Species composition of frugivorous insects of citrus and attractant–repellent-based management of primary fruit piercer, *Eudocima materna*

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Studies were conducted to understand the preference of fruits by fruit-piercing moth (*Eudocima* sp.) and the efficacy of repellents/deterrents for the management of insect-pest-related fruit drop in citrus. The activity of *Eudocima* sp. was observed between August and December, with the most damage occurring in September (13.35%) and October (21.5%) during the color-breaking stage of Nagpur mandarin. Foliar application of petroleum spray oil at a rate of 2% or neem oil at a rate of 1% every two weeks during the color-breaking stage until harvest significantly reduced fruit drop (48.0%–70.0%) caused by the fruit-piercing moths. Simultaneously, hanging two polypropylene sachets with phorate or acephate, 10 g per tree, during the ambia (spring) season also significantly reduced fruit drop (<7%) due to the moths.

Keywords: Citrus, *Eudocima materna*, frugivorous insects, fruit drop, species composition.

CITRUS reticulata Blanco (mandarin) is one of India's most important economically grown fruit crops. It occupies 40% of the total area under citrus cultivation in the country[1]. A perusal of the literature reveals that citrus fruits are known to be infested by a wide array of insect pests[2]. Several management strategies have been developed for tackling sucking and defoliator pests, but comparatively less work has been done on the fruit-infesting pests of citrus in India. Among them, fruit-piercing moths and fruitflies are important because of their severity and quarantine concerns respectively. Fruit-piercing moths, *Eudocima* spp. (family: Erebidae) are considered notorious polyphagous insect pests that attack the crops during their maturity stage, causing serious economic loss to citrus growers[3,4]. Immature stages of this moth are not found feeding on any fruit crops but on the leaves of creepers belonging to the family Menispermaceae[5]. Adult moths cause serious damage to tropical and subtropical fruits during the night. The nocturnal nature, piercing and sucking feeding pattern, and strong migratory ability of the adult moth make it difficult for entomologists to manage this pest.

Fruits attacked by these insects become dry and spongy, and lose their commercial value. The punctures caused by adult moths also become a permanent site for secondary disease infection, causing further injury to the damaged fruits[6]. Damaged fruits are unmarketable and, if packed, pose a serious threat to healthy fruits through pathogenic contamination. The use of insecticides to control this pest has not been an option because the insect begins infesting the fruits at the ripening stage, during which insecticides cannot be sprayed due to pesticide residues. Other management strategies include hand collection of moths, smoking the orchards in the evening for 2 h, bagging the fruits, netting the trees/orchards, light traps and destruction of the larval host plants; however, all these have not been effective[7,4]. Studies to assess the effectiveness of baits containing synthetic feeding attractants for moth control in citrus showed that sugared-agar baits containing esters, aldehydes and alcohol were more attractive to the primary moth species[8]. Basic taxonomic studies are considered one of the most important steps in pest management. Hence, studies regarding the species composition of frugivorous pests of mandarin also deserve attention. Knowledge concerning the most susceptible stage to fruit-piercing moth attack is important for several reasons. Therefore, the present study was undertaken to (i) document the species composition of frugivorous pests of *Citrus reticulata* Blanco, (ii) assess the feeding preference of *Eudocima materna* moths under caged conditions, and (iii) evaluate selected plant oils, soaps and extracts against *E. materna* in mature Nagpur mandarin orchards during the ambia (spring) season.

Materials and methods

Species composition

For documentation of fruit-piercing moth species, roving surveys were carried out in four selected orchards, each of

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a minimum 1 acre area (diagonal transect), of Nagpur mandarin during fruit set to harvest in Nagpur (21.2924°N, 78.8149°E) and Amravati districts (20.3276°N, 78.5860°E), Maharashtra, India. Eggs and larvae of fruit-piercing moths were collected from farmers' fields on *Tinospora* leaves along the boundaries of the orchards. These leaves were brought to the laboratory and reared in petri dishes (9 cm) or plastic trays (35 cm × 27 cm × 6 cm) covered with a muslin cloth under laboratory conditions. Simultaneously, adult moths were collected using hand nets in the evening hours (after 7 pm) from the research farm (21.145°N, 79.025°E) of ICAR-Central Citrus Research Institute (CCRI), Nagpur, from September to December, and transferred to plastic containers (2 l capacity). The newly emerged adult moths of *E. materna* from the reared larvae were released in a nylon mesh cage (2 m × 2 m × 3 m) to record their feeding patterns. For taxonomic identification, a few adults were killed with ethyl acetate vapour and processed according to standard techniques in lepidopterology. The collected samples were identified using the pertinent literature[9–11].

Assessment of fruit drop in Nagpur and Amaravti districts during the ambia fruiting season

The fruits damaged by *E. materna* were assessed out at two-week intervals from August to December in Nagpur and Amravati districts, Maharashtra. The percentage of fruit drop was estimated from the number of fallen fruits with pierced holes out of the total number of fruits per tree. TSS content of green fruits (seven months from flowering), colour-breaking fruits (8-month-old) and fully ripe fruits (9-month-old) were also sampled to ascertain any effect of total solids (a random collection of ten fruits per replication/stage).

Cage and field studies for the assessment of feeding preference in E. materna

Under choice tests, the feeding preference of primary piercer, *E. materna* was observed in artificial cages provided with fresh fruits, viz. ripe banana (cv. Robusta) and tomato (cv. Local red) against synthetic ester–aldehyde–alcohol agar-based (2%) combinations consisting of ethyl butyrate (99%), formaldehyde (37%) and ethanol (99.9%) in the ratio 5 : 2 : 1; (ester : alcohol) 1 : 3 and (aldehyde : alcohol) 7 : 3 under caged conditions (2 m × 2 m × 3 m). The synthetic compounds were procured from Sigma-Aldrich Chemicals Private Limited, Bengaluru, India. Five 2–3-day-old female moths were released into each cage and replicated four times. Fruits were replenished regularly when they started rotting. Banana fruit was considered as a standard check. The same treatments were replicated in a 12-year-old Nagpur mandarin orchard with two baits per tree and replicated four times during the colour-break stage. The number of feeding holes per bait was recorded at 24 and 48 h intervals. The preference index was calculated (free choice) using the following formula[5]:

$$\text{Preference index} = \frac{\text{Mean no. of feeding holes in the test fruit/moth/24 h}}{\text{Mean no. feeding holes in banana fruit/moth/24 h}} \times 100.$$

Field studies

Evaluation of botanicals against fruit-piercing moths was carried out in the ambia season in a 10-year-old Nagpur mandarin orchard at the ICAR-CCRI research farm during 2018–2020. Table 1 provides the treatment details.

Sapindus trifoliatus (soapnut) seeds were soaked overnight at 200 g seeds in 1 l of water and extracted with a cheesecloth to remove the sediments. From this fresh stock, 20 ml was measured and diluted in 1 l of water for spraying. Similarly, 20 g powdered sweet flag rhizome (*Acorus calamus*, Acoraceae) was diluted in 1 l of water for spraying. The trees were spaced at 6 × 6 m^2 in a square pattern, maintained by following standard horticultural operations during the experimental period. Two sprays were given at 15-day intervals coinciding with the colour-breaking stage of Nagpur mandarin (trees with approximately 90% of the fruits in the colour-breaking stage were selected), which starts by the second fortnight of September or the first fortnight of October. All treatments were done with a tractor-mounted sprayer of 250 l tank capacity with 10 l of spray volume/tree.

Further, trials were conducted to evaluate common repellents with potent odour, viz. camphor and naphthalene (balls); bone and fish-meal powder (locally purchased from a fertilizer shop) and two insecticides (commercial formulation of phorate 10G (thimet 10G, Insecticides India Ltd, Delhi; acephate 75SP (ASATAF 75SP, TATA Rallis India Ltd, Mumbai)) for two ambia fruiting seasons against fruit-piercing moths at the ICAR-CCRI research farm. Sachets were made from muslin cloth (10 cm × 5 cm) with and without a carrier. The carrier compound used in the study was soapstone powder at 10 g/sachet. The sachets were tied with twine threads on two sides of each plant at two sachets (10 g repellent powder/sachet)/plant. The sachets were replaced at 15 days intervals. Observations of per cent fallen fruits due to fruit-piercing moths were recorded weekly.

Statistical analysis

Preference index values for two consecutive seasons were averaged (five female moths of *E. materna*/cage and replicated four times for two seasons) and expressed as a percentage. Evaluation of different plant oils, soaps and extracts was carried out in randomized block design with four replications (two trees/replication), while the repellents trial was

Table 1. Details of botanical treatments evaluated against fruit-piercing moth, *Eudocima materna* in 10-yr-old Nagpur mandarin orchard

Category	Product	Place of procurement
Plant oil	Neem oil (10 v/v)	Local market
	Castor oil (10 v/v)	
	Mustard oil (10 v/v)	
	Citronella oil (10 v/v)	
Horticulture mineral oil	MAK HMO Agri spray oil	Bharat Petroleum Corporation Limited
Herbal oil soap	Neem soap (1%)	ICAR-Indian Institute of Horticultural Research, Bengaluru
	Pongamia soap (1%)	
Botanical extracts	Soapnut 2%	Local market
	Sweet flag 2%	

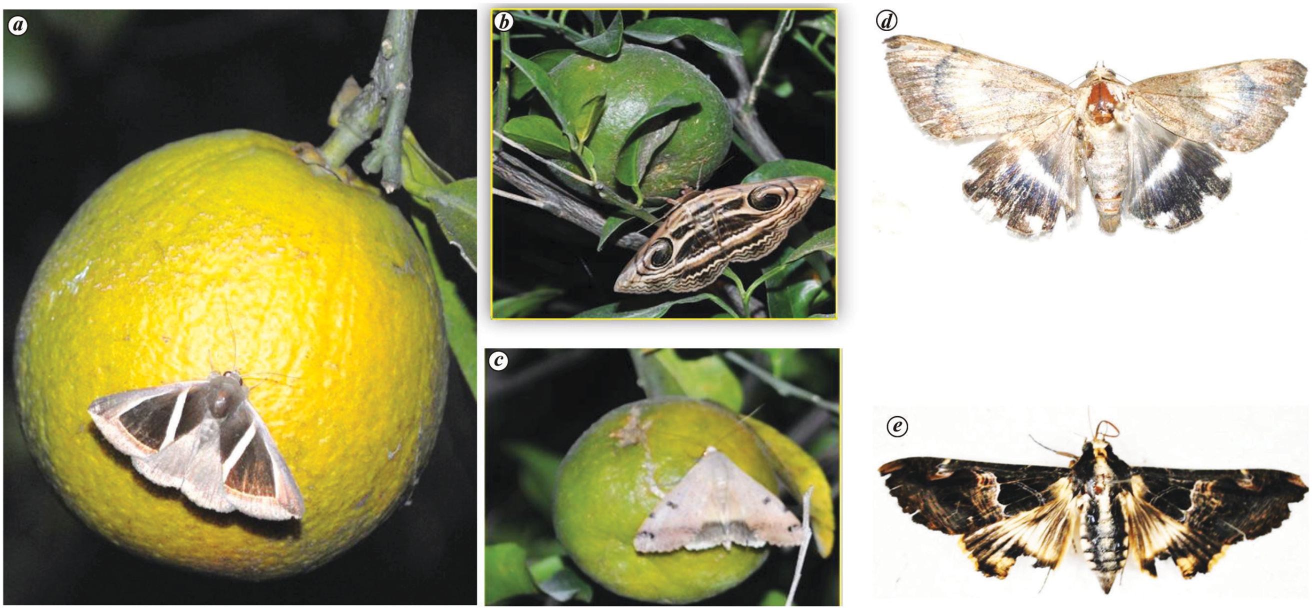

Figure 1. ***a***, *Chalciope mygdon* (Cramer). ***b***, *Spirama retorta* Clerck. ***c***, *Ophiusa* sp. ***d***, *Achaea janata* (Linnaeus). ***e***, *Sphingomorpha* sp.

replicated seven times with two plants/replication. The respective data were pooled and subjected to arcsine transformation to normalize them. Data analysis (ANOVA) was performed using WASP 1.0 software. Mean separation was carried out according to the least significant difference (LSD) at 0.05 probability level.

Results

Species composition of primary and secondary fruit piercers

During the roving surveys and evening scouting, two species of primary fruit piercers, namely *E. materna* (Linnaeus, 1767) and *Eudocima phalonia* (Linnaeus, 1763), were documented. *Tinospora cordifolia* (Menispermaceae) and *Cocculus villosus* were the major larval hosts for both species. *E. materna* was the predominant species recorded from roving surveys, as well as hand collection done during the evening hours, followed by *E. phalonia.* Out of the 56 fruit-piercing moth larvae collected from *Tinospora* leaves, 49 adults that emerged were identified as *E. maternal*, while only seven were *E. phalonia*. During night scouts, 28 adult *E. materna* and four *E. phalonia* moths were found feeding on Nagpur mandarin fruits. Larvae of both species exhibited colour variation.

Apart from the primary fruit-piercing moths recorded, seven different secondary fruit-piercing moths were also observed. One each of *Parallellia stuposa* Fabricius (family Erebidae), *Chalciope mygdon* (Cramer) (family Noctuidae), *Ericeia inangulata* (Guenèe) (family Erebidae), *Thyas* sp. (family Erebidae), *Sphingomorpha chlorea* (family Erebidae), three *Achaea janata* (Linnaeus) (family Erebidae) and two *Spirama retorta* Clerck (family Erebidae) were found feeding on Nagpur Mandarin fruits which were already damaged by primary fruit piercers (Figure 1 *a–e*). Some of these moths were found feeding on the damaged fallen fruits, and the rest on intact fruits which had already been attacked by *E. materna*.

Feeding pattern and incidence levels of adult moths

During the preference index studies, it was observed that the presence of *E. materna* adult moths was maximum for ripe banana (100%) followed by ester + alcohol combination after 24 (P-value <0.05, df = 10, t-value = 2.228) and 48 h of release (Table 2). The 'pin holes' made by these adult moths while feeding were visualized and recorded. The same treatments were replicated in the field during ambia fruiting season but significantly failed to attract the primary fruit piercer.

Per cent fallen fruits due to *E. materna* was as low as 3.5% in August from Nagpur district and the trees were loaded with green coloured near maturing fruits at the time of sampling (Figure 2). The scenario changed from September to November with a maximum fruit drop of 20.8% in October and 11.9% in November in Nagpur district, as the colour-breaking stage was initiated with fruit colour changing from green to light orange–yellow. A similar trend was observed in citrus orchards of the Amravati district, with a per cent fruit drop ranging between 4.3–22.2 from August to December (Figure 2). Fruit damage was considerably more in orchards with fallen fruits than clean ones. Ripe fruits attached to the tree were preferred by the adult fruit-piercing moths than fallen ones, and the number of pierced holes ranged from 1 to 13 per fruit in our sampling.

Evaluation of botanicals and repellents

Among the botanicals evaluated, a significant reduction in fallen fruits was observed in petroleum spray oil/horticulture mineral oil (HMO)-treated plots with consistent results over three seasons of the experimental period. Pooled mean over treatment results showed that per cent of fallen fruits ranged from 10.96 to 11.95 on trees sprayed with HMO at 1% during the ambia season. The treatment with neem oil at 1% (15.44–17.19%), pongamia soap at 2% (11.83–13.32%) and sweet flag @ 2% (12.12–17.77%) was also at par with the HMO treatment. Results of the overall pooled mean over seasons also substantiated the fact that trees sprayed with HMO 2% over a period of 40 days in a season had significantly fewer fallen fruits due to fruit-piercing moth attacks (11.29%). Per cent fruit drops were 16.23, 16.03 and 12.35 in plots sprayed with neem oil @ 1%, sweet flag at 2% and pongamia soap at 2% respectively (Table 3). On the evaluation of repellent chemicals against fruit-piercing moths, insecticides, viz. phorate and acephate alone and along with carrier, were found to significantly deter the moths, thereby reducing fallen fruits in the treated orchard. Per cent fallen fruits in plots treated with acephate alone, acephate + sand, acephate + carrier was 6.45, 7.15 and 9.01 respectively. These treatments were at par with phorate alone, phorate + sand and phorate + carrier (Table 4).

Table 2. Preference index of attractant baits tested against *E. materna* 24 h after feeding

Treatment	PI 24 HAT	PI 48 HAT
EB + FA + E	56.400 ± 1.466^{b}	66.687 ± 12.355^{c}
EB + E	94.890 ± 1.512^{a}	74.453 ± 13.158^{bc}
FA + E	60.667 ± 18.332^{b}	67.397 ± 10.677^{c}
Banana	100.000 ± 0.000^{a}	100.000 ± 0.000^{a}
Tomato	86.223 ± 1.826^{a}	89.823 ± 5.885^{ab}

Means within each column with the same lowercase letter are not significant at 5% level of probability (LSD test).
EB, Ethyl butyrate, FA, Formaldehyde and E, Ethanol.

Discussion

Four species of *Eudocima*, viz. *Eudocima phalonia* (Clerck), *Eudocima materna* (L.), *Eudocima homaena* (Hubner) and *Eudocima cajeta* (Cramer) have been reported in India as prominent fruit-piercers, and they are considered as very serious pests on citrus as well as other fruits[12,13]. *E. phalonia* and *E. materna* were the dominant species from Gwalior (Madhya Pradesh), Nagpur (Maharashtra) and Punjab respectively[14–16]. Our findings on predominant fruit piercing moth were in line with the observation that *E. materna* was the dominant species representing 95% of trap catch and only 5% was *E. phalonia* reported from Cuddapah, Andhra Pradesh[17]. *E. materna* outnumbered all other species of the genus[18]. Among the secondary piercers, *S. retorta* and *A. janata* were frequent in the night collection. *A. janata*, *E. materna*, *E. homaena*, *Parallelia algira* L., *E. cajeta*, *Ophius acoronata* (F.) and *Thyas honesta* Hübner were reported as fruit piercers from Rajampet, Andhra Pradesh[19].

The crop damage caused by fruit-piercing moths in citrus orchards varied from 10% to 15% in Fiji[20], 10% to 55% in India[21], 17% to 39% in Malaysia[3] and up to 95% in New Caledonia[22]. *Eudocima* outbreaks and piercing activity also coincide with the rainy season in many parts of India[13]. The peak incidence was recorded in Nagpur and Amravati districts of Maharashtra during September and October, with the population declining thereafter. We observed that soluble solids content (°Brix), rainfall and external ripening or change in fruit colour affected fruit-piercing moth

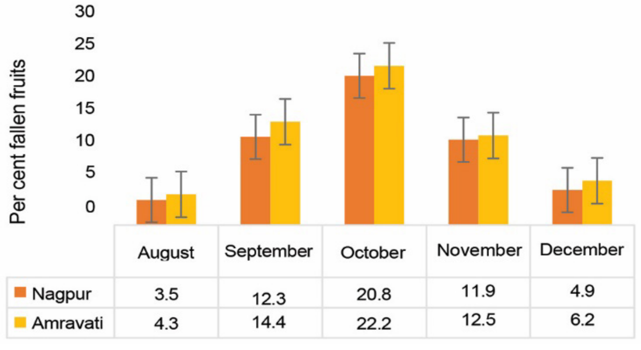

Figure 2. Peak incidence levels of fruit-piercing moth during spring season.

Table 3. Evaluation of efficacy of different plant oils, soaps and extracts against *E. materna* in Nagpur mandarin orchard

Treatment	Fallen fruits due to moths (%)						
	Spring 2018		Spring 2019		Spring 2020		
	Pre-treatment	Pooled mean over treatment	Pre-treatment	Pooled mean over treatment	Pre-treatment	Pooled mean over treatment	Pooled mean over season
T_1-Neem oil @ 1%	27.62 (30.46)	16.06 (23.58)^{bc}	43.50 (41.26)	17.19 (24.29)^{b}	40.43 (39.42)	15.44 (23.13)^{bc}	16.23 (23.75)^{ab}
T_2-Castor oil @ 1%	30.35 (33.30)	19.32 (26.07)^{d}	32.22 (34.57)	31.77 (34.16)^{d}	38.60 (38.16)	29.31 (32.69)^{ef}	26.80 (31.05)^{ed}
T_3-Mustard oil @ 1%	28.15 (31.94)	17.28 (24.54)^{c}	43.05 (40.94)	34.64 (36.00)^{def}	41.13 (39.87)	33.19 (35.04)^{fg}	28.37 (31.93)^{ed}
T_4-HMO @ 1%*	31.51 (33.07)	10.96 (19.32)^{a}	40.40 (39.17)	11.95 (20.07)^{a}	39.38 (38.86)	10.98 (19.33)^{a}	11.29 (19.64)^{a}
T_5-Soapnut @ 2%	49.54 (44.74)	26.59 (31.04)^{f}	34.61 (35.89)	23.44 (28.88)^{c}	33.29 (35.22)	22.48 (28.21)^{d}	24.17 (29.43)^{cd}
T_6-Sweet flag @ 2%	20.70 (27.01)	12.12 (20.36)^{a}	43.00 (40.90)	17.77 (24.76)^{b}	42.20 (40.51)	18.21 (25.88)^{c}	16.03 (23.45)^{ab}
T_7-Neem oil @ 1% + soapnut @ 2%	26.62 (30.94)	11.94 (20.22)^{a}	41.48 (40.00)	21.81 (27.70)^{c}	38.69 (38.46)	20.01 (26.53)^{d}	17.92 (24.87)^{bc}
T_8-Castor oil @ 1% + soapnut @ 2%	32.06 (33.61)	24.36 (29.57)^{e}	42.05 (40.41)	31.19 (33.88)^{d}	39.31 (38.82)	28.14 (31.98)^{e}	27.89 (31.85)^{ed}
T_9-Citronella oil @ 1%	40.44 (39.45)	38.76 (39.50)^{g}	35.47 (36.48)	35.68 (36.65)^{ef}	37.44 (37.72)	33.96 (35.63)^{g}	36.13 (36.94)^{f}
T_{10}-Pongamia soap @ 2%	36.30 (36.76)	11.83 (22.97)^{a}	45.69 (42.48)	13.32 (21.22)^{a}	41.30 (39.95)	11.90 (20.18)^{ab}	12.35 (20.56)^{ab}
T_{11}-Neem soap @ 2%	34.81 (36.11)	15.23 (22.97)^{b}	36.95 (37.42)	32.96 (34.90)^{de}	34.81 (36.15)	31.77 (34.30)^{efg}	26.65 (30.77)^{ed}
T_{12}-Citronella @ 1% + castor @ 1% oil + soapnut @ 2%	42.00 (40.38)	24.44 (29.62)^{e}	34.16 (35.66)	37.30 (37.61)^{f}	36.50 (37.16)	34.97 (36.22)^{g}	33.23 (35.16)^{ef}
T_{13}-Control	49.32 (44.66)	41.44 (43.81)^{h}	48.58 (44.18)	51.04 (47.32)^{g}	45.30 (42.30)	50.01 (45.01)^{h}	47.49 (43.55)^{g}
CD ($P = 0.05$)	NS	1.39	NS	2.41	NS	2.80	4.48

*HMO, Horticultural mineral oil. Data were arcsine transformed to meet normality assumptions. Means within each column with the same lowercase letter are not significant at 5% level of probability (LSD test).

Table 4. Evaluation of repellants against *E. materna* in Nagpur mandarin orchard

Treatment	Fallen fruits due to fruit piercing moths (%)													
	Spring 2017							Spring 2018						
	Pre-treatment	7 DAT	14 DAT	21 DAT	28 DAT	35 DAT	Pooled mean	Pre-treatment	7 DAT	14 DAT	21 DAT	28 DAT	35 DAT	Pooled mean	Overall pooled mean
T_1-Phorate + C*	35.0	9.66	6.33	5.33	6.83	12.33	8.09	34.42	7.66	4.60	3.94	4.21	9.21	5.92	11.60
	(36.15)	(18.07)^{a}	(14.56)^{a}	(13.34)^{a}	(15.15)^{a}	(20.55)^{a}	(16.31)^{a}	(35.83)	(16.03)^{a}	(12.24)^{ab}	(11.37)^{a}	(11.77)^{a}	(17.66)^{a}	(14.05)^{a}	(19.24)^{a}
T_2-Acephate + C*	38.88	10.00	6.00	5.66	6.16	11.33	7.81	36.18	8.45	4.46	3.91	4.19	9.44	6.08	9.01
	(38.52)	(18.43)^{a}	(14.17)^{a}	(13.76)^{a}	(14.37)^{a}	(19.65)^{a}	(16.07)^{a}	(36.81)	(16.84)^{a}	(12.16)^{ab}	(11.28)^{a}	(11.75)^{a}	(17.86)^{a}	(14.23)^{a}	(17.25)^{a}
T_3-Camphor + C*	39.28	27.00	33.00	25.66	35.33	34.33	31.00	38.39	25.27	32.31	24.96	36.46	34.21	30.64	28.05
	(38.63)	(31.28)^{bc}	(35.05)^{b}	(30.43)^{c}	(36.45)^{b}	(35.83)^{b}	(33.80)^{b}	(38.24)	(30.17)^{b}	(34.61)^{c}	(29.96)^{b}	(37.12)^{bc}	(35.77)^{b}	(33.59)^{b}	(31.92)^{b}
T_4-Napthalene + C*	36.81	31.00	37.66	34.33	36.66	35.33	37.40	37.82	30.74	37.61	34.62	38.62	36.52	35.62	32.67
	(37.20)	(33.82)^{bc}	(37.85)^{bc}	(35.86)^{bc}	(37.22)^{b}	(36.43)^{b}	(36.23)^{b}	(37.89)	(33.60)^{c}	(37.82)^{de}	(36.02)^{d}	(38.41)^{c}	(37.17)^{cd}	(36.63)^{d}	(34.78)^{d}
T_5-Bone meal + C*	35.71	32.33	40.33	32.00	36.33	35.33	35.26	34.46	31.44	39.78	31.93	35.43	36.66	35.09	32.74
	(36.61)	(34.58)^{c}	(39.42)c	(34.44)^{c}	(37.05)^{b}	(36.43)^{b}	(36.38)^{b}	(35.83)	(34.09)^{c}	(39.09)^{c}	(34.39)^{c}	(36.52)^{b}	(37.25)^{d}	(36.31)^{d}	(34.87)^{cd}
T_6-Fish meal + C*	40.53	25.00	36.33	31.33	34.00	33.33	34.61	39.65	24.55	35.27	33.68	37.68	34.43	33.34	31.94
	(39.46)	(29.99)^{b}	(37.02)^{bc}	(34.03)^{bc}	(35.64)^{b}	(35.43)^{b}	(34.42)^{b}	(38.97)	(29.70)^{b}	(36.43)^{cd}	(36.04)^{d}	(37.84)^{bc}	(35.92)^{bc}	(35.25)^{c}	(34.39)^{c}
T_7-Phorate	36.66	11.00	7.66	5.66	6.43	11.33	8.41	37.39	8.34	5.81	4.06	4.22	9.47	6.17	7.29
	(36.93)	(19.33)^{a}	(16.02)^{a}	(13.76)^{a}	(14.68)^{a}	(19.65)^{a}	(16.68)^{a}	(37.61)	(16.77)^{a}	(13.86)^{b}	(11.45)^{a}	(11.80)^{a}	(17.91)^{a}	(14.35)^{a}	(15.63)^{a}
T_8-Phorate + sand	34.76	12.33	6.66	5.23	7.00	12.00	8.64	33.68	8.98	4.68	4.15	4.25	9.50	6.06	7.35
	(35.47)	(20.55)^{a}	(14.95)^{a}	(13.34)^{a}	(15.31)^{a}	(20.26)^{a}	(16.88)^{a}	(35.30)	(17.43)^{a}	(12.40)^{ab}	(11.69)^{a}	(11.85)^{a}	(17.94)^{a}	(14.19)^{a}	(15.69)^{a}
T_9-Acephate + sand	36.11	11.00	7.00	5.00	6.66	10.33	7.97	35.94	9.10	4.99	4.37	4.62	8.62	6.33	7.15
	(36.75)	(19.35)^{a}	(15.31)^{a}	(12.87)^{a}	(14.94)^{a}	(18.72)^{a}	(16.23)^{a}	(36.70)	(17.54)^{a}	(12.78)^{b}	(11.99)^{a}	(12.22)^{a}	(17.02)^{a}	(14.52)^{a}	(15.49)^{a}
T_{10}-Acephate	35.55	8.33	5.33	6.5	5.33	9.33	6.96	34.87	7.69	3.52	4.48	4.27	8.27	5.94	6.45
	(36.58)	(16.73)^{a}	(13.34)^{a}	(14.74)^{a}	(13.34)^{a}	(17.78)^{a}	(15.18)^{a}	(36.09)	(16.02)^{a}	(10.78)^{a}	(12.03)^{a}	(11.71)^{a}	(16.70)^{a}	(14.03)^{a}	(14.71)^{a}
T_{11}-Control	42.50	50.00	53.33	53.33	51.66	51.66	52.00	41.96	48.77	51.14	52.62	50.62	51.12	50.90	51.45
	(40.66)	(45.00)^{d}	(46.92)^{d}	(46.92)^{d}	(45.95)^{c}	(45.95)^{d}	(46.14)^{c}	(40.35)	(44.29)^{d}	(45.65)^{f}	(46.50)^{e}	(45.35)^{d}	(45.64)^{e}	(45.52)^{e}	(45.83)^{e}
CD at (P = 0.05)	NS	3.98	2.93	2.44	3.13	3.44	2.74	NS	1.65	1.33	1.09	1.36	1.30	0.57	5.36

DAT, Days after treatment. Data were arcsine transformed to meet normality assumptions.
*Means within each column with the same lowercase letter are not significant at 5% level of probability (LSD test).

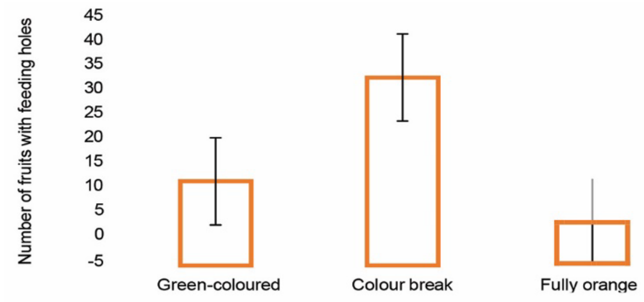

Figure 3. Preference of fruit colour for fruit piercing moth in Nagpur mandarin.

Figure 4. Colour-breaking and fully ripe stage of Nagpur mandarin fruit.

incidence in citrus orchards. In Nagpur and surrounding areas, it was observed that *Tinospora* flush emergence coincided with the July–August monsoon showers, with continuous availability of larval host till December; thereafter, the vine withered, and the fruit-piercing moth population also declined. TSS content of green fruits (seven months from flowering), colour-breaking fruits (8-month-old) and fully ripe fruits (9-month-old) during the ambia season was 7%–8%, 10%–11% and 11%–12% respectively (Figure 3). Among the green-coloured, colour-breaking (transient from green to orange) and fully orange-coloured fruits, the maximum preference was for colour-breaking fruits (based on the visual colour of 50 fruit samples/stage) (Figure 4). It has been reported that damage to green-coloured fruits was observed when the moth population was high during certain years, which substantiates our findings[23].

Olfaction is the ability of an organism to detect and discriminate odours in the environment. Insects rely mainly on olfaction to locate their food. Fruit-sucking moths are known to attack more than 40 different types of fruits[24]. In the present study, fruit-piercing moths preferred ripe bananas followed by agar-based ethyl butyrate + ethanol. Fruit esters are more in ripe fruits than green ones. Among them, ethyl butyrate has a strong fruity odour similar to pineapple and was selected as an attractant option based on preliminary screening in the laboratory. Studies have found that extracts of ripe or overripe fruits mixed with sodium arsenic in glass bait jars attract adult moths[18]. Among 14 fruit preferences of *E. fullonia*, it was found that the preference index was very high for bananas (100)[24]. Baits with aldehydes, esters and alcohol were more attractive to primary fruit-piercing moths, including *E. phalonia*, compared to baits containing esters only[24]. Fruit based attractant baits often fail under field conditions owing to the release of large quantity of fruit odours from the ripening fruits in the trees which will mask the odour from the man-made baits. Such baits may attract many non-target or secondary moth species also. Thus, in-depth studies need to be conducted to identify potential fruit odours that will enable the making of synthetic baits that can be deployed to attract pests in standing crops.

The present study shows that spraying HMO, neem oil, pongamia soap and sweet flag against fruit-piercing moths significantly reduces citrus fruit infestation. In a similar study, it was reported that plant oils such as jatropa, citronella, poppy, thevetia, neem and pongamia, along with neem seed kernel extract, were effective in preventing *E. materna* from feeding on the treated guava and pomegranate fruits[8]. A foliar spray with neem oil 10,000 ppm at 2 ml/l + citronella oil at 1.0 ml/l water is recommended to ward-off the moths for 3–4 days (https://nrcpomegranate.icar.gov.in/files/Advisory/122.pdf).

Conclusion

Fruit-piercing moths are a menace to fruit growers, as they are strong fliers and nocturnal in nature. Surveys have helped document the insect pests attacking mature or near-maturing citrus fruits, and the information generated can be used to check the pest status. The use of organic phosphate insecticides with strong odours like phorate 10G and acephate 75SP in sachets significantly reduced fruit drop due to fruit-piercing moths. Foliar application of petroleum spray oil at 2% or neem oil at 1% at two-week intervals coinciding with the colour-breaking stage till harvest significantly reduced the fruit drop (48.0–70.0%) due to *E. materna*. Simultaneously, hanging two polypropylene sachets with phorate or acephate (10 g per tree) during the ambia season also significantly reduced fruit drop (<7%).

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