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Research Article

Management of the red flour beetle, *Tribolium castaneum* (Herbst), through attractant-based strategies in rice moth, *Corcyra cephalonica* (Stainton), mass rearing

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ABSTRACT: The red flour beetle, *Tribolium castaneum,* infestation is a major problem in rice moth, *Corcyra cephalonica,* mass rearing. Reduction in the emergence of rice moths due to this predator's activity seeks attention for management options in order to enhance the mass production of this factitious host. The study demonstrated that increasing densities of *T. castaneum* adults negatively impacted *C. cephalonica*, with notable reductions in adult emergence and prolonged developmental periods. The maximum number of adult emergences of *C. cephalonica* was recorded in treatments without *Tribolium* (15.33), while minimum emergence (4.33) and extended developmental periods up to 55.46 days were observed at higher predator densities. In attractant evaluations, mahua oil (21.11%) emerged as the most effective food oil, closely matching the commercial kairomone (26.66%), followed by coconut oil (11.75%). Among various flours, wheat flour showed the highest attraction index (25.12%), confirmed by olfactometer assays, where 31.39% of *T. castaneum* adults oriented toward wheat. GC-MS analysis of food baits revealed that hydrocarbons and fatty acids were predominant attractant compounds, with wheat and mahua oil exhibiting the richest volatile profiles. Key attractant compounds included hexadecanoic acid, octadecanoic acid, and 1,2-benzenedicarboxylic acid. These findings underline the dual ecological role of *T. castaneum* and highlight promising attractants for its monitoring and management in stored grain environments.

KEYWORDS: Attraction index, *Corcyra cephalonica*, olfactometer, *Tribolium castaneum*, volatile compounds

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INTRODUCTION

In India, losses in crops due to insect pests have been decreasing over the years from 23.3 to 15.7 per cent owing to the advancements in biocontrol strategies (Dhaliwal *et al.*, 2015). Biological control is seen as an important element of many integrated pest management programmes, and it helps in the control of 90 per cent of the potential pests that cause crop losses (Shukla, 2014). Mass production of biocontrol agents in an inexpensive, well-organised manner and timely releases of biological agents by inundation and inoculation determine the success of biological control. Mass production of predators and parasitoids demands an

intricate arrangement while culturing the host insects in laboratories. In the event of the absence of the original host or the tedious, overpriced process involved in mass production of the required biocontrol agent, an appropriate alternative host needs to be utilised (Manjunath, 2014). The rice moth *Corcyra cephalonica* (Stainton) (Pyralidae: Lepidoptera), although a notorious pest in stored products, has immense significance in biocontrol. In India, it is mass-produced for the purpose of producing parasitoids like *Bracon hebator* Say, *Bracon krikpatricki* Wilkinson, *Bracon brevicornis* Wesmael, *Chelonus blackburni* Cameron, *Goniozus nephantidis* Muesebeck, *Trichogramma tids* Westwood and predators like Anthocorid bugs and Chrysopid larvae (Lalitha & Ballal, 2015). It is the most efficient surrogate host employed for rearing several biocontrol agents in many countries of the world due to its amenability, adaptability and beneficial impact (Gauraha & Deole, 2016). *C. cephalonica* eggs, larvae and pupae can act as a perfect host for mass production of a wide range of biocontrol agents such as natural enemies, mites and nematodes. About 75 natural enemies, consisting of 15 predators and 60 parasitoids from 5 insect orders such as Heteroptera, Coleoptera, Neuroptera, Diptera and Hymenoptera, were mass-produced using *C. cephalonica* (Vincent *et al*., 2021). Various commercial facilities use *C. cephalonica* for mass-producing the egg parasitoids *Trichogramma* spp. (Sithanantham *et al.*, 2013) which are commonly used for managing pests like cotton bollworms, sugarcane borers, *etc.*, in India and other countries of the world. The quality of biocontrol agents depends on the nutritional quality of their host (Mehendale *et al.*, 2014) and is also influenced by the biotic and abiotic factors present in the rearing environment. Among the biotic factors, contamination of *C. cephalonica* cultures by the red flour beetle, *Tribolium castaneum* Herbst, has been seen as a serious menace in the rearing laboratories. *C. cephalonica* is mass-reared in broken grains of pearl millet, sorghum and wheat. Since *Corcyra* is a polyphagous pest, mixed diets are also preferred, and a groundnut + corn mix can be preferred for the production of robust eggs economically and biologically (Bhandari *et al.*, 2014). The larval period is between 23 to 25 days, and the pupal period is 10 days. The moths are nocturnal in nature with one week of life span and the fecundity ranged from 90 to 200 eggs with 5 days of incubation period (Vignesh *et al.*, 2022). The red flour beetle, *T. castaneum*, a stored product pest which is found to be present in all regions of the world, feeds on a large number of food products such as milled grain products, nuts, broken grains, dried flowers, cereals, dried pet foods, spices, beans and chocolate (Oppert *et al.*, 2010; Fedina and Lewis, 2007). It also extensively infests food processing facilities, retail stores, mills and warehouses (Campbell *et al.*, 2010). It feeds on and contaminates the products with excreta, body odour, cast skin and frass (Khaliq *et al.*, 2014), thereby causing quantitative and qualitative loss (Astuti *et al.*, 2020). Control of this insect pest during *Corcyra cephalonica* rearing is constrained by the limited availability of suitable management techniques, particularly because chemical control options are undesirable in insectary conditions. Therefore, novel approaches that can modify the behavioural or locomotory responses of *T. castaneum* should be explored. In addition to its role as a stored-grain pest, *T. castaneum* can act as an important predator and competitor in *C. cephalonica* mass-rearing systems, where its adults and larvae may feed on *Corcyra* eggs and other vulnerable developmental stages, thereby reducing host availability and adult emergence and adversely affecting the efficiency of mass production. Increasing *Tribolium* infestation can therefore result in substantial losses in *Corcyra* culture and prolong the developmental period of the host, making its early detection and effective management essential for maintaining consistent production of quality biocontrol agents. Generally, adults of *T. castaneum* tend to take refuge in cracks and crevices found in grain stores, rearing facilities and warehouses, and this harbourage-seeking behaviour makes them difficult to detect visually. However, traps containing food attractants with attractive volatile compounds acting as kairomones can provide a promising behavioural management strategy by drawing *Tribolium* adults away from the rearing substrate. Similarly, baits containing attractive food oils in corrugated-paper traps and dome traps have been employed not only to attract the insects but also to kill them through suffocation (Dissanayaka *et al.*, 2018a). Thus, attractant-based trapping may offer a practical, non-chemical approach for reducing *T. castaneum* populations and minimising its detrimental effects on *C. cephalonica* mass rearing. Monitoring traps designed for the control of coleopteran pests are being exploited in large-scale industries to determine the beetle's interaction in response to kairomone and pheromone lures (Collins & Chambers, 2003; Campbell, 2012; Hodges *et al.,* 2004). Pest control measures using kairomones and colour cues can increase the effectiveness of natural enemies and reduce losses economically and biologically. In addition to olfaction, colour cues play a crucial role in the process of locating the host in numerous insect species (Briscoe & Chittka, 2001). When multimodal cues such as odour and colour are combined, greater attraction is ensured (Arnold *et al.*, 2015). The red flour beetle, *T. castaneum*, a predator on the egg, larval and adult stages of *C. cephalonica,* significantly affected the biological characters of the rice moth in the experiments conducted in the present study.

MATERIALS AND METHODS

Mass culturing of *Tribolium castaneum*

Adults of the red flour beetle, *T. castaneum*, were collected from infested *Corcyra* rearing trays in the *Corcyra* breeding laboratory at the Insectary, Agricultural College and Research Institute, Madurai. Mass culture was carried out in 250 g-capacity plastic containers containing 150 g of culture medium, consisting of wheat flour supplemented with 5% brewer's yeast. The adults were released into the plastic containers and covered with a muslin cloth to prevent entry of other insects and escape of beetles. The containers were maintained at suitable temperature and relative humidity (33 ± 2°C and 60 ± 5%) (Gurdasani, 2017). Adults emerged from the mother culture were collected and used to perform various laboratory experiments. Subculturing was carried out to ensure an uninterrupted supply of insects for further experiments every 25 days.

Effect of competition by *T. castaneum* on *C. cephalonica* rearing

Competition between *T. castaneum* and *C. cephalonica* was studied by experimentation. The experiment was done in plastic jars of 50 g capacity with 20 g of *Corcyra* rearing diet. *Corcyra* diet and rearing procedure was adopted from Gandhi *et al.* (2005). Broken pearl millet (2.5 kg) grains and 10 g of yeast were mixed to provide them as a food source. To prevent storage mites and disease incidence, 5 g of 80% wettable sulphur and 0.5% streptomycin sulphate were added. The jars were covered with khada cloth and kept at room temperature (33 ± 1ºC) with 60 ± 10% RH until the cessation of *Corcyra* adult emergence. The experiments were replicated thrice.

Twenty eggs of *Corcyra* with increasing densities of *T. castaneum* adults were released into the jars. One-week-old *T. castaneum* adults were used for the experiment. Jars with 20 eggs of *Corcyra* alone served as the control (Larsen *et al.*, 2005). Treatment details of competition between *C. cephalonica* and *T. castaneum* at different densities of *Tribolium* adults.

T_1 -20 eggs of *C. cephalonica* alone
T_2 - 20 eggs of *C. cephalonica* + 10 *T. castaneum* adults
T_3 - 20 eggs of *C. cephalonica* + 20 *T. castaneum* adults
T_4 - 20 eggs of *C. cephalonica* + 30 *T. castaneum* adults
T_5 - 20 eggs of *C. cephalonica* + 40 *T. castaneum* adults
T_6 - 20 eggs of *C. cephalonica* + 50 *T. castaneum* adults
T_7 - 20 eggs of *C. cephalonica* + 60 *T. castaneum* adults

Effect of food oils as kairomones

Food oils, *viz.*, coconut oil, sesame oil, groundnut oil, soybean oil, rice bran oil, palm oil, sunflower oil and mahua oil were tested for their kairomonal activity at quantities of 10 ml and 20 ml each. The experiment was conducted using dome traps. A multiple-choice test was conducted by circularly placing the dome traps in the experimental arena. Using the OHP sheet and clay, a setup was provided around the arena to avoid the escape of beetles. Food oils were placed inside the dome traps using a disposable syringe. Commercial kairomone (Storgard® Oil), purchased from Giridhar Pai Associates, LLP, was used as the standard attractant. Adults of *T. castaneum* (400 Nos.) were released



Figure 1. Multi-choice dome trap setup for food oil attractant evaluation in *T. castaneum*.

at the centre (Dissanayaka *et al.*, 2018a). The experiment was laid out in a Completely Randomised Design (CRD) with 3 replications (Figure 1). The number of beetles attracted to a particular food source was counted after 3 h, and the attraction index was calculated using the formula given by Smith *et al.* (1993).

$$\text{Attraction index} = \frac{T - C}{N} \times 100$$

where,

T- Number of insects drawn to the treatment.

C- Number of insects drawn to the control

N - Total number of individuals

Effect of different flours as kairomones

Aluminium foil cups were used for the experiment. Each cup was filled with 100 g of different flours: maize flour, rice flour, wheat flour, groundnut flour, sorghum flour, oats flour, cocoa flour, and pearl millet flour, along with a control containing no bait. To enhance attraction, 5% brewer's yeast was added to each flour type, as recommended by Nolan and Hood (2008). The baited cups were then placed near *Corcyra* rearing trays at a rate of one trap per ten trays (Figure 2). Adult beetles captured by the flour attractants were sieved and counted and then discarded. The number of beetles captured was recorded on the 5th, 10th, 15th and 20th days after placement, and the attraction index was subsequently calculated.

Olfactometer-based evaluation of food attractants against *Tribolium castaneum*

Attraction of red flour beetle, *T. castaneum,* towards the food sources wheat, pearl millet and cocoa flour was evaluated using the four-way olfactometer. It consisted of a square-shaped glass box which was connected to four horizontal side tubes. Four stands at the bottom supported the glass box. A detachable centre portion was provided in order to release the test insects, *i.e.,* red flour beetle, *T. castaneum*. Four arms from the glass box extended to an odour container into which the adults were attracted. To create a vacuum inside the container, a suction pump was attached to it. To prevent the movement and settling of insects in the four corners, the corners were closed, thus making the insects move towards the source with preferred volatiles. Before conducting the experiment, the olfactometer was cleaned using ethanol. From an air delivery system, purified air was pumped into the four arms through the Teflon tubes for 45 min. To avoid the volatile mixing, a vacuum was created before and after each run. After creation of vacuum, wheat, pearl millet and cocoa flour were placed inside the odour container. Each run was conducted with 30 adults of *T. castaneum*. The adults were released inside the olfactometer through the detachable opening at the centre of the box (Ahmad *et al.*, 2012). The number of beetles attracted to



Figure 2. Evaluation of flour-based kairomones for *T. castaneum* in *C. cephalonica* rearing rooms.

particular volatile sources was counted, and the attraction index was subsequently calculated.

GC-MS/MS ANALYSIS

Sample preparation: Ten grams of wheat and pearl millet were ground into powder, and each sample was directly extracted with 100 ml of hexane and kept in ultrasonication at 50ºC for 60 min. The extract was filtered and evaporated in the rotary evaporator in order to eliminate the solvent. Then the compounds, diluted with 1 ml of hexane, were filtered through a polyvinylidene fluoride syringe filter of size 0.2 µm. In the case of food oils, 0.1 ml of coconut oil and mahua oil were mixed with 1.4 ml of hexane, and each sample extract was filtered using a PVDF syringe filter. Aliquots of 1ml were taken from the filtered extract for analysis.

Analysis of samples: Aliquots were analysed using a gas chromatograph - mass spectrometer model GCMS/MS - Tq8040 Shimadzu. Separation was performed on an Rxi®-5 Sil MS capillary column (30m × 0.25mm × 0.25 µm). The carrier gas used was helium (Purity percentage > 99.99%) with a flow rate of 1 ml/min. Samples were injected in splitless mode. The column oven temperature was set at 110ºC and held for 5 mins, then a temperature gradient of 10ºC per minute was applied and finally up to 260ºC was held for 5 mins. The interface, injector and source ionisation temperatures were maintained at 250ºC, 250ºC and 230ºC, respectively, for oil samples. For flour samples, the column oven temperature was 110ºC with a holding time of 5 min, then increased to 200ºC with a holding time of 10 min and finally up to 240ºC held for 10 min. Compounds were identified using NIST 17 (National Institute of Standards and Technology) Libraries and by using standards.

STATISTICAL ANALYSIS

All the experiments conducted in the present study were laid out in a Completely Randomised Design (CRD). The per cent data and the count data were subjected to analysis after transforming them into arcsine values and square root values, respectively (Gomez & Gomez, 1984). Means and variances of the treatments were analysed using IBM SPSS software version 16.0, and Tukey's test was used for mean separation at p = 0.05.

RESULTS AND DISCUSSION

The red flour beetle, *T. castaneum*, a predator on the egg, larval and adult stages of *C. cephalonica* significantly affected the biological characters of the rice moth in the experiments conducted in the present study. Negative impacts on the desirable characters such as adult emergence, developmental period and fecundity were evident from the study and presented below.

Emergence and development of *C. cephalonica* under different *T. castaneum* adult densities

Adult emergence of *Corcyra* was found to be predominant in the treatments with *Corcyra* alone and

Table 1. Adult emergence and development period of *C. cephalonica* at different densities of *T. castaneum* adults

Treatment	No. of adults emerged (Mean ±SE*)	Development period (days)		
		Min	Max	Mean ± SE*
T_1 - 20 eggs of *Corcyra* alone	15.33 ± 0.33^{a}	35	54	41.12 ± 0.88^{a}
T_2 - 20 eggs of *Corcyra* + 10 *Tribolium* adults	13.67± 0.33^{ab}	36	56	44.36± 0.68^{b}
T_3 - 20 eggs of *Corcyra* + 20 *Tribolium* adults	12.00± 0.58^{b}	39	55	46.35± 0.74^{bc}
T_4 - 20 eggs of *Corcyra* + 30 *Tribolium* adults	9.33± 0.33^{c}	39	57	49.47± 0.44^{cd}
T_5 - 20 eggs of *Corcyra* + 40 *Tribolium* adults	7.00 ± 0.58^{d}	43	59	52.29± 0.78^{de}
T_6 - 20 eggs of *Corcyra* + 50 *Tribolium* adults	4.67± 0.33^{e}	45	60	53.85± 0.46^{e}
T_7 - 20 eggs of *Corcyra* + 60 *Tribolium* adults	4.33± 0.33^{e}	48	60	55.46± 0.24^{e}
SEd	**0.10**			0.06

SE – Standard Error; * Mean ± Standard Error of three replicate values

Mean values followed by the same letter(s) in a column are not significantly different at p = 0.05

treatments provided with lower densities of *Tribolium* adults, followed by the treatments with increasing densities. The number of adults emerged was maximum in treatments consisting of *Corcyr*a alone (15.33) and *Corcyra* + 10 *Tribolium* adults (13.67), which were on par with each other statistically. Minimum adult emergence was observed in treatments consisting of *Corcyra* + 50 *Tribolium* adults (4.67) and *Corcyra* + 60 *Tribolium* adults (4.33), *i.e*., at higher densities. The developmental period of *Corcyra* was found to be extended in the treatments with *Tribolium* at higher densities, such as 60 adults (55.46 days) and 50 adults (53.85 days), followed by treatments with 40 (52.29 days), 30 (49.47 days), 20 (46.35 days), and 10 (44.36 days). The minimum development period (41.12 days) was observed in the treatment which excludes *Tribolium* adults (Table 1).

This pattern is consistent with the known role of *T. castaneum* as a competitor and predator of eggs and other vulnerable stages of stored-product insects. Previous work has documented competition between *T. castaneum* and moth species, including *C. cephalonica*, and reported reciprocal effects of the two insect populations (Adeyemi, 2009).

The results of variations in olfactory responses from the *T. castaneum* adults to different flours and food oils

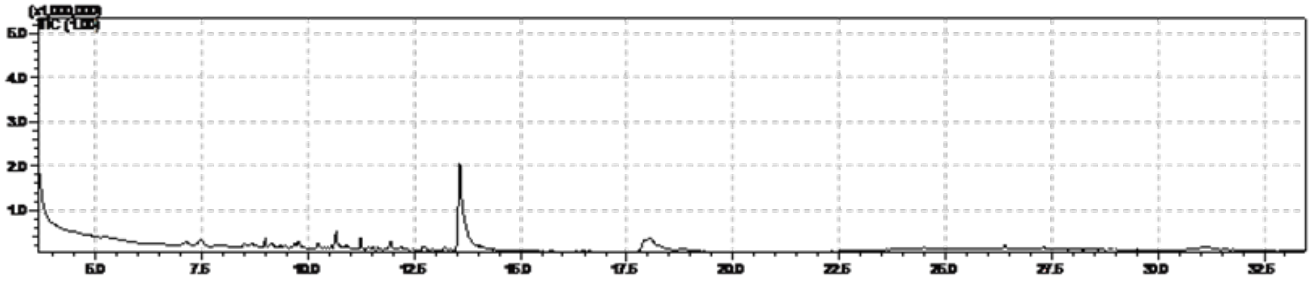


Figure 3. GC MS/MS chromatogram volatile profile of wheat flour.

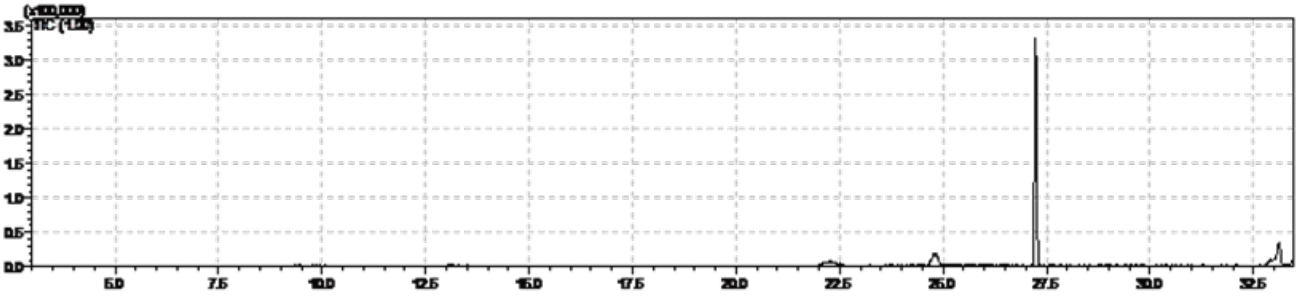


Figure 4. GC MS/MS chromatogram volatile profile of pearl millet flour.

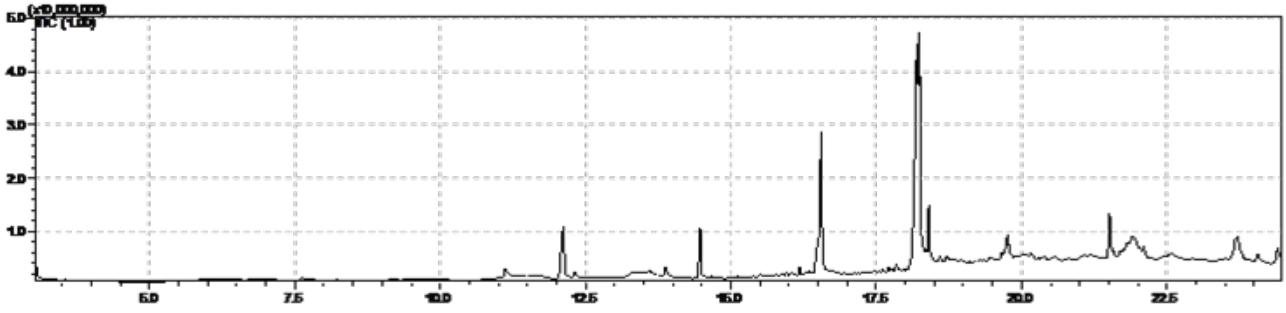


Figure 5. GC MS/MS chromatogram volatile profile of coconut oil.

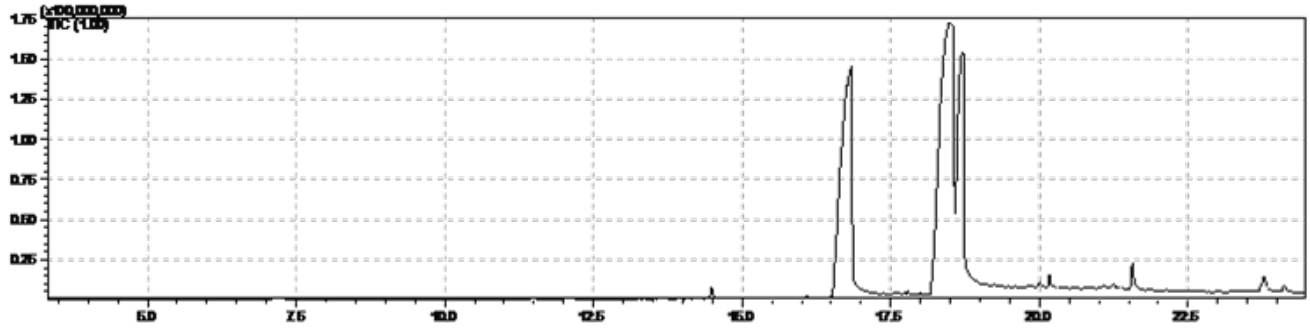


Figure 6. GC MS/MS chromatogram volatile profile of mahua oil.

indicated that a wide range of volatile cues were detected by the beetle (Figures 3-6). The results revealed that *T. castaneum* was highly attracted to wheat and pearl millet flour, whereas in the case of oils, greater attraction was found in mahua oil and coconut oil. Dooley *et al.* (2018) stated that the volatiles produced from wheat germ oil and from the fungi associated with it can perform attractant roles for the stored product pest *T. castaneum*, and this report supports the present finding that wheat had maximum attraction. Minimum attraction was seen in groundnut, rice and maize flour.

This present result is in agreement with the reports of Gerken and Campbell (2020) that teff and wheat flour were identified as the suitable hosts for the development of *T. castaneum.* The findings are in accordance with the results of Kayode *et al.* (2014) that wheat and maize flour had higher and lower attraction levels, respectively, and they also stated that the minimum attraction in maize flour may be due to its tannins and other anti-nutrients, and that millet flour was the most susceptible one for *T. castaneum*, which was closely followed by wheat flour.

Attraction level of *T. castaneum* adults towards different food oils

Compared to the respective control (empty trap), the Attraction index of different food oils for *T. castaneum* was remarkably higher in commercial kairomone (26.66%). While using 10 ml of food oils as attractant, maximum attraction was found in mahua oil (21.12%) followed by coconut oil (11.42%). Groundnut oil (4.68%), sesamum oil (4.08 %), rice bran oil (5.66%), palm oil (4.96%) and sunflower oil (4.28%) were found to be on par with each other statistically. Similarly, mahua oil (21.10%) and coconut oil (12.08%) were observed as superior attractants, followed by palm oil, rice bran oil, groundnut oil and sunflower oil at 20 ml volume. Soybean oil was found to be the least attractive one with 3.58 and 2.83 per cent Attraction index at 10 ml and 20 ml, respectively. Considering the mean values, the performance of mahua oil (21.11%) was closely related to the commercial kairomone (26.66%), followed by coconut oil (11.75%). Meagre attraction was seen in sunflower oil (4.17%). The lowest trapping percentage was observed in soybean oil (3.21%), and it was on par with the control (Table 2).

The present findings are in close agreement with Dissanayaka *et al*. (2018a), who evaluated different food oils as kairomones for *T. castaneum*. They reported that mee/ mahua oil and coconut oil produced the highest attraction among the tested food oils. The authors concluded that these two oils had considerable potential as kairomones for *T. castaneum*.

The present results are also supported by Bandara *et al*. (2021), who investigated the orientation of *T. castaneum* to 4,8-DMD, a commercial kairomone and botanical oils. They reported that combining 4,8-DMD with botanical oils could improve trapping, with particularly strong trapping obtained with pheromone + neem oil and pheromone + coconut oil. Their findings further demonstrate that botanical oils can influence the behavioural response of *T. castaneum* and can be incorporated into pheromone-based monitoring systems.

Attraction levels of *T. castaneum* adults towards different flours

Among the flours tested, wheat flour attracted the highest, with 21, 24.89, 25.60 and 28.97 per cent Attraction index at 5, 10, 15 and 20 days after placement of the trap, respectively. Pearl millet followed wheat with 16.72, 17.14, 20.34 and 22.10 per cent attraction index at 5th, 10th, 15th and 20th day, respectively. Although cocoa flour (19.14%)

Table 2. Attraction level of *T. castaneum* adults towards different food oils

Treatment	Attraction Index (%) *		
	10 ml	20 ml	Mean
T_1 - Coconut oil	11.42 (19.75)^{c}	12.08 (20.34)^{c}	11.75 (20.04)^{c}
T_2 - Groundnut oil	4.68 (12.49)^{de}	4.99 (12.91)^{de}	4.83 (12.70)^{de}
T_3 - Sesamum oil	4.08 (11.66)^{de}	5.21 (13.19)^{de}	4.65 (12.45)^{e}
T_4 - Soybean oil	3.58 (10.90)^{e}	2.83 (9.69)^{f}	3.21 (10.31)^{fe}
T_5 – Rice bran oil	5.66 (13.76)^{d}	5.56 (13.64)^{de}	5.61 (13.70)^{d}
T_6 - Palm oil	4.96 (12.86)^{de}	6.88 (15.21)^{d}	5.92 (14.08)^{d}
T_7 - Sunflower oil	4.28 (11.94)^{de}	4.05 (11.62)^{ef}	4.17 (11.78)^{de}
T_8 - Mahua oil	21.12 (27.36)^{b}	21.10 (27.34)^{b}	21.11 (27.35)^{b}
T_9 - Commercial kairomone	27.37 (31.55)^{a}	25.95 (30.63)^{a}	26.66 (31.09)^{a}
T_{10} -Control	0.00 (5.23)^{f}	0.00 (5.23)^{g}	0.00 (5.23)^{f}
SEd	0.76	0.77	0.75

*****Mean values of three replications; Figures in the parentheses are arcsine transformed values; Mean values followed by same letter(s) do not differ significantly at p = 0.05

attracted much more initially than all other flours excluding wheat, on the 5th day it started to decrease to 14.85, 10.62 and 6.49 per cent attraction index on the 10th, 15th and 20th day, respectively. Next to cocoa, sorghum was found to be effective with 12.19, 12.72, 10.23 and 11.78 per cent attraction index on the 5th, 10th, 15th and 20th day, respectively. From the comparison of mean values, wheat (25.12%) was on par with pearl millet (19.07%) and attracted the most when compared with others. Rice flour (4.33%) and maize flour (4.95%) were on par with each other statistically, with moderate attraction levels, whereas groundnut flour was the least attractive one with 1.61 per cent attraction index (Table 3).

Our findings that mahua oil and coconut oil performed well in attracting *T. castaneum* are similar to the previous report that these oils attract the maximum number of red flour beetles (Dissanayaka *et al.,* 2018a). The fact that coconut oil and mee oil have the potential to attract *T. castaneum* adults equal to that of pheromones and kairomones was reported by Dissanayaka *et al.* (2018b). Minimum attraction in soybean oil may be due to the fact that soybean flour is an unsuitable host, due to its effect of lower fecundity, relative growth and efficiency of conversion of ingested food for the development of *T. castaneum* (Naseri *et al.*, 2017). This difference in our results may probably be attributed to the change in volatiles by the hydrogenation process.

Positive responses from *T. castaneum* towards certain food oils were evident from the study, and this is corroborated by the findings of Doud and Phillips (2020) that food oils can enhance attraction of *T. castaneum* towards them. In this study, it was found that olfactory cues played a major role in finding the host regardless of the colour and viscosity

Table 3. Attraction levels of *T. castaneum* adults towards different flours

Treatment	Attraction Index (%) *				
	5 DAP	10 DAP	15 DAP	20 DAP	Mean
T_1 – Maize	4.68 (12.49)^{f}	6.93 (15.26)^{f}	4.81 (12.67)^{d}	3.38 (10.59)^{f}	4.95 (12.85)^{c}
T_2 – Rice	5.02 (12.94)^{f}	4.55 (12.31)^{g}	4.27 (11.93)^{d}	3.50 (10.78)^{f}	4.33 (12.01)^{cd}
T_3 – Wheat	21.00 (27.27)^{a}	24.89 (29.97)^{a}	25.60 (30.40)^{a}	28.97 (32.56)^{a}	25.12 (30.08)^{a}
T_4 – Groundnut	2.13 (8.39)^{g}	1.79 (7.70)^{h}	1.31 (6.56)^{e}	1.10 (6.02)^{g}	1.61 (7.29)^{de}
T_5 – Sorghum	12.19 (20.43)^{d}	12.72 (20.89)^{d}	10.23 (18.66)^{c}	11.78 (20.07)^{c}	11.74 (20.04)^{b}
T_6 – Oats	9.42 (17.88)^{e}	10.76 (19.15)^{e}	10.87 (19.25)^{c}	9.98 (18.42)^{d}	10.26 (18.68)^{b}
T_7 – Cocoa	19.14 (25.94)^{b}	14.85 (22.66)^{c}	10.62 (19.02)^{c}	6.49 (14.76)^{e}	12.76 (20.93)^{b}
T_8 – Pearl millet	16.72 (24.13)^{c}	17.14 (24.46)^{b}	20.34 (26.81)^{b}	22.10 (28.04)^{b}	19.07 (25.89)^{a}
T_9 – Control	0.00 (5.50)^{h}	0.00 (5.50)^{i}	0.00 (5.50)^{e}	0.00 (5.50)^{g}	0.00 (5.50)^{f}
SEd	0.24	0.30	0.34	0.38	1.49

*DAP Days After Placement

*Mean values of three replications; Figures in the parentheses are arcsine transformed values; Mean values followed by same letter(s) do not differ significantly at p = 0.05

of the oils. Although there were no significant differences in the attraction levels when the volume was increased, a combination of these oils with other alluring food sources can enhance the attraction levels of *T. castaneum*.

Attraction levels of *T. castaneum* adults towards flours in a four-way olfactometer.

The results from the confirmatory study using a four-way olfactometer, the highest proportion of *T. castaneum* (31.39%) moved toward wheat, indicating its strong attractiveness. Next to the control, higher attractiveness was observed in pearl millet (24.10 %) and cocoa flour (9.50%) after 10 min (Table 4).

Volatile profile of food bait attractants

In the GC-MS chromatogram of the food attractants, the number of compounds identified was 15, 29, 46 and 68 in wheat flour, pearl millet flour, coconut oil and mahua oil,

Table 4. Attraction levels of *T. castaneum adults* towards flours in a four-way olfactometer

Treatment	Attraction Index (%)*
T_1 - Pearl millet flour	24.10 (29.40)^{b}
T_2 - Wheat flour	31.39 (34.07)^{a}
T_3 - Cocoa flour	9.50 (17.95)^{c}
T_4 - Control	0.62 (4.52)^{d}
SEd	1.51

*Mean values of ten replications; Figures in the parentheses are arcsine transformed values; Mean values followed by same letter(s) in a column are not significantly different at p = 0.05

respectively. From the enormous numbers of compounds exhibited in chromatograms, only the volatile compounds, previously identified as attractants for *T. castaneum* and those which were present in substantial amounts, were projected as the factors that prompt significant changes in their behaviour on account of olfactory cues.

The compounds taken into account from the four food bait samples were dodecanoic acid (lauric acid), tetradecanoic acid (myristic acid), 9-octadecanoic acid (oleic acid), pentadecanoic acid (pentacyclic acid), octadecanoic acid (stearic acid), hexadecanoic acid (palmitic acid), eicosanoic acid (arachic acid), 1,2-benzenedicarboxylic acid, hexanoic acid, 1- (+) – Ascorbic acid 2,6 – dihexadecanoate, octadecane, undecane, hexadecane, nonane, eicosane, heneicosane, nonacosane, 1- butanol, 3- hexanol and hexacosane. It was observed that hydrocarbons and fatty acids are more commonly present in the food baits, whereas the presence of alcohol compounds was low and infrequent among the food baits. In wheat flour, compounds such as tetradecanoic acid, pentadecanoic acid, hexadecanoic acid, 1,2-benzenedicarboxylic acid, undecane, hexadecane, eicosane, heneicosane and hexacosane were found to be present with area percent of 3.24, 0.93, 75.71, 3.01, 0.72, 2.83, 2.38, 0.84 and 0.90, respectively. In pearl millet 1,2 - benzenedicarboxylic acid was the most predominant compound with an area per cent of 79.36. Dodecanoic acid, hexadecanoic acid, hexanoic acid, undecane, nonane, 1-butanol and 3-hexanol were detected with 0.13, 1.53, 0.70, 0.63, 2.50, 0.22 and 0.38 per cent of area, respectively. In coconut oil, dodecanoic acid (4.87 %), tetradecanoic acid (4.72 %), 9-octadecanoic acid (0.36 %), octadecanoic acid (5.7 %), hexadecanoic acid (13.14 %), eicosanoic acid (0.1 %), 1,2-benzenedicarboxylic acid (20.89 %), eicosane (1.18 %), heneicosane (0.27 %) and hexacosane (2.81 %) were detected. In mahua oil, dodecanoic acid (0.12 %), tetradecanoic acid (1.87 %), 9-octadecanoic acid (2.66 %), pentadecanoic acid (0.2 %), octadecanoic acid (39.92 %), hexadecanoic acid (4.47 %), eicosanoic acid (2.14 %), 1- (+) – Ascorbic acid 2,6-dihexadecanoate (38.07 %), octadecane (0.06 %), heneicosane (0.11 %) and nonacosane (0.23 %) were present (Table 5).

This present study disclosed that the volatile compounds in the food baits mediated interactions in *T. castaneum* enabling it to discriminate the most attractive and unappealing host substrates. Many of the volatile compounds identified from the chromatographic profile which were detected in remarkable amounts might also be a attractant in behavioural assays as few of the compounds were tested earlier in behavioural studies of *T. castaneum* by the authors Balakrishnan *et al.* (2017), Dissanayaka *et al.* (2020) and Athanassiou *et al.* (2006).

Palmitic acid, a long carbon chain fatty acid eliciting stronger attraction towards it in other insects such as *Callosobruchus maculatu*s and *Aulacophora foveicollis* of the same order Coleoptera were reported by Adhikary *et al.* (2016) and Mukherjee *et al.* (2014). Lauric and myristic acids are available in pearl millet and wheat, respectively in addition to coconut oil and mahua oil, whereas the monounsaturated fatty acid with long carbon chain (C_{18}), *i.e.,* oleic acid was found only in the food oils. Hexanoic acid in pearl millet (0.70%) can elicit stronger behavioural responses in *T. castaneum* (Balakrishnan *et al.*, 2017) and this describes the higher attraction in it undoubtedly.

In our results 1,2-benzenedicarboxylic acid was the most prominent compound in pearl millet (79.36%) and it is supported by the previous reports of Singh *et al.* (2015). Together with the fact that 3-Hexanol can attract *O. surinamensis* and *S. granarius* (Collins *et al.*, 2007; Germinara *et al.*, 2008) this alcoholic compound along with the other aliphatic alcohol 1-Butanol (0.22%) in pearl millet inferred that these compounds were responsible for attraction (Dooley *et al.*, 2018). Saturated long chain hydrocarbons such as octadecane, undecane and linear alkane hydrocarbon nonane presence in food baits are accountable for attracting *T. castaneum* as it had been previously identified as stronger attractants to *T. castaneum* by (Dooley *et al.*, 2018). Similar findings reported by (Balakrishnan *et al.*, 2017) that undecane and octadecane can elicit stronger positive responses are in line with our results.

The volatile compounds such as hexacosane, heneicosane, nonacosane and hexadecane from the body washes of *C. cephalonica* are known to elicit positive responses from the parasitoids, *T. brasiliensis* and *T. exigum* (Singh *et al.*, 2002). The presence of these long chain hydrocarbons in food baits had the possibility to be identified as cues by the predator *T. castaneum* in the process of searching and location of its host *C. cephalonica* thereby explaining the higher attractiveness to the food baits.

Table 5. Comparison of volatile profile of food bait attractants

S. No.	Volatile compounds	Area %				Report on insect Attraction	References
		Wheat flour	Pearl millet flour	Mahua oil	Coconut oil		
	Dodecanoic acid (Lauric acid)	-	0.13	0.12	4.87	*T. castaneum*	Cohen *et al.* (1974)
	Tetra decanoic acid (Myristic acid)	3.24	-	1.87	4.72	*Callosobruchus maculatus* *T. castaneum*	Cohen *et al.* (1974)
	9 - Octadecenoic acid (Oleic acid)	-	-	2.66	0.36	*T. castaneum, D. casignetum*	Cohen *et al.* (1974)
	Penta decanoic acid (Pentadecylic acid)	0.93		0.2	-	*T. castaneum*	Cohen *et al.* (1974)
	Octadecanoic acid (Stearic acid)	-	-	39.92	5.7	*T. castaneum, C. maculatus*	Cohen *et al.* (1974)
	Hexa decanoic acid (Palmitic acid)	75.71	1.53	4.47	13.14	*T. castaneum, C. maculatus, A. foveicollis*	Mukherjee *et al.* (2014)
	Eicosanoic acid (Arachidic acid)	-	-	2.14	0.1	-	-
	1,2–Benzene dicarboxylic acid	3.01	79.36	-	20.89	-	-
	Hexanoic acid		0.70			*T. castaneum*	Balakrishnan *et al.* (2017)
	l-(+)-Ascorbic acid 2,6-di hexa decanoate	-	-	38.07	-	-	-
	Octadecane	-	-	0.06	-	*T. castaneum*	Balakrishnan *et al.* (2017)
	Undecane	0.72	0.63	-	-	*T. castaneum*	Balakrishnan *et al.* (2017)
	Hexadecane	2.83	-	-	0.8	*T. chilonis*	Bhagat & Bakthavatsalam (2012)
	Nonane	-	2.50			*T. castaneum*	Sathiyaseelan *et al.* (2022)
	Eicosane	2.38	-	-	1.18	-	-
	Heneicosane	0.84	-	0.11	0.27	*Trichogramma* sp.	Bakthavatsalam & Tandon (2006)
	Nonacosane	-	-	0.23	-	*T. chilonis*	Bakthavatsalam & Tandon (2006)
	1 – Butanol		0.22			*T. castaneum*	Sathiyaseelan *et al.* (2022)
	3–Hexanol		0.38			*O. surinamensis, S. granarius*	Sathiyaseelan *et al.* (2022)
	Hexacosane	0.90	-	-	2.81	*Trichogramma* sp.	Bakthavatsalam & Tandon (2006); Paul *et al.* (2002)

CONCLUSION

The present study demonstrated that the red flour beetle, *Tribolium castaneum*, significantly impacted the biological parameters of *Corcyra cephalonica*, particularly at higher predator densities, by reducing adult emergence and extending the developmental period. The study further revealed that *T. castaneum* adults exhibit strong olfactory responses to specific food sources, with wheat and pearl millet flours, as well as mahua and coconut oils, emerging as the most attractive substrates. These preferences were confirmed through both trap-based assays and four-way olfactometer studies. GC-MS analysis of volatile profiles identified key attractant compounds, particularly fatty acids and hydrocarbons responsible for eliciting behavioural responses from *T. castaneum*. Notably, compounds such as palmitic acid, oleic acid, undecane, octadecane, and 1,2-benzenedicarboxylic acid were strongly correlated with beetle attraction. The study highlights the potential use of specific food-based volatiles and oils as attractants in pest monitoring and management strategies. Particularly, the demonstrated efficacy of mahua and coconut oils, comparable to commercial kairomones, indicates promising alternatives for eco-friendly attractant formulations in Integrated Pest Management (IPM) programs targeting *T. castaneum* in *C. cephalonica* mass production.

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AUTHOR CONTRIBUTION

M. Sathiyaseelan contributed to the conceptualization, methodology, investigation, experimentation, data collection, data analysis and preparation of the original manuscript. K. Balaji contributed to supervision, methodology, validation, interpretation of results and critical review of the manuscript. R. Senthilkumar contributed to experimental design, investigation, data collection, data analysis, and interpretation of results. A. B. Sruthi contributed to investigation, data collection, experimentation, literature review and manuscript preparation. G. Selvakumari contributed to data analysis, validation, interpretation of results and critical revision of the manuscript and V. Yamini Prakashini contributed to literature review, data curation, manuscript editing and formatting. All authors have read and agreed to the published version of the manuscript.