to 104880), and the net profit over control is Rs. 97463. Overall, 47.33 percent yield losses were recorded in the unprotected plots compared with the protected plots in the Kesar variety of mango in humid tropics (Table 6).

CONCLUSION

This study showed that mango hopper, thrips, and

Table 4. Intensity of powdery mildew and anthracnose in protected and unprotected plot

Treatment details	Powdery mildew PDI (%)											
	2015-16		2016-17		2017-18		2018-19		2019-20		Pooled	
	UP	P	UP	P	UP	P	UP	P	UP	P	UP	P
Mean	12.20	3.80	7.80	3.00	6.20	1.80	5.40	1.20	4.80	1.60	7.28	2.28
SD	6.42	2.39	5.12	2.16	3.59	1.75	2.98	1.39	3.68	1.83	1.42	1.00
T-Statistic	4.78**		2.51*		3.50**		3.71**		2.67**		12.90**	
	Anthracnose PDI (%)											
Mean	20.40	8.80	14.80	6.20	9.40	3.20	12.60	4.20	8.60	3.80	14.30	5.24
SD	5.95	4.73	3.01	3.05	3.77	1.93	4.11	1.98	5.25	2.40	1.98	0.87
T-Statistic	5.81**		6.61**		4.39**		5.44**		2.30*		17.47**	
	Post-Harvest Diseases (%)*											
Anthracnose	11	3	4	3	9	4	5	2	8	3	7.25	3.00
Stem end rot	6	2	7	4	13	6	8	3	12	5	8.50	3.75

*, Significant at 0.05 level; **, Significant at 0.01 level

Table 5. Yield in protected and unprotected plot

Treatment details	Yield (Kg/tree)											
	2015-16		2016-17		2017-18		2018-19		2019-20		Pooled	
	UP	P	UP	P	UP	P	UP	P	UP	P	UP	P
Mean	46.30	73.60	35.60	69.90	29.65	62.43	25.18	60.43	18.30	65.25	31.01	66.32
SD	8.52	12.15	6.67	9.95	7.41	13.21	4.97	10.49	4.95	11.28	2.16	5.51
T-Statistic	5.99**		12.43**		8.06**		11.39**		14.65**		20.03**	

** Significant at 0.01 level

Powdery mildew symptoms on inflorescences **External symptoms of SER on ripe mango fruits**

Fig. 2: Symptoms of different major pre and post-harvest disease of mango under humid tropic

fruit fly are recorded as significant insect pests, and anthracnose, powdery mildew, and SER are primary pre and post-harvest fungal diseases that threaten the production and marketing of mango fruits in humid conditions. Hopper and thrips populations remained significantly lower in protected orchards (1.84 hopper/panicle and 1.73 thrips/panicle/tap, respectively) than in unprotected orchards (11.58 and 8.84). Similarly,

Table 6. Economics of yield losses in protected and unprotected plot

Treatment (s)	UP	P
Yield (kg/ha)	4017.78	8239.20
Yield loss (kg/ha)	4221.42	0.0
Gross return (kg/ha)	108480.06	222458.40
Pesticides cost and spraying charges	0.00	16514.86
Net return	108480.06	205943.54
Net profit over control	0.00	97463.48
Avoidable losses (%)	47.33	0.0

Cost of pesticides: Acephate 693/kg, Spinosad 1380/75ml, Thiamethoxam 887/kg, Carbendazim 506/kg and Hexaconazole 310/lit., price of mango Rs. 27 per kg.

the incidence of pre-harvest diseases, *viz*., powdery mildew (2.28%), anthracnose (5.24%), and post-harvest diseases, *viz*., anthracnose (3.00%) and SER (3.75%) was also found significantly lower in protected orchards as compared to un-protected orchard (7.28, 14.30, 7.25 and 8.50, respectively). The average yield losses of 47.33 percent were recorded in unprotected trees compared to protected trees in the Kesar variety of mango under humid tropics.

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