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Efficiency of Food Bait Attractants and Volatile Compounds for Monitoring of Pests in Stored Paddy

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Abstract: Food baits are one of the ways for monitoring and mass trapping of stored product insects. Based on this principle wheat flour, sorghum flour, pearl millet flour, rice flour, cracked corn, crushed groundnut, rice bran + rice flour as attractive materials. Observations were taken on 25 days after placement of bait traps. Behavioural response of insects to wheat flour, cracked sorghum and pearl millet flour were more attractive. The effective baits were also test verified through four-arm olfactometer and found the highest orientation in the arm containing wheat flour. The major attractive volatile compounds present in the baits were analysed using GCMS/MS. The attractive volatile compounds such as 1- butanol, 3-octen-1-ol, pentanal, nonane and undecane were present in wheat. Butyric acid, 3-hexanal and 7-octen-4-one present in sorghum. Undecane 7-octen-4-one, 1-octanal, hexanal, butanal, nonanal present in pearl millet. The attractant compound 3-hexanal was present in groundnut and rice bran. Butanal and 7-octen-4-one were present in corn and rice bran respectively, attracted less insects. Volatile compounds such as pentadecanoic acid, n-Hexadecanoic acid, cis-Vaccenic acid and propionic acid acted as repellents. cis-vaccenic acid present in rice bran, effected low attraction. Therefore, the effective bait of wheat flour may be exploited for monitoring and trapping of insects in paddy storage godowns.

Keywords: Bait traps, Rice godown, Stored product insects, Volatile, Food bait attractants

Rice is one of the most important food crops for more than half of the world's population. Large number of people affected by food availability due to losses in storage rice. In storage godown, number of biotic and abiotic agents like insects, birds, mites, fungi, rodents and moisture are causing damage to rice (Pandey 2018). Storage insects cause more considerable losses in every year. Stored product insect particularly adult beetles due to their harbourage seeking behaviour seek refuge in cracks and crevices of warehouse and storage godown. Although it is very difficult to detect the activity of insects visually in storage godown, detection of insect population using bait trap with pheromones or food sources or combination of both pheromone and food attractants may influence in stored product insect management.

The food bait trap is one of the detection techniques for stored-product insects in storage (Neethirajan et al 2007). Olfactory cues play an important role as attractants, and diversity of substances are as kairomone for stored product pests (Rizana and Phillips 2007). The granary weevil, *Sitophilus granarius* is the most widely studied storage insect species with regard to its response to kairomone, with its reaction to crushed seed or whole seed (Reidorf and Steidle 2002). The present study aims at to know the response of insects to different host odours in paddy storage godowns. The main objective of the study was to identify an easily available, cheap and effectively attracting bait source for major pests in stored paddy. Volatile chemical olfactory cues play an important role as attractants, and diversity of substances as kairomones for stored product pests (Rizana and Phillips 2007). The granary weevil, *Sitophilus granarius* is the most widely studied storage insect species concerning its response to kairomone, with its reaction to crushed seed or whole seed (Rietdorf and Steidle 2002). Since a lot of insect species feed on any one of the foods, volatile from this food attracts more than one species (Collins et al 2007). Combining food and pheromone odour can increase the pitfall traps efficiency against Sitophilus spp. (Likhayo and Hodges 2000, Wakefield et al 2005).

Bait traps have become the most useful tools in the management programmes of Angoumois grain moth, *Sitotroga cerealella*, lesser grain borer, *R. dominica*, red flour beetle, *Tribolium* spp. rice weevil, *S. oryzae* and saw-toothed grain beetle, *O. surinamensis*. Response of insects to various food bait attractants are wanting for efficient utilization of foods for the control of insects in paddy storage godown. Therefore the present study aims at to investigated the olfactory responses of insects by experimenting with different bait based materials in paddy storage godowns.

MATERIAL AND METHODS

Rearing of test insects: In plastic jar adults of the lesser grain borer, *R. dominica*, rice weevil, *S. oryzae*, and red flour beetle, *Tribolium* spp., were mass produced. The insects were fed with wheat flour and wheat grains as a diet. Twenty to thirty pairs of each insect species were placed in plastic jars containing 250 g of grains. A piece of kada cloth was secured to the jars with rubber bands. The cultures were kept in a controlled environment with a 12:12 hour light: dark photoperiod, temperatures between 26 and 28°C and relative humidity levels between 60 and 65 percent. All of the experiments were carried out under the identical circumstances where the cultures were kept in.

Olfactometer Bioassay

Four armed olfactometer apparatus: Three different odour sources such as wheat flour, sorghum flour and pearl millet flour were selected for olfactometer bioassay. To study the chemoreception and attraction, the experiment was conducted by way of an olfactometer apparatus. It consisted of square-shaped box with four horizontal side tubes. The plastic box (25 cm X 25 cm X 11.5 cm) was supported at the bottom by four supports with a removable top of the centre for the insertion of test insects. The protruded four arms from the plastic box were linked to the container which contained the odour samples. The air pumping system was linked to this volatile container to attract the test insects. To produce the vacuum, a suction pump was connected to the glass container independently. The corners of the plastic box were blocked to prevent insects from moving and resting in the corners, as well as to cause the insects to migrate towards their favourite volatiles. The olfactometer was first cleaned with 70% ethanol to minimize odour residue. Purified air was pumped into the four arms via Teflon tubes from an air delivery system for 45 minutes before and after each experiment, a vacuum was generated within the olfactometer to keep the volatiles from mixing.

Orientation studies of storage insects: Test insects viz., *R. dominica*, *Tribolium* spp. and *S. oryzae* were starved for 24 h in petri plates before the commencement of olfactory bioassay. Fifty unsexed adults were released in the centre of the olfactometer (7mm hole) and it was covered with cloth to minimise the phototactic response of insects. At 5, 10, 15, 20, 25 Minutes After Release (MAR), the location of the insects was observed (Vijay et al 2020). Each treatment was replicated 5 times. The response of *R. dominica*, *Tribolium* spp. and *S. cerealella* was assessed on wheat flour, sorghum flour and pearl millet flour. On each arm, the numbers of settled and unsettled insects were observed.

Volatile Profiling of Food Baits in GC-MS/MS

Sample preparation: GC-MS/MS spectroscopic analysis was performed to determine the exact active principles present in the attractive baits. For this purpose, a fresh sample of food baits was dried and ground into powder. Ten gram of the sample was extracted in an ultrasonic bath for 30 minutes with 30 ml of methanol and filtered through a 0.45 µm polyvinylidene fluoride syringe filter (Kim et al 2020).

GC- MS/MS analysis: Chemical profiling study was done at the Central Instrumental Laboratory, Department of Agricultural Entomology, Madurai where the methanol extract was characterized using a gas chromatograph-mass spectrometer (GC- MS/MS) (GC 2010 plus, GCMS – TQ 8040 SHIMADZU). On the capillary column (Rxi® - 5 Sil MS), the compounds were separated. The carrier gas was helium (purity percentage > 99.99%), with a column flow rate of 1ml/min and injection in split less mode. The oven temperature was set to 110°C, which was gradually increased to 150°C at a rate of 10°C/min and held for 5 minutes before being increased to 200°C at a rate of 10°C/min. After another 20 minutes, it was raised to 240°C at a rate of 10°C/min and held for 5 minutes. The MS was run in Electron ionisation (EI) mode at 70 eV, with an ion source temperature of 200°C, an interface temperature of 230 °C, and a scan range of 45-600 m/z. The solvent cut time was three minutes. Each sample was given 30 minutes to run. The NIST17 (National Institute of Standards and Technology) MS library database was used to identify the spectrum of the unknown volatile compounds. The obtained compounds were tabulated, along with the peak percent area and retention time (RT).

Statistical analysis: The data on attraction index and behavioural response/orientation of the beetles were statistically analysed using completely randomized design (CRD) by one-way ANOVA subjecting the data to arcsine/square root transformation and were separated by using Duncan's multiple range test (DMRT) with IBM SPSS statistics 22.0 software and differences were regarded as significant at $p < 0.05$.

RESULTS AND DISCUSSION

Behavioural response of insects: Based on the observation made in four arm olfactometer maximum preference percentage of *Tribolium* spp. was in wheat flour (32.66%) followed by sorghum flour (24.5%) and pearl millet flour 16% at 25 MAR. Olfactometer bioassay showed that at 25 MAR more *S. oryzae* (24.83%) settled in the test arm containing sorghum flour which was on par with wheat flour. Olfactometer bioassay revealed the significant variations on orientation/behavioural response of *R. dominica* towards wheat flour, sorghum flour, pearl millet flour and control (without food bait) in a four-arm olfactometer. At 25 Minutes

After Release (MAR), the highest orientation of 28.5% recorded towards wheat flour and found significantly superior to other flours followed by sorghum flour (21.16%) and pearl millet flour (17.5%) (Table 1). Vijay et al (2020) reported that the highest orientation of *S. oryzae* was towards sorghum (53.33% and 48.67%) in 20 MAR. While in our study the highest orientation of *S. oryzae* towards wheat flour as 31% and 39% of 20 and 25 MAR respectively, while 26% of *S. oryzae* settled in sorghum flour at 5 and 20 MAR. Trematerra et al (2000) observed that *O. surinamensis*, *T. castaneum*, and *T. confusum* use grain volatile odours to determine whether stored wheat grain kernels have been damaged mechanically or by insects and these studies are corroborative to our findings.

Identification of volatile profile of different food baits in GC-MS/MS: The separation of the volatile compound was obtained using the RX i – 5 Sil MS capillary column (Table 2). The 114 different compounds were detected in the methanolic food bait extract and components can be divided into 10 categories including 22 alcohols, 10 ketones, 7 aldehydes, 16 hydrocarbons, 14 esters, 3 ethers, 23 fatty acids, 5 nitrogenous compounds, 4 pyrans and 10 other group compounds. Among the various compounds detected 2.81, 0.58, 3.84, 1,0, 0.84 and 1.69 percent alcohol were present in the wheat, sorghum, pearl millet, groundnut, rice and rice bran respectively. The maximum ketones were present in wheat (2.15 %) and minimum in rice bran (0.14%). The highest amount of aldehyde presents in pearl millet (19.76%) followed by wheat and maize. The maximum hydrocarbons 6.57% were present in wheat and minimum 3.6% in rice. The higher amounts of esters present in groundnut (8.84%) followed by wheat, sorghum, rice bran, maize and rice (1.71%). Furthermore, 0.79%, 1.23% and 0.16% of ethers present in wheat, groundnut and maize, respectively. The greater amounts of fatty acids were identified in rice bran (68.88%) followed by sorghum, rice, pearl millet, wheat and maize. The least amounts of fatty acids identified in groundnut were (18.94%). Nitrogenous compounds were present only in wheat, sorghum and groundnut (0.99, 0.73 and 0.8% respectively). Pyrans were present in wheat, sorghum, pearl millet and maize. Large amounts of other compounds were also identified in wheat (7.01%) followed by sorghum (4.73%) and groundnut (3.98%), and minimum in rice bran (0.87%) (Table 2).

Table 1. Behavioural/orientation response of *Tribolium* spp., *Sitophilus oryzae* and *Rhyzopertha dominica* to various food attractants

Food attractants	**Tribolium* spp. settled (%)	*S. oryzae* settled (%)	*R. dominica* settled (%)
	20 MAR	20 MAR	20 MAR
Wheat flour	32.66	27.83	28.5
Sorghum flour	24.5	22.33	21.16
Pearl millet flour	16	16.5	17.5
Control (Without food)	3.66	4.33	4.83
Unsettled	23.16	29	28

*MAR- Minutes after release

Insects attracting volatile compounds: The attractive volatile compounds such as 1- butanol (0.25%), 3-octen-1-ol (0.24%), pentanal (0.32%), nonane (0.3%) and undecane (1.73%) were present in wheat, and were major attractants of *S. cerealella* and *S. oryzae* (Table 3) Sorghum have 3-hexanal (0.09%), 7-octen-4-one (0.12%) and butyric acid (0.10%) of volatile compounds which are responsible for the attraction of greater number of *R. dominica*, *Tribolium* spp. and *S. oryzae*. In pearl millet 7-octen-4-one (0.26%), 1-octanal (0.78%), hexanal (0.58%), butanal (0.24%), nonanal (1.55%) and undecane (0.73%) of attractive volatile compounds were present which responsible for the attraction of *O. surinamensis*. In groundnut and rice bran 0.18% and 0.34% of 3-hexanal present respectively, even though it attracted a smaller number of insect because other attractive volatile compounds are absent. Similarly, butanal (0.14%) was present in maize and 0.14% 7-octen-4-one was present in rice bran this also attracts less insects.

Insect repellent volatile compounds: The n-Hexadecanoic acid, cis-Vaccenic acid, propionic acid and pentadecanoic acid were present in the baits and acted as repellent. The highest quantity of cis-vaccenic acid was present in rice bran (59.06%) resulting more repellency. Repellent volatile compounds were absent in wheat excepting n-Hexadecanoic which was present in a lower amount (12.65%) compared with other food bait, which exhibited very high attraction per cent in wheat compared to others (Table 4).

Behavioural reactions of stored product insect: In the present analytical investigation, the presence of volatile chemicals such nonane, undecane, butanol, and 3-octen-1-ol in wheat flour (Fig. 1) had attracted *S. cerealella* and *S. oryzae*. E-2-nonenal and 4-ethylacetophenone compounds induced favourable responses in *S. granaries*, *O. surinamensis*, and *Cryptolestious ferrugineus*, hexanoic acid, 2-phenylethanol and E-3-octen-2-one had elicited a response for *O. surinamensis* and *S. granarius* confirming previous findings (Collins et al 2007). Balakrishnan et al (2017) reported a related findings that amongst biologically active compound groups, undecane, octanal, 1-hexen-3-ol, 2-heptanone, ethyl hexanoate and hexanoic acid elicited the strongest Electroantennographic (EAG) responses to *Tribolium castaneum.* The maximum attraction of *O.*

Table 2. Volatile profiles of different food bait attractant

S. No.	Compounds	Peak area % (Mean ± SE)						
		Wheat	Sorghum	Pearl millet	Groundnut	Maize	Rice	Rice bran
Alcohol								
1.	3-Hexanol, 2-methyl-	-	0.09±0.0008	-	0.18±0.003	-	-	0.34±0.003
2.	Propargyl alcohol	-	0.11±0.0005	-	-	-	0.15±0.004	-
3.	2-Propanol, 1-propoxy-	-	-	-	0.64±0.174	-	-	-
4.	1-Penten-3-ol	0.27±0.003	-	-	-	-	-	-
5.	2,5-Hexanediol	-	-	-	0.18±0.002	-	-	-
6.	1-Butanol	0.25±0.004	-		-	-	-	-
7.	RS-2,3-hexanediol	0.17±0.004	-	-			0.11±0.002	0.28±0.007
8.	1,2-Butanediol	-	-	-	-	-	-	0.65±0.021
9.	2-Bromo-1,3-dicyclopropylpropane-1,3-diol	0.33±0.004	-	-	-	-	0.35±0.001	-
10.	2-Furanmethanediol	0.29±0.002	-	-	-	-	-	-
11.	1,14-Tetradecanediol	0.52±0.01	-	-	-	-	-	-
12.	3-Octen-1-ol	0.24±0.006			-	-	-	-
13.	5-Methyl-2-hexanol	0.23±0.005	-	-	-	-	-	-
14.	3-Ethyl-3-methyl-2-pentanol	0.51±0.002	-	-	-	-	-	-
15.	DL-2,3-Butanediol	-	0.10±0.002	0.21±0.005	-	-	-	-
16.	2,3-Epoxyhexanol	-	0.09±0.001	-	-	-	-	-
17.	(SS)- or (RR)-2,3-hexanediol	-	0.19±0.002	-	-	-	-	-
18.	(S)- (+)-Isoleucinol	-	-	0.19±0.002	-	-	-	-
19.	Cyclohexane propanol	-	-	0.88±0.010	-	-	-	-
20.	4-Ethyl-1-hexyn-3-ol	-	-	1.56±0.011	-	-	-	-
21.	1,7-Octanediol	-	-	0.81±0.016	-	-	-	-
22.	4-Dodecanol	-	-	0.19±0.0008	-	-	0.23±0.006	0.42±0.0002
Total Alcohol		2.81	0.58	3.84	1	0	0.84	1.69
Ketones								
23.	1,2-Dioxolan-3-one	-	-	-	0.41±0.005	-	-	-
24.	1,3-Dioxan-4-one,2-(1-methylethyl)-5-methyl		0.17±0.002		0.20±0.0024	0.07±0.0007	-	-
25.	Tetrahydro [2,2'] bifuranyl-5-one	0.14±0.001	-	-	-	-	-	-
26.	delta. -Nona lactone	-			1.21±0.0021	-	-	-
27.	Spirohexan-5-one	0.70±0.018	-	-	-	-	-	-
28.	Dihydro-2(3H)-thiophenone	-	-		0.75±0.003	-	-	-
29.	Cyclononanone	1.31±0.021	-	-	-	-	-	-
30.	7-Octen-4-one	-	0.12±0.0003	0.26±0.002	-	-	-	0.14±0.004
31.	2-Hydroxy-3-hexanone	-	0.14±0.004	-	-	-	-	-
32.	2-Nonanone	-	-	-	0.36±0.004	-	-	-
Total Ketones		2.15	0.43	0.26	2.93	0.07	0	0.14
Aldehydes								
33.	7-Tetradecenal	-	-	16.61±0.371	-	-	-	-
34.	1-Heptanal	0.19±0.002	-	-	-	-	-	-
35.	1-Octanal	-	-	0.78±0.005	-	-	-	-
36.	Pentanal	0.32±0.0005	-	-	-	-	-	-

Cont...

Table 2. Volatile profiles of different food bait attractant

S. No.	Compounds	Peak area % (Mean ± SE)						
		Wheat	Sorghum	Pearl millet	Groundnut	Maize	Rice	Rice bran
37.	Hexanal	-	-	0.58±0.014	-	-	-	-
38.	Butanal	-	-	0.24±0.001	-	0.14±0.001	-	-
39.	Nonanal	-	-	1.55±0.008	-	-	-	-
Total Aldehydes		0.51	0	19.76	0	0.14	0	0
Hydrocarbons								
40.	2-Methoxy-2-methylbut-3-ene	-	0.10±0.002	-	0.18±0.001	-	-	-
41.	2-Pentene	-	-	0.34±0.003	-	-	-	-
42.	Nonadecane	-	1.24±0.033	-	-	-	-	-
43.	2-Bromononane	0.28±0.0001	-	-	-	-	-	-
44.	1-Bromodocosane	-	-	-	-	-	1.8±0.020	-
45.	Pentane	-	-	-	-	0.07±0.0007	0.30±0.007	-
46.	1-Hexyl-2-nitrocyclohexane	0.21±0.002	-	0.25±0.003	-	-	-	-
47.	Dodecane	-	-	-	-	-	1.5±0.009	-
48.	Nonane	0.3±0.005	-	-	-	-	-	-
49.	Octacosane	-	-	-	5±0.091	-	-	-
50.	Undecane	1.73±0.041	-	-	-	-	-	-
51.	Decane	3.86±0.020	-	-	-	-	-	-
52.	Cis-1-methyl-3-n-	0.19±0.003	-	-	-	-	-	-
53.	Heptane	-	0.16±0.0004	-	-	0.09±0.001	-	-
54.	4-Trifluoroacetoxyoctane	-	0.2±0.001	-	-	0.09±0.001	-	-
55.	Octadecane	-	3.8±0.109	-	-	-	-	-
Total Hydrocarbons		6.57	5.5	0.59	5.18	0.25	3.6	0
Esters								
56.	Glycidyl palmitate	1.1±0.029	-	-	-	-	-	-
57.	Methyl ester	2.81±0.022	1.58±0.028	-	-	1.03±0.20	-	-
58.	Pentyl ester	-	-	-	-	-	-	2.34±0.062
59.	Dineopentyl ester	-	0.09±0.001	-	-	-	0.12±0.002	-
60.	5-hexenyl ester	-	-	-	1.32±0.037	-	-	-
61.	1-cyclopentylethyl ester	0.75±0.012	0.15±0.001	-	-	-	0.31±0.001	-
62.	2-pentadecyl ester	-	-	-	3.8±0.020	-	-	-
63.	Dodecyl ester	0.15±0.001	-	-	-	-	-	-
64.	2-methoxyethyl ester	-	0.11±0.002	-	-	-	-	-
65.	Hexadecyl ester	0.32±0.008	-	-	-	-	-	-
66.	3-hexenyl ester	0.26±0.007	-	-	-	-	-	0.46±0.010
67.	Octadecyl 2-propyl ester	-	1.22±0.014	-	-	-	-	-
68.	2-hydroxy-1-(hydroxymethyl)ethyl ester	-	-	-	3.72±0.032	1.32±0.009	1.28±0.015	-
69.	(E)-But-2-en-1-yl 2-methylbutanoate		0.14±0.002	-	-	-	-	0.11±0.001
Total Esters		5.39	3.29	0	8.84	2.35	1.71	2.91
Fatty Acids								
70.	n-Hexadecanoic acid	12.65±0.022	15.42±0.181	20.36±0.512	13.46±0.109	19.45±0.344	13.47±0.174	-
71.	Oleic Acid	10.2±0.072	14.18±0.434	-	-	-	36.92±1.022	-
72.	Butyric acid	-	0.10±0.001	-	-	-	-	-
73.	linoleic acid	-	14.18±0.115	-	-	-	-	-
74.	Heptacosanoic acid	0.24±0.006	-	-	-	-	-	-

Cont...

Table 2. Volatile profiles of different food bait attractant

S. No.	Compounds	Peak area % (Mean ± SE)						
		Wheat	Sorghum	Pearl millet	Groundnut	Maize	Rice	Rice bran
75.	2-Methylvaleric acid	-	-	1.66±0.046	-	-	-	-
76.	Hexanoic acid	-	-	0.57±0.001	-	-	-	-
77.	Valproic Acid	-	-	-	0.51±0.008	-	-	-
78.	Octanoic acid	-	0.34±0.004	-	-	-	-	-
79.	Pentadecanoic acid	-	-	-	0.88±0.014	-	-	-
80.	Butanoic acid	0.26±0.006	0.13±0.003	-	-	-	0.15±0.003	0.07±0.0009
81.	Tetradecanoic acid	1.81±0.042	1.2±0.032	1.22±0.012	0.79±0.011	0.91±0.003	3.33±0.058	1.29±0.022
82.	Tridecanoic acid	1.36±0.019	-	0.7±0.002	-	-	-	-
83.	cis-Vaccenic acid	-	-	-	-	-	-	59.06±0.174
84.	Octadecanoic acid	2.31±0.001	-	3.11±0.054	-	3.07±0.014	3.35±0.057	7.2±0.097
85.	Undecanoic acid, 10-bromo-	-	-	-	1.47±0.009	0.26±0.005	-	-
86.	2-Octenoic acid	-	-	-	-	1.29±0.037	-	0.30±0.004
87.	9-Octadecenoic acid	-	20.5±0.559	-	-	15.11±0.222	-	-
88.	Decanoic acid	-	0.69±0.003	-	-	-	-	-
89.	Tridecanoic acid	-	-	0.70±0.017	-	-	-	-
90.	11,14-Eicosadienoic acid	-	-	1.43±0.026	1.14±0.004	-	-	-
91.	9-Oxononanoic acid	-	-	-	0.69±0.002	-	-	0.96±0.005
92.	9,12-Octadecadienoic acid	13.65±0.369	-	18.35±0.075	-	-	-	-
Total fatty acids		42.48	66.4	48.1	18.94	40.09	57.22	68.88
Ethers								
93.	Chloromethyl octyl ether	-	-	-	1.23±0.028	-	-	-
94.	Allyl n-octyl ether	0.79±0.012	-	-	-	-	-	-
95.	Ethyl-1-propenyl ether	-	-	-	-	0.16±0.002	-	-
Total Ethers		0.79	0	0	1.23	0.16	0	0
Nitrogenous Compounds								
96.	o-Acetyl-L-serine	-	-	-	0.51±0.011	-	-	-
97.	Imidazole, 2- [[(. beta. -carboxy) propionyl] amine	0.27±0.006	-	-	0.29±0.003	-	-	-
98.	Hex-5-enylamine	0.45±0.006	-	-	-	-	-	-
99.	Isoxazole, 3,5-dimethyl-	0.27±0.003	-	-	-	-	-	-
100.	Pyrazol-4-amine, 1,5-dimethyl-	-	0.73±0.017	-	-	-	-	-
Total nitrogenous compounds		0.99	0.73	0	0.8	0	0	0
Pyrans								
101.	Tetra hydropyran	0.85±0.020	-	-	-	0.11±0.002	-	-
102.	6-(3-Methyl) butoxytetrahydro-2H-pyran	-	0.11±0.0002	0.23±0.005	-	-	-	-
103.	2H-Pyran,2-[(5-chloropentyl)oxy] tetrahydro-	-	-	0.17±0.003	-	-	-	-
104.	2H-Pyran, 2-(3-butynyloxy) tetrahydro-	0.34±0.003	-	-	-	-	-	-
Total Pyrans		1.19	0.11	0.4	0	0.11	0	0
Others								
105.	2,5-Dimethyl-1-pyrroline	0.21±0.001	-	0.22±0.004	-	-	-	-
106.	(S)-(+)-1-(2-Pyrrolidinylmethyl)-pyrrolidine	-	1.76±0.022	-	-	-	-	-
107.	1,4-Bis(tri methylsilyl)-1,3-butadiyne	2.12±0.027	-	-	-	-	-	-
108.	2-Pentyne, 5-methoxy-	0.20±0.003	-	0.22±0.004	-	-	-	-
109.	7,9-Di-tert-butyl-1-oxaspiro (4,5) deca-6,9-dien	4.18±0.061	2.64±0.015	2.29±0.006	3.98±0.063	1.96±0.040	2.56±0.004	0.75±0.002
110.	Furan, tetrahydro-2,5-dimethyl-	-	-	0.36±0.004	-	-	-	-
111.	Digitoxose	-	-	-	-	0.18±0.003	-	-
112.	Oxalic acid	-	0.21±0.006	0.17±0.003	-	-	-	0.12±0.001
113.	Propionic acid	-	0.12±0.001	0.23±0.002	-	-	-	
114.	Phenol, 2-(1,1-dimethylethyl)-4-(1,1,3,3-tetra	0.30±0.001	-	-	-	-	-	-
Total others compounds		7.01	4.73	3.49	3.98	2.14	2.56	0.87

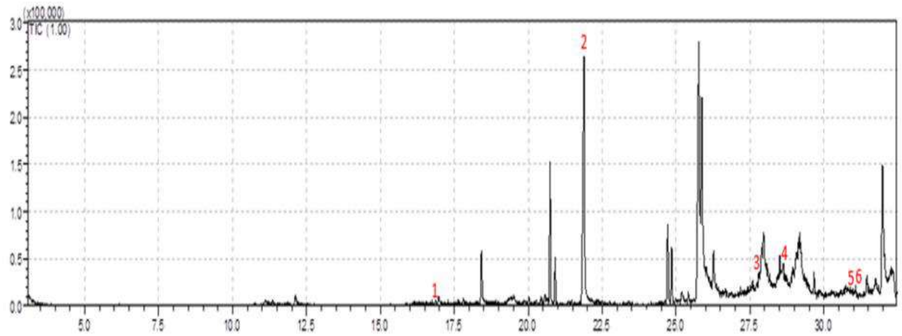

Fig. 1. Chromatogram of methanolic extract of wheat
1. Nonane, 2. n- Hexadecanoic acid, 3. Undecane, 4. 3-octen-1-ol, 5. Pentanal, 6. 1- Butanol
X axis – Retention time; Y axis – Intensity

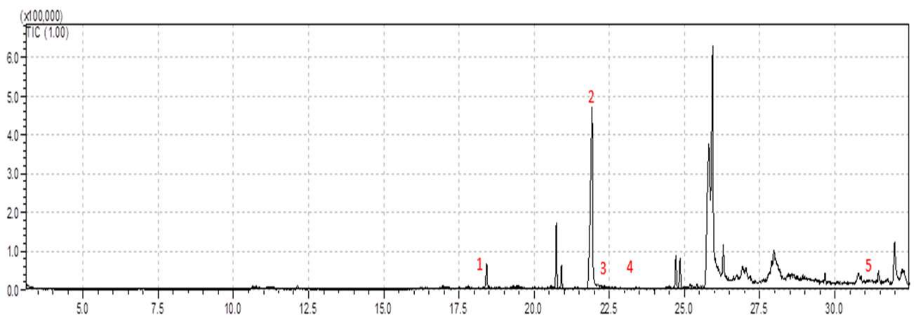

Fig. 2. Chromatogram of methanolic extract of sorghum
1. Propionic acid, 2. n- Hexadecanoic acid, 3. Butyric acid, 4. 3-Hexanol, 5. 7-octen-1-ol
X axis – Retention time; Y axis – Intensity

Table 3. Volatile compounds as insect attractants

Compounds	Peak area (%)						
	Wheat	Sorghum	Pearl millet	Groundnut	Maize	Rice	Rice bran
3-Hexanol	-	0.09±0.0008	-	0.18±0.003	-	-	0.34±0.003
1-Butanol	0.25±0.004	-	-	-	-	-	-
3-Octen-1-ol	0.24±0.006			-	-	-	-
7-Octen-4-one	-	0.12±0.0003	0.26±0.002	-	-	-	0.14±0.004
1-Octanal	-	-	0.78±0.005	-	-	-	-
Pentanal	0.32±0.0005	-	-	-	-	-	-
Hexanal	-	-	0.58±0.014	-	-	-	-
Butanal	-	-	0.24±0.001	-	0.14±0.001	-	-
Butyric acid	-	0.10±0.001	-	-	-	-	-
Nonanal	-	-	1.55±0.008	-	-	-	-
Nonane	0.3±0.005	-	-	-	-	-	-
Undecane	1.73±0.029	-	0.73±0.009	-	-	-	-

Table 4. Volatile compounds as insect repellent

Compounds	Peak area (%)						
	Wheat	Sorghum	Pearl millet	Groundnut	Maize	Rice	Rice bran
n-Hexadecanoic acid	12.65±0.022	15.42±0.181	20.36±0.512	13.46±0.109	19.45±0.344	13.47±0.174	-
Pentadecanoic acid	-	-	-	0.88±0.014	-	-	-
cis-Vaccenic acid	-	-	-	-	-	-	59.06±0.696
Propionic acid	-	0.12±0.001	0.23±0.002	-	-	-	-

surinamensis was due to some odour produced by pearl millet flour followed by wheat flour (Fig. 3). *T. confusum* and *S. oryzae* responses to plant extracts and pheromones were examined by Athanasius et al., (2006), where traps with baits like oil and seeds are more attractive than traps without bait.

T. castaneum female responded effectively towards common fungal semiochemicals such as 2-octanol, octan-3-ol, and 3-octanone. Earlier scientist reported that plant volatiles elicited responses in *R. dominica*, whereas wheat seeds elicited the strongest responses (Thakeow et al 2008; Holighaus et al 2014; Edde and Phillips 2006a). Adult granary weevils, *S. granarius* can respond behaviourally to a wide spectrum of cereal volatiles, and their responses can vary depending on concentration (Germinara et al 2008), which are related to present study. For *O. surinamensis* and *O. mercator*, several doses of benzaldehyde and aliphatic aldehyde were evaluated, and an estimated 10 aliphatic and benzaldehyde showed positive reaction in both species. Adults of *Callosobruchus sinensis* showed preference behaviour towards benzaldehyde and 2-hexanal (Wang et al 2020). *Callosobruchus maculatus* attracted to 3-octanol, linalool oxide, 3-octanone, nonanal and 1-octanol (Adhikary et al 2015). The attractive compounds like 3-hexanol and butanal present in groundnut and maize respectively (Fig. 4 & 5), 3-Hexanol and 7-octen-4-one present in rice bran whereas attractive compounds are absent but repellent compound cis- Vaccenic acid present in rice (Fig. 6). Ukeh and Umoetok (2011) reported that (R)-linalool and (S)-2-heptanol were stronger repellent volatile compounds than the others. Linalool showed good repellent activity against *T. castaneum*. Propionic acid, n-Hexadecanoic acid, cis-Vaccenic acid and pentadecanoic acid were acted as repellent. In our current study, cis-Vaccenic acid was present in rice bran (59.06%) (Fig. 7) and attraction per cent was very low towards this bait, whereas, n-Hexadecanoic acid was present in a lower amount in wheat (12.65%), which exhibited very high attraction per cent in wheat compared to others. Propionic acid absents in wheat, this is also reason wheat flour attracting more numbers of insects compared to other flours. Germinara et al (2007) reported that *Sitophilus oryzae* and *S. granarius* showed repellent effects towards propionic acid. Appalasamy et al (2021) observed that octadecanoic acid, pentadecanoic acid and cis- Vaccenic acid acted as repellent and insecticidal activity against termites, *Macrotermes carbonarius* and cockroaches, *Periplaneta americana,* which are comparable with our investigation. Sathiyaseelan et al (2022) reported that wheat, sorghum and pearl millet flour baits were tested and verified using four-arm

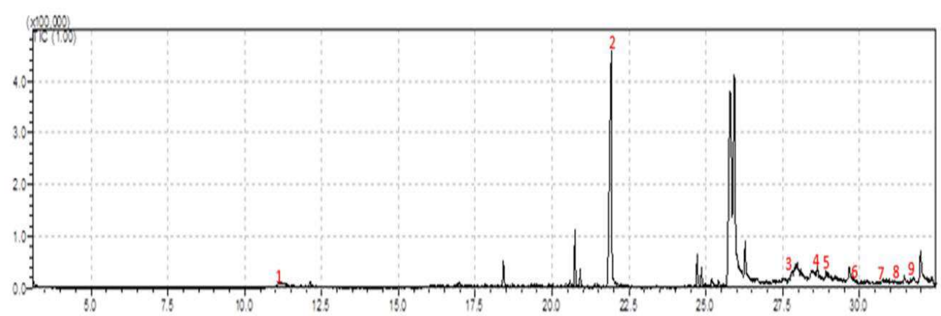

Fig. 3. Chromatogram of methanolic extract of pearl millet
1. Propionic acid, 2. n- Hexadecanoic acid, 3. Nonanal, 4. Nonane, 5. Hexanal, 6. 1-octanal, 7. Butanal, 8. 7-octen-4-one, 9. Hexanoic acid
X axis – Retention time; Y axis – Intensity

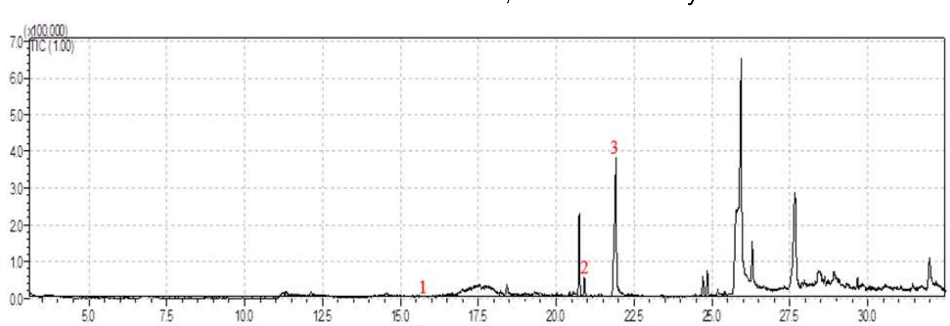

Fig. 4. Chromatogram of methanolic extract of groundnut
1. 3- Hexanol, 2. Pentadecanoic acid, 3. n- Hexadecanoic acid
X axis – Retention time; Y axis – Intensity

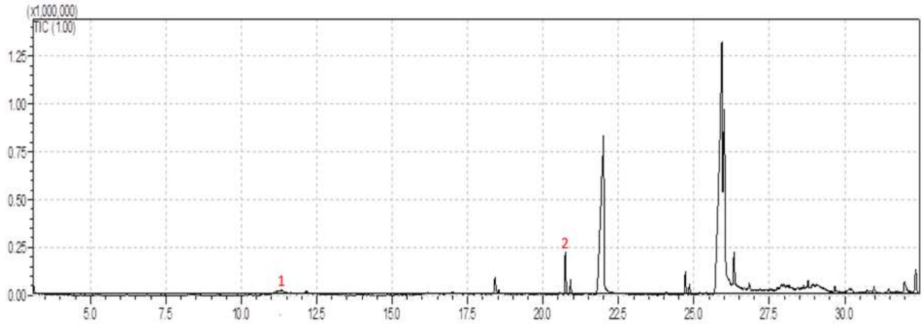

Fig. 5. Chromatogram of methanolic extract of corn
1. Butanal, 2. n- Hexadecanoic acid
X axis – Retention time; Y axis – Intensity

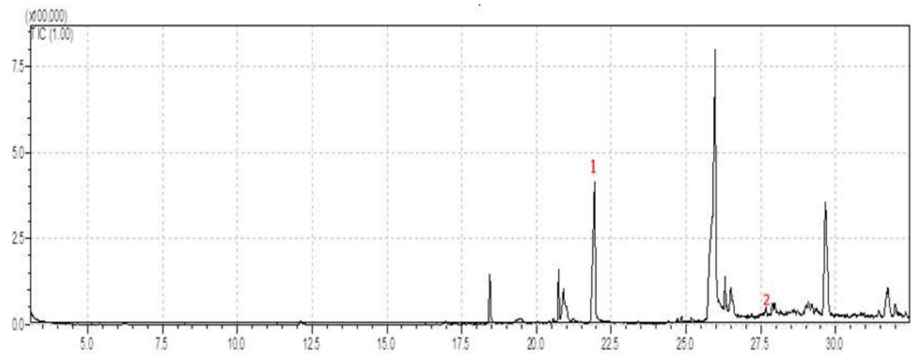

Fig. 6. Chromatogram of methanolic extract of rice
1. n- Hexadecanoic acid, 2. 3- Hexanol
X axis – Retention time; Y axis – Intensity

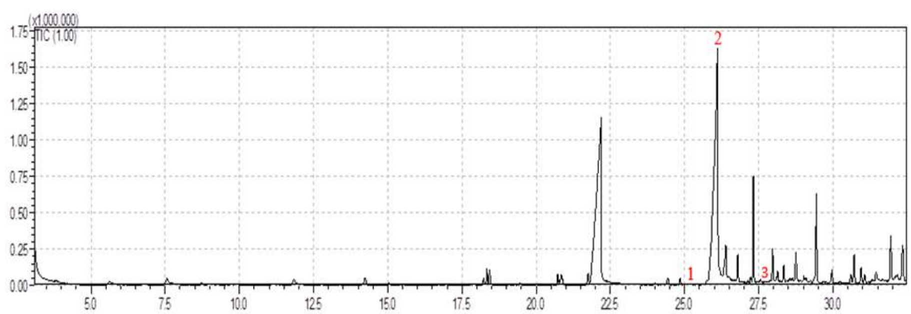

Fig. 7. Chromatogram of methanolic extract of rice bran
1. 7-octen-4-one, 2. Cis- Vaccenic acid, 3. 3- Hexanol
X axis – Retention time; Y axis – Intensity

olfactometer and the highest orientation was found in the arm containing wheat flour by attracting *S. oryzae, Triboliumi* sp. and *R. dominica* of 43.19,39.61 and 37.41% respectively which possessed nonane, undecane, 3-octen-1-ol, butanal and pentanal volatile compounds.

CONCLUSION

The attraction efficiency of different food baits to various storage insect pests from this present study emphasized that these attractants can be used to develop a multi-species lure for the control of stored pests economically and eco-friendly and thus the effective bait such as wheat flour, sorghum flour/cracked sorghum and pearl millet flour can be further exploited for monitoring and mass trapping of insect pests in rice godowns.

AUTHOR CONTRIBUTION

The study was conceptualised and designed by J. Jayaraj and M. Shanthi. M. Sathiyaseelan carried out the experiments and prepared the manuscript. K. Sujatha

assisted with the storage grain sample collection and data analysis. The article was read and approved by all the authors.

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