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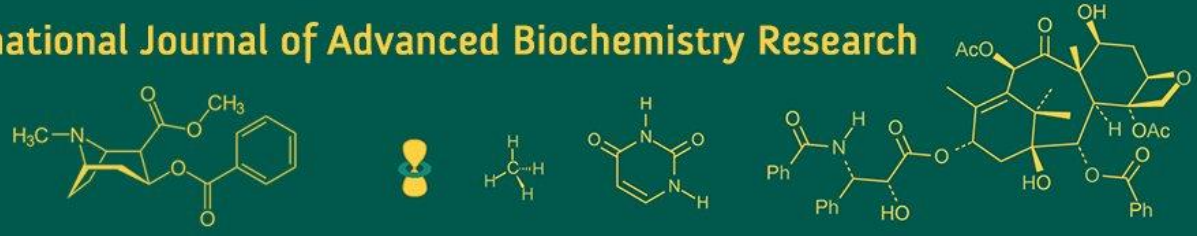

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Evaluation of eco-friendly pesticides against custard apple mealybug, *Maconelicoccus hirsutus* (Green) in North Gujarat

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Abstract
The present investigation on evaluation of eco-friendly pesticides against custard apple mealybug, *Maconelicoccus hirsutus* (Green) was carried out at the Horticultural Instructional Farm, Chimanbhai Patel College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar during *Kharif*, 2024. Among eight eco-friendly pesticides, azadirachtin 10000 ppm (0.003%) was most effective, recording the lowest (7.86) infestation of mealybugs per fruit, closely followed by NSKE 5% (8.29 mealybugs/fruit) and *L. lecanii* 1.15 WP (8.85/fruit). Microbial treatments *viz*., *B. bassiana* and *M. anisopliae* showed moderate efficacy against mealybugs, whereas botanical extracts *viz*., nafatiya + dhatura and calotropis at 10% recorded higher populations of mealybugs, though all treatments significantly outperformed the untreated control. Correspondingly, azadirachtin 10000 ppm produced the highest fruit yield (69.25 q/ha) resulting in to maximum increase in yield over control (70.45%) and the treatment was at par with NSKE 5% and *L. lecanii*.

Keywords: Eco-friendly pesticides, mealybug, *Maconelicoccus hirsutus* (Green), custard apple

Introduction
Custard Apple (*Annona squamosa* Linnaeus) belonging to family Annonaceae, is one of the finest fruit introduced in India from Tropical America. It is very hardy, tolerant to drought, salinity and saline irrigation water to certain extent. It shed off leaves during stress periods to evade moisture loss from plant and thus a most appropriate fruit crop for arid regions of the Gujarat state. It is a climacteric fruit and starts ripening soon after detachment from the tree (Wills *et al*., 2001) [17]. In India, it is cultivated especially in Andhra Pradesh, Bihar, Madhya Pradesh, Maharashtra, Tamil Nadu, Gujarat and Odisha. It is cultivated on an estimated area of 51.73 thousand hectares with 548.27 thousand MT production with productivity 8.45 MT/ha (Anon., 2023[a]) [1]. In Gujarat, it is cultivated on an estimated area of 7,900 hectares with 79.56 thousand MT of production with productivity 10.08 MT/ha (Anon., 2023[b]) [2]. Custard apple is generally used as a table fruit. Its pulp can also be mixed with milk or ice cream.

The production of custard apple at the farmer's field is quite low due to various reasons. Among the several factors responsible for low yield and quality, insect pest is one of the most important limiting factors. More than 20 species of insect pests have been reported damaging to custard apple plants in India (Butani, 1976) [3]. Among the various insect pests, the mealybug is the most destructive and predominant. These small, soft-bodied, sap-sucking insects constitute the second-largest family of scale insects (Hemiptera: Coccoidea). Three species of mealybugs *viz*., *Planococcus citri* (Risso), *Maconellicoccus hirsutus* (Green) and *Ferrisia virgata* (Cockerell) have been recorded on custard apple. The mealybugs species were reported causing the most severe damage by sucking the cell sap from fruits, leaves and young shoots of different fruit crops (Mani and Krishnamoorthy, 1989) [9]. In recent years, *M. hirsutus*, also known as pink hibiscus mealybug has become a serious menace to successful cultivation of different fruit crops in India (Sahu *et al*., 2019) [14]. Both nymphs and adults of mealybug suck the sap from leaves causing withering and yellowing of leaves. They excrete copious amount of honey dew that attracts ants and help in development of black sooty mould which inhibits the plant ability to manufacture food. When fruits are infested with mealybugs, they can be entirely covered with the white waxy coating of the

mealybug. Infestation can lead to fruit drop or fruit may remain on the host in a dried and shrivelled condition. Mealybug infected fruits are unfit for marketing, making the effective management of this pest necessary. The mealybugs were observed infesting custard apple from fruit setting during August and heavy fruit damage ranging from 40 to 80 percent during October-November in Vanthli (Junagadh) and Sanosara/Sinhor (Bhavnagar) areas of Saurashtra, Gujarat (Sapteshwriya and Barad, 2020) [15]. Indiscriminate and excessive use of synthetic pesticides leads to several consequences *viz*., destruction of natural enemies and pollinators, environmental pollution, health hazards, pest resurgence and resistance development in insect-pests (Meena *et al*., 2013) [10]. By affecting pollinators, soil microbes and bio-control agents, pesticide use also threatens key ecosystem services (Pelsoi *et al*., 2021) [12]. The threats associated with conventional insecticide have necessitated the need to find alternate economical and environmentally safe methods. Biopesticides are cost-effective, sustainable, less hazardous and safe for non-target organisms (Pan *et al*., 2023) [11]. These are phytochemical compounds that exhibit complex mechanisms of mode of action which may reduce resistance development in insect pests and are sustainable in nature. Hence, the present investigation was carried out to evaluate some eco-friendly pesticides against custard apple mealybug in North Gujarat.

Materials and Methods

The investigation on evaluation of eco-friendly pesticides against custard apple mealybug was conducted at the Horticultural Instructional Farm, Chimanbhai Patel College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar during *Kharif*, 2024. For the purpose, an experiment was laid out in a Completely Randomized Design with three repetitions in custard apple orchard (var. Sindhan), having spacing of 6 m × 6 m. The trial aimed to determine the relative efficacy of various eco-friendly pesticides *viz*., Azadirachtin 10000 ppm 0.003%, *Beauveria bassiana* 1.15 WP (1×10^8 cfu/g) 0.0046%, *Lecanicillium lecanii* 1.15 WP (1×10^8 cfu/g) 0.0046%, *Metarhizium anisopliae* 1.15 WP (1×10^8 cfu/g) 0.0046%, Neem seed kernel extract 5%, Calotropis leaf extract 10% and Nafatiya + Dhatura leaf extract 10%.

To prepare the botanical extracts for the experiment, 1 kg of fresh Calotropis leaves were crushed using electric mixer to make paste and thoroughly dissolved in 10 liters of water, kept overnight and filtered in next day to obtain 10 percent leaf extract. For the Nafatia + Dhatura 10% leaf extract, the same method was followed, where 500 g leaves of each botanical were taken and crushed together to form the paste. To prepare the NSKE 5%, 500 g of crushed neem kernels were filled in a muslin bag and dipped in 10 L of water overnight; the bag was then squeezed the next morning to obtain the filtrate for further experimentation.

The treatments were applied by using high volume knapsack sprayer with required concentration. The first spray was applied on the appearance of mealybug and subsequent two sprays were given at 10 days interval. For recording the population, four branches were selected from each cardinal direction (*viz*., East, West, North and South) and four fruits from each selected branches were tagged for observation. The number of nymphs and adult female mealybugs was counted using a magnifying lens. These observations were recorded using a magnifying lens before application of treatment as well as 3, 7 and 9 days after each spray.

At harvest, the fruit yield was recorded individually for each tree and the resulting data were subjected to statistical analysis. The increase in yield over control and percentage of avoidable loss in custard apple yield due to mealybug infestation was determined following the formula suggested by Khosla (1977) [7].

$$\text{Increase in yield over control (\%)} = \frac{\text{Yield in treatment} - \text{Yield in control}}{\text{Yield in control}} \times 100$$

$$\text{Avoidable loss (\%)} = \frac{\text{Highest yield in treated tree} - \text{Yield in treatment}}{\text{Highest yield in treated tree}} \times 100$$

Results and Discussion

Mealybug population

After first spray (Table 1), the minimum population of mealybugs (10.72/fruit) was recorded in treatment of azadirachtin 10000 ppm 0.003 percent and it was at par with NSKE 5 percent (11.06 mealybugs/fruit) and *L. lecanii* 1.15 WP 0.0046 percent (11.33 mealybugs/fruit). The trees treated with *B. bassiana* 1.15 WP 0.0046 percent and *M. anisopliae* 1.15 WP 0.0046 percent recorded 15.34 and 15.82 mealybug population per fruit, respectively and they were equally effective. Treatment with nafatiya + dhatura leaf extract 10 percent recorded higher mealybug population (19.84/fruit) on custard apple and it was at par with calotropis leaf extract 10 percent (20.29/fruit). However, all the eco-friendly treatments were significantly different from untreated control (26.54 mealybugs/fruit).

The data on mealybugs per fruit after second spray (Table 1) clearly revealed that the lowest (7.68) mealybug population was recorded in the treatment of azadirachtin 10000 ppm 0.003 percent and it was at par with NSKE 5% (8.14/fruit) and *L. lecanii* 1.15 WP 0.0046 percent (8.86/fruit). Trees treated with entomopathogens *viz*., *B. bassiana* 1.15 WP 0.0046 percent and *M. anisopliae* 1.15 WP 0.0046 percent registered 12.46 and 13.12 mealybugs per fruit, respectively and they were at par with each other. The trees treated with nafatiya + dhatura leaf extract 10 percent and calotropis leaf extract 10 percent recorded 18.34 and 19.21 mealybugs per fruit, respectively and they proved as less effective. However, untreated control recorded significantly the highest (28.66/fruit) *M. hirsutus* population on custard apple.

The data recorded from trees sprayed with azadirachtin 10000 ppm 0.003 percent exhibited least number (5.55) of mealybugs per fruit after third spray and it was statistically on par with NSKE 5 percent (6.05/fruit) and *L. lecanii* 1.15 WP 0.0046 percent (6.63/fruit). Entomopathogenic fungi *viz*., *B. bassiana* 1.15 WP and *M. anisopliae* 1.15 WP 0.0046 percent recorded 11.06 and 11.47 mealybugs per fruit, respectively and they were at par with each other. The higher number of mealybugs was recorded in nafatiya + dhatura leaf extract 10 percent (17.48) and calotropis leaf extract 10 percent (18.51) and they were at par with each other. The untreated control recorded significantly the highest (29.97) mealybugs per fruit.

Based on pooled over spray, it can be concluded that the population of mealybug ranged from 7.86 to 28.49 mealybugs per fruit (Table 1). The trees sprayed with azadirachtin 10000 ppm 0.003 percent exhibited lowest (7.86) mealybugs per fruit and proved as most effective against the pest. However, it was at par with NSKE 5 percent (8.29) and *L. lecanii* 1.15 WP 0.0046 percent (8.85).

The trees treated with *B. bassiana* 1.15 WP 0.0046 percent and *M. anisopliae* 1.15 WP 0.0046 percent registered 12.89 and 13.42 mealybugs per fruit, respectively and they were at par with each other. Botanical leaf extracts *viz*., nafatiya + dhatura leaf extract 10 percent (18.54 mealybugs/fruit) and calotropis leaf extract 10 percent (19.33 mealybugs/fruit) were least effective treatments. Moreover, all the eco-friendly treatments were significantly superior over untreated control (28.49 mealybugs/fruit).

Katke (2008) [6] reported that NSKE 5% effectively reduced mealybug populations in grape bunches, with an average of 5.10 mealybugs per bunch, comparable to *L. lecanii* (5.8 mealybugs/bunch) and *M. anisopliae* (6.0 mealybugs/bunch). Similarly, Elango and Sridharan (2021) found that among the treatments tested, azadirachtin 10000 ppm was the most effective in reducing mealybug populations, followed by NSKE 5%, *L. lecanii* and *B. bassiana*. These findings aligned with the present study. Rajendra Singh *et al*. (2011) [13] reported that NSKE 5% and *B. bassiana* @ 1.0× 10^9 cfu/ml resulted in mango mealybug mortality rates of 23.1% to 26.7% and 18.3% to 21.2%, respectively within 48 hours of treatment. The satisfactory control of pest by *L. lecanii* in the present study is in agreement with that reported by Kulkarni *et al*. (2003) [8] and Jayachakravarthy (2001) [5] on *Ferrisia virgata* and *M. hirsutus*, respectively. According to Sapteshwariya and Barad (2020) [15], *L. lecani* 1.15% WP was the most effective treatment against custard apple mealybug and it was at par with *M. anisopliae* 1.15% WP, whereas NSKE 5% and *B. bassiana* 1.15% WP were significantly less effective. The variation in the results may be due to differences in environmental conditions. which is due to varying environmental conditions.

Fruit yield

The data presented in Table 2 indicated that trees treated with different eco-friendly pesticides recorded significantly higher yield (48.01 to 69.25 q/ha) than untreated control (40.63 q/ha). The highest (69.25 q/ha) fruit yield of custard apple was harvested from the tree treated with azadirachtin 10000 ppm 0.003 percent and it was at par with NSKE 5% and *L. lecanii* 1.15 WP 0.0046 percent with fruit yield of 68.33 and 67.40 q/ha, respectively. Trees treated with *B. bassiana* 1.15 WP 0.0046 percent and *M. anisopliae* 1.15 WP 0.0046 percent recorded fruit yield of 59.09 and 57.25 q/ha, respectively and they were at par with each other. The nafatiya + dhatura leaf extract 10 percent produced lower (48.94 q/ha) yield and it was at par with calotropis leaf extract (48.01 q/ha).

Increase in yield over control

The results presented in Table 2 clearly revealed that the maximum increase in yield over control was computed in the treatment azadirachtin 10000 ppm 0.003 percent (70.45%) followed by NSKE 5% (68.18%) and *L. lecanii* 1.15 WP 0.0046 percent (65.91%). *B. bassiana* 1.15 WP 0.0046 percent and *M. anisopliae* 1.15 WP 0.0046 percent recorded 45.45 and 40.91 percent increase in yield over control, respectively. However, nafatiya + dhatura leaf extract 10 percent and calotropis leaf extract 10 percent recorded lower increase in yield over control with 20.45 and 18.18 percent, respectively.

Table 1: Bio-efficacy of eco-friendly pesticides against mealybug infesting custard apple

Tr. No.	Treatments	Conc. (%)	No. of mealybugs/fruit													
			Before spray	1st spray				2nd spray				3rd spray				Pooled over sprays
				3 DAS	6 DAS	9 DAS	Pooled over periods	3 DAS	6 DAS	9 DAS	Pooled over periods	3 DAS	6 DAS	9 DAS	Pooled over periods	
T_1	Azadirachtin 10000 ppm	0.003	4.66^a (21.24)	3.49^a (11.68)	3.28^a (10.28)	3.29^a (10.34)	3.35^a (10.72)	2.98^a (8.39)	2.79^a (7.28)	2.81^a (7.38)	2.86^a (7.68)	2.56^a (6.04)	2.41^a (5.31)	2.41^a (5.31)	2.46^a (5.55)	2.89^a (7.86)
T_2	*Beauveria bassiana* 1.15 WP (1 x 10^8 cfu/g)	0.0046	4.67^a (21.32)	4.04^b (15.84)	3.93^b (14.91)	3.96^b (15.19)	3.98^b (15.34)	3.65^b (12.81)	3.56^b (12.18)	3.59^b (12.38)	3.60^b (12.46)	3.48^b (11.58)	3.35^b (10.71)	3.38^b (10.91)	3.40^b (11.06)	3.66^b (12.89)
T_3	*Lecanicillium lecanii* 1.15 WP (1 x 10^8 cfu/g)	0.0046	4.59^a (20.54)	3.57^a (12.23)	3.35^a (10.71)	3.39^a (11.01)	3.44^a (11.33)	3.16^a (9.50)	2.99^a (8.47)	3.03^a (8.66)	3.06^a (8.86)	2.75^a (7.07)	2.62^a (6.37)	2.65^a (6.52)	2.67^a (6.63)	3.06^a (8.85)
T_4	*Metarhizium anisopliae* 1.15 WP (1 x 10^8 cfu/g)	0.0046	4.74^a (22.01)	4.09^b (16.25)	4.00^b (15.46)	4.03^b (15.77)	4.04^b (15.82)	3.73^b (13.39)	3.66^b (12.88)	3.69^b (13.08)	3.69^b (13.12)	3.53^b (11.96)	3.42^b (11.16)	3.44^b (11.35)	3.46^b (11.47)	3.73^b (13.42)
T_5	Neem seed kernel extract	5	4.63^a (20.91)	3.53^a (11.96)	3.31^a (10.49)	3.34^a (10.68)	3.40^a (11.06)	3.09^a (9.05)	2.86^a (7.66)	2.87^a (7.71)	2.94^a (8.14)	2.63^a (6.44)	2.52^a (5.83)	2.54^a (5.94)	2.56^a (6.05)	2.97^a (8.29)
T_6	Calotropis leaf extract	10	4.73^a (21.96)	4.60^c (20.63)	4.53^c (19.99)	4.55^c (20.24)	4.56^c (20.29)	4.47^c (19.49)	4.41^c (18.98)	4.45^c (19.27)	4.44^c (19.21)	4.39^c (18.78)	4.32^c (18.16)	4.36^c (18.47)	4.36^c (18.51)	4.45^c (19.33)
T_7	Nafatiya + Dhatura leaf extract	10	4.63^a (20.95)	4.56^c (20.31)	4.46^c (19.42)	4.50^c (19.71)	4.51^c (19.84)	4.39^c (18.74)	4.30^c (18.01)	4.33^c (18.27)	4.34^c (18.34)	4.27^c (17.75)	4.21^c (17.21)	4.25^c (17.52)	4.24^c (17.48)	4.36^c (18.54)
T_8	Untreated control	-	4.80^a (22.54)	5.06^d (25.10)	5.21^d (26.63)	5.27^d (27.30)	5.20^d (26.54)	5.30^d (27.63)	5.37^d (28.32)	5.40^d (28.65)	5.40^d (28.66)	5.46^d (29.33)	5.52^d (29.92)	5.58^d (30.66)	5.52^d (29.97)	5.38^d (28.49)
S. Em.±	Treatment (T)		0.21	0.15	0.15	0.15	0.08	0.16	0.16	0.16	0.09	0.16	0.15	0.15	0.08	0.05
	Period (P)		-	-	-	-	0.05	-	-	-	0.06	-	-	-	0.05	0.03
	Spray (S)		-	-	-	-	-	-	-	-	-	-	-	-	-	0.03
	T×P		-	-	-	-	0.15	-	-	-	0.16	-	-	-	0.15	0.08
	T×P×S		-	-	-	-	-	-	-	-	-	-	-	-		0.15
	C.D. at 5%		N.S	0.45	0.44	0.44	0.23	0.48	0.48	0.47	0.25	0.47	0.46	0.44	0.23	0.14
	C.V.%		7.89	6.30	6.38	6.32	6.33	7.16	7.34	7.23	7.31	7.41	7.56	7.16	7.38	7.00

DAS: Days after spray, Figures in parentheses are retransformed values of $\sqrt{X+0.5}$ transformation. Treatment means with the letter(s) in common are not significantly different by DNMRT at 5% level of significance

Table 2: Effect of eco-friendly pesticides on fruit yield, increase in yield over control and avoidable loss in custard apple

Tr. No.	Treatments	Conc. (%)	Fruit yield (q/ha)	Increase in yield over control (%)	Avoidable losses (%)
T_1	Azadirachtin 10000 ppm	0.003	69.25[a]	70.45	-
T_2	*Beauveria bassiana* 1.15 WP (1 x 10^8 cfu/g)	0.0046	59.09[b]	45.45	14.67
T_3	*Lecanicillium lecanii* 1.15 WP (1 x 10^8 cfu/g)	0.0046	67.40[a]	65.91	2.67
T_4	*Metarhizium anisopliae* 1.15 WP (1 x 10^8 cfu/g)	0.0046	57.25[b]	40.91	17.33
T_5	Neem seed kernel extract	5	68.33[a]	68.18	1.33
T_6	Calotropis leaf extract	10	48.01[c]	18.18	30.67
T_7	Nafatiya + Dhatura leaf extract	10	48.94[c]	20.45	29.33
T_8	Untreated control	-	40.63[d]	-	41.33
	S. Em.±	-	2.35	-	-
	C. D. at 5%	-	7.06	-	-
	C. V. (%)	-	7.11	-	-
Treatment means with the letter(s) in common are not significantly different by DNMRT at a 5% level of significance					

Avoidable loss

The avoidable loss in custard apple trees sprayed with various treatments was ranged from 1.33 to 41.33 percent (Table 2). It was minimum in the trees treated with NSKE 5% (1.33%) followed by *L. lecanii* 1.15 WP 0.0046 percent (2.67%), *B. bassiana* 1.15 WP 0.0046 percent (14.67%), *M. anisopliae* 1.15 WP 0.0046 percent (17.33%) and nafatiya + dhatura leaf extract 10 percent (29.33%). Moreover, the highest avoidable loss in custard apple yield was recorded in the untreated control (41.33%) followed by calotropis leaf extract (29.33%).

Conclusion

From the results, it can be concluded that among the evaluated eco-friendly pesticides, azadirachtin 10000 ppm proved to be the most effective, recording the lowest population of (7.86) mealybugs per fruit and the highest fruit yield (69.25 q/ha). It was followed closely by NSKE 5% (8.29; 68.33) and *L. lecanii* 1.15 WP (8.85; 67.40) in terms of number of mealybugs per fruit and yield (q/ha), respectively. Maximum increase in yield over control was registered in azadirachtin 10000 ppm 0.003 percent (70.45%) followed by NSKE 5% (68.18%) and *L. lecanii* 1.15 WP 0.0046 percent (65.91%), whereas minimum avoidable loss was computed in NSKE 5% (1.33%) followed by *L. lecanii* 1.15 WP 0.0046 percent (2.67%).

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