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OPTIMAL MECHANICAL EXCLUSION DEVICES FOR MANAGEMENT OF KHAPRA BEETLE IN STORED WHEAT

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ABSTRACT

The effect of mechanical exclusion devices and its number in combination viz. probe trap (A; 1-3), two-in-one trap with 3 mm perforations (B; 1-5) and two-in-one trap with 2 mm perforations (C; 1-3) were investigated to test the efficiency of these traps for trapping larvae and adults of khapra beetle *Trogoderma granarium* Everts. Colour change and weight loss (%) happening in wheat stored in bins of 50 kg capacity for six months were used as the criteria. The experiments were planned using a three-factor-three-level Box and Behnken design of response surface methodology and were optimized for maximum trapping, with minimum change in colour and weight loss. Analysis of variance (ANOVA) revealed significantly ($p \leq 0.05$) higher effects of quantity (number) of two in one trap with 3 mm perforations followed by two in one trap with 2 mm perforation on total trapping efficiency. Colour change and weight loss in stored wheat exhibited a negative relationship with trap capture. Among the process parameters studied, the probe trap and its number in experimental combination demonstrated a significantly lower effect on the response variables. The optimal combinations of mechanical exclusion process parameters obtained by numerical optimization technique for trapping larvae and adults were 3:4:3 and 2:5:3 (probe trap: two in one model trap 3 mm: two in one model trap 2 mm) with desirability of 0.61 and 0.63, respectively.

Key words: *Trogoderma granarium*, mechanical exclusion, combinations, probe trap, two-in-one traps, perforations, trap capture, numerical optimization, colour change, weight loss

The khapra beetle *Trogoderma granarium* Everts (Coleoptera: Dermestidae), is one of the most noxious and quarantine insect-pest of food grains and other stored food products (Athanassiou et al., 2019). It is considered one of the 100 worst invasive species in the world. Infestation caused by khapra beetle are difficult to control because these survive without food for long periods and also as these prefer dry conditions and have resistance to many insecticides (Ali et al., 2012). Therefore, it is necessary to evaluate alternate strategies against, one of them is use of mechanical exclusion devices which has been developed by the Tamil Nadu Agricultural University (TNAU) (Mohan et al., 2004). Mechanical exclusion devices viz. probe trap and two-in-one trap have significantly reduced the damage in wheat and pulses by trapping *Sitophilus granarius* (L.) and bruchids, respectively (Debebe et al., 2008). There are probe pit fall trap for adults of *Cryptolestes ferrugineus* (Stephens) in wheat filled containers (Mohan et al., 2008), TNAU stack probe trap for *Lasioderma serricorne* (F.) in turmeric, TNAU two-in-one trap for bruchids in pulses are well documented (Subramanyam and Harein, 1990; Debebe et al., 2008; Rajesh et al., 2015), probe trap and two-in-one trap for *T. granarium* in stored wheat and rice (Anonymous, 2017, 2018a). But the number of these traps needs to be optimised for their use in wheat stored in bulk in stored bins. Keeping in view, the present study was planned to optimize the type and number of mechanical exclusion devices in combination against management of *T. granarium* in stored wheat by using response surface methodology (RSM) which is an effective statistical technique for optimizing complex processes (Yagci and Gogus, 2008; Alam et al., 2011).

MATERIALS AND METHODS

In order to assess the effect of mechanical exclusion devices and to optimize its type and number against khapra beetle in stored wheat, present investigations were conducted during the year 2019-20 and 2020-21 in the Department of Processing and Food Engineering, Punjab Agricultural University (PAU), Ludhiana. For experimentation, the wheat grains were procured from the Research Farm of Department of Agronomy, PAU, Ludhiana. The mixed age populations of *T. granarium* were collected from different locations of Distt. Ludhiana, Punjab. The wheat grains used for rearing *T. granarium* were disinfested at 60ºC for one hour so as to make them free from any other insect infestation (Mookherjee et al.,1968). Later, these wheat grains were kept in jars having 1 kg capacity and were artificially infested with the larvae of *T. granarium* to get the pure culture. These jars were placed in BOD incubators maintained at 29±2 ºC and 70±5% RH for the multiplication of *T. granarium*. For long term storage, wheat grains were disinfested as per recommended package of practices (Anonymous 2018b) and then filled in 15 bins of 50 kg capacity. These wheat grains were infested with 20 pairs of *T. granarium* which showed good movement, then left it for 30 days for its multiplication.

The mechanical exclusion devices viz. probe trap, two-in-one trap with 3mm and 2mm perforations selected for the study were procured from Tamil Nadu Agricultural University (TNAU) as given in Fig. 1 a-c. Response surface methodology (RSM) was adopted in the design of experimental combinations (Altan et al., 2008; Yagci and Gogus, 2008) with an advantage of reduced number of experimental runs needed to provide sufficient information for statistically acceptable results. The independent variables with three different levels viz. -1, 0 and +1 which formed a total of 15 combinations (Giles et al., 2004) which included three replicates of the centre point each sighed the coded value 0. Response variables were larvae and adult trapped, colour change and weight loss. The data on number of trapped larvae/adults of *T. granarium* were recorded by calculating the total mean trapping efficiency of larvae/adults (TMTE L/A) and the proportion of larvae/adults trapped in different traps. Thus, to calculate total mean trapping efficiency of larvae/adults trapped, cumulative number of larvae/adults trapped by different traps in each experimental combination were divided by total number of larvae/adults present. While, to calculate the proportion of larvae/adults trapped by different traps, the cumulative number of larvae/adults trapped by different traps in each experimental combination is multiplied by total mean efficiency of larvae/adults and then divided by total number of larvae/adults present.

Colour change was measured by using Colour Reader CR-10 (Konica Minolta Sensing Inc.) with the equation given by Gnanasekharan et al. (1992) and weight loss was calculated using the count and weight method given by Adams and Schulten (1978) for each experimental combination were recorded at regular interval of 15 days for a period of 6 months. The regression coefficients were estimated through least square method. The adequacy of fitted model was tested through the analysis of variance showing lack of fit and coefficient of correlation (R^2). The values of various responses were related to the coded variables by a second degree polynomial using the equation- $Y= b_0+ b_1x_1 + b_2x_2 + b_{12}x_1x_2+ b_{13}x_1x_3 + b_{23}x_2x_3 + b_{11}x_{12} + b_{22}x_{22} + b_{33}x_{32.}$ Optimization of mechanical exclusion devices in different combinations to trap maximum test insect were carried out using the Box Behnken design of response surface methodology (Design-Expert software version 8.0.3.1, Stat-Ease Inc., Minneapolis, U.S.A) (Box and Behnken, 1960) with the target of finding the levels of independent variables viz. number and type of traps based on the responses of maximum trapping of insect (adults and larvae) and minimum change in colour and weight loss.

RESULTS AND DISCUSSION

The results related to application of different traps in different combinations against *T. granarium* in wheat showed that the mean maximum trapping efficiency recorded in T_2 (53.67) for larvae (A: B: C; 12.66, 63.0 and 24.24) and (66.94) for adults (A: B: C; 6.94, 75.61 and 17.46) when the total number of 8 traps were placed having combination of 1:5:2. While, minimum trapping efficiency was found in treatment T_4 (43.18) for larvae (A:B:C; 52.28, 19.39 and 28.33 proportion of total) and (53.67) for adults (A:B:C; 43.85, 18.64 and 37.52) when a total number of 6 traps were placed having combination of 3:1:2 (Table 1). The results showed that the two in one trap having 3 mm perforation was more effective. The efficiency of traps was greatly influenced by the number and type of traps, irrespective of their combinations. Present resutls corroborate with those of Rajesh et al.(2015) who recorded high frequency of detection of *Lasioderma serricorne* with higher

Fig. 1a. Probe trap b. Two in one trap (3 mm) c. Two in one trap (2 mm)

Table 1. Effect of different traps and their combinations for trapping *T. granarium* in wheat

Treat-ments	Combination of different traps A:B:C	Larvae trapped				Adults trapped				Colour change*	Weight loss* (%)
		Total mean efficiency* (%)	Proportion of total			Total mean efficiency* (%)	Proportion of total				
			A	B	C		A	B	C		
T_1	3:3:1	48.50	42.69	43.31	14.00	57.78	45.67	42.32	12.02	2.71	8.34
T_2	1:5:2	56.05	12.66	63.00	24.34	66.94	6.94	75.61	17.46	1.34	4.94
T_3	3:3:3	48.49	34.45	34.66	30.89	59.23	32.99	35.76	31.24	1.26	4.63
T_4	3:1:2	43.18	52.28	19.39	28.33	53.67	43.85	18.64	37.52	2.42	7.82
T_5	1:3:1	54.58	24.80	50.20	25.00	64.89	25.91	53.23	20.86	2.59	9.41
T_6	1:3:3	52.57	15.46	42.54	42.00	64.72	14.15	46.13	39.72	2.63	8.01
T_7	2:1:1	44.55	52.99	20.01	27.00	54.42	56.98	23.48	19.54	2.73	10.56
T_8	2:3:2	50.53	26.07	42.82	31.11	61.25	30.38	46.92	22.70	2.38	9.32
T_9	1:1:2	48.13	29.96	22.16	47.88	60.50	27.40	31.36	41.24	2.81	11.24
T_{10}	2:1:3	45.55	33.24	12.54	54.22	57.72	32.49	24.10	43.41	1.96	7.03
T_{11}	2:3:2	50.54	25.10	45.45	29.45	61.25	32.45	48.51	19.04	2.41	8.45
T_{12}	2:5:1	54.27	21.29	67.07	11.64	63.90	22.31	71.25	6.44	1.49	5.01
T_{13}	2:5:3	52.93	23.24	46.76	30.00	63.98	17.39	55.29	27.31	1.17	4.32
T_{14}	2:3:2	50.53	24.30	42.49	33.21	61.25	28.54	43.50	27.96	2.89	8.89
T_{15}	3:5:2	51.50	23.24	52.82	23.94	61.55	27.50	52.84	19.66	1.15	3.54

Where A-probe trap, B- Two in one trap with 3 mm perforations, C-Two in one trap with 2 mm perforations; * based on 6 month storage

number of traps, whereas the number of insect catches in wheat bag stack increased with number of traps (Hategekimana et al., 2013).

The regression equation of the fitted quadratic model for TMTEL, TMTEA are 47.57-4.46 A+ 4.81 B+0.29 C+0.05 AB +0.50 AC -0.29 BC+0.21 A^2-0.37 B^2-0.18 C^2 and 59.01-6.08 A+ 4.19 B + 1.99 C+0.18 AB +0.41 AC -0.40 BC+0.41 A^2-0.31 B^2-0.25 C^2, respectively. While, the regression equation of the fitted quadratic model for trapping larvae/ adults by different traps i.e. by probe trap (A) for larvae is 67.09 +10.49 A- 13.78 B-27.81 C-1.47 AB +0.28 AC +2.71 BC+0.52 A^2 +0.96 B^2 +3.67 C^2 and for adult is 53.38 + 21.66 A- 10.27 B -23.80 C+ 0.51 AB -0.23 AC +2.45 BC-3.32 A^2 -0.18 B^2 +2.55 C^2; by two in one trap (3mm) (B) for larvae is 0.94-3.87 A+ 22.53 B +7.11 C-0.93 AB -0.25 AC -1.60 BC+ 0.92 A^2 -1.29 B^2 -1.82 C^2 and for adult is 38.42-19.79 A- 8.12 B + 15.43 C+ 0.74 AB +0.09 AC -0.38 BC+3.76 A^2 +0.49 B^2 -1.03 C^2; by two in one trap (2mm) (C) for larvae is 31.97- 6.63 A- 8.75 B + 20.69 C+ 2.39 AB -0.027 AC -1.11 BC-1.44 A^2 +0.33 B^2 -1.85 C^2 and for adult is 8.16-1.86 A+18.39 B + 8.39 C- 1.26 AB + 0.14AC -2.07 BC-0.43 A^2 -0.32 B^2 -1.52 C^2. These regression models were highly significant ($p< 0.0001$, $R^2> 0.9436$) for all the tested parameters, with none showing lack of fit ($p > 0.01$), indicating that all the second-order polynomial models correlated well with the experimental data. It is apparent that linear terms of probe trap and two in one trap with 3 mm perforations ($p<0.01$) had significant effect on total mean efficiency of larvae trapped whereas, all the three traps witnessed significant effect on total mean efficiency of adults trapped (Table 2). Total mean efficiency for both larvae and adults trapped were highly influenced by number of traps i.e. two in one trap with 3 mm perforation followed by 2 mm perforation in comparison to probe trap recording higher total mean efficiency of larvae/ adults trapped for the experimental combination with more number of type B and C traps (Table 3). Thus, based on trapping efficiency, these traps can also be used as early warning tool as suggested by Duarte et al. (2021).

Colour change of wheat grains over a period of six months ranged from 1.15 (T_{15}; 3:5:2) to 2.81 (T_9; 1:1:2), irrespective of experimental combination witnessing positive relationship with type and number of traps installed. The quadratic model fitted for colour change was found to be significant with non-significant lack of fit (Table 3). The regression equation of the fitted quadratic model for colour change is 1.26 + 0.78 A + 0.36 B + 0.97 C+0.025 AB - 0.37 AC + 0.056 BC-0.085 A^2 - 0.136 B^2 -0.177 C^2 ; R^2 for the model fitted was found to be 0.95 for stored wheat grain after six month of storage. It is apparent that linear terms of type of traps (A, B & C) had significant effect ($p<0.01$) on colour change witnessing higher effect of two in one trap with 3mm perforations irrespective of the experimental combinations (Table 1, 2). Among the quadratic and

Table 2. ANOVA table of response surface quadratic model of use of TNAU traps for trapping *T. granarium* in wheat

Source	F-value									
	Larvae trapped				Adults trapped				Colour change	Weight loss
	Total mean efficiency (%)	Proportion of total			Total mean efficiency (%)	Proportion of total				
		A	B	C		A	B	C		
Model	108.74*	176.38*	69.43*	22.89*	119.30*	37.89*	53.25*	9.29*	10.95*	38.07*
A	237.51*	487.04*	16.99*	26.49*	406.85*	111.48*	52.00*	2.30	7.08**	46.01*
B	683.04*	775.28*	535.04*	68.26*	596.77*	146.17*	399.81*	32.57*	48.09*	190.03*
C	3.42	125.20*	42.99*	94.58*	14.34*	56.55*	13.57*	44.52*	13.21*	46.60*
AB	0.20	27.57*	2.43	10.98**	2.74	0.66	3.26	0.45	0.17	4.37
AC	4.92	0.24	0.043	3.62E-004	3.47	0.03	9.41E-003	1.68E-003	9.38**	5.71
BC	6.73**	94.20*	7.29**	2.35	13.70**	14.94*	8.87**	0.12	0.86	8.64**
A^2	0.82	0.80	0.55	0.92	3.24	6.36**	0.090	2.71	0.45	5.09
B^2	40.70*	44.00*	17.41*	0.75	30.12*	0.29	0.76	0.75	18.54*	32.55*
C^2	0.57	39.88*	2.18	1.51	1.24	3.74	1.10	0.21	1.97	8.25**
Lack of Fit	0.64	1.98	2.91	3.25	4.38	2.13	1.30	0.93	0.54	1.39
R^2	0.99	0.99	0.99	0.98	0.99	0.99	0.99	0.94	0.95	0.99
C V (%)	0.90	3.80	5.89	9.57	0.71	8.54	6.24	17.05	11.42	6.50

Where A-probe trap, B- Two in one trap with 3 mm perforations, C-Two in one trap with 2 mm perforations, *significant at 1% level and ** significant at 5% level

product terms, the product term (AC) and quadratic term (B^2) showed significant effect ($p<0.01$). Among the three traps, higher effectiveness of two in one trap with 3 mm perforation followed by 2 mm perforation in comparison to probe trap resulted in lesser colour change for the experimental combination with more number of type B and C traps (Table 1). The trapping efficiency was observed to be directly affecting the colour change with higher values in the samples with lower trapping efficiency or higher population of *T. granarium*. These results derive support from Myers and Hagstrum (2012) that presence of *T. granarium* causes contamination of grains with their body parts and cast skins leads to change in colour of grains.

The total weight loss ranged from 3.54 (T_{15}; 3:5:2) to 11.24 (T_9; 1:1:2); the quadratic model fitted for weight loss was significant (p=0.01; F-38.07; R^{2} - 0.9856 (Table 2). The model clearly depicts the negative effect of trap A and B whereas positive effect of trap C on weight loss. Previous studies also reported that weight loss caused by *T. granarium* was 5-30% and up to 73% in extreme cases (Anonymous, 2005). It is apparent that linear terms of type of traps (A, B & C) had significant effect ($p<0.01$) on weight loss with two in one trap- 3 mm perforations whereas the probe trap and two in one trap with 2 mm perforations were at par, irrespective of the experimental combinations (Table 2). The regression equation of the fitted quadratic model is $0.02 – 1.51 A- 0.24 B + 1.81 C+0.25 AB -0.58 AC +0.36 BC-0.57 A^2 -0.36 B^2 -0.72 C^2$. The product term (BC) and quadratic terms (B^2 and C^2) showed significant effect. Among the three traps, higher effectiveness of two in one trap with 3 mm perforation followed by 2mm perforation in comparison to probe trap was resulting in lower weight loss for the experimental combinations with more number of type B and C traps (Table 1). Further, trapping efficiency showed direct effect on weight loss as lower trapping efficiency resulted in higher weight loss. This might be due to the fact that higher population of *T. granarium* in the sample causes contamination of wheat grains resulting in powder formation causing weight loss (Demis and Yenewa, 2022). The results obtained were similar to those of Ahmedani et al. (2011).

The optimum values of number and type of different traps based on responses of trapping of larvae and adults, colour change and weight loss of wheat grains is presented in Table 3. The number and type of traps for trapping larvae and adults were optimized using numerical optimization technique for maximum trapping, and minimum change in colour and weight loss. Equal importance was given to all the parameters and responses. The zone of optimization for larval

Table 3. Optimization of mechanical exclusion devices for trapping *T. granarium* in stored wheat

Type of trap	Goal	Lower limit		Upper limit		Importance	Calculated value		Desirability	
		Larvae trapping	Adults trapping	Larvae trapping	Adults trapping		Larvae trapping	Adults trapping	Larvae trapping	Adults trapping
Probe trap	in range	1	1	3	3	3	3	2		
Two-in-one trap (3 mm perforations)	in range	1	1	5	5	3	4	5		
Two-in-one trap (2 mm perforations)	in range	1	1	3	3	3	3	3	0.61	0.63
		Response					Predicted value			
Total mean trapping efficiency (%)	Maximize	43.18	53.67	56.05	66.94	3	50.22	63.59		
Probe trapping efficiency (Proportion of total)	Maximize	12.66	6.94	52.99	56.98	3	30.62	19.42		
Two-in-one trap (3 mm perforations) trapping efficiency (Proportion of total)	Maximize	12.54	18.64	67.07	75.61	3	39.15	55.64		
Two-in-one trap (2mm perforations) trapping efficiency (Proportion of total)	Maximize	11.64	6.44	54.22	43.41	3	30.23	24.94		
Colour change	Minimize	1.15	1.15	2.89	2.89	3	1.07	1.05		
Weight loss (%)	Minimize	3.54	3.54	11.24	11.24	3	3.88	3.95		

trapping of *T. granarium* depicts that the number and type of traps; probe trap, two-in- one trap with 3 mm perforations and two- in- one trap with 2mm perforations were 3, 4 and 3, respectively recording optimized predicted values i.e. 50.22% total mean trapping efficiency, 1.07 of colour change and 3.88% weight loss with desirability of 0.61. For adult trapping, the optimal type and number of mechanical exclusion devices i.e. probe trap, two-in- one trap with 3 mm perforations and two- in- one trap with 2 mm perforations obtained were 2, 5 and 3, respectively. The corresponding values of responses obtained were 63.59% of total mean trapping efficiency, 1.05 of colour change and 3.95% weight loss with desirability of 0.63 (Table 3); thus, RSM was effective for optimizing mechanical exclusion devices. Numerical technique, in connection with RSM, was used to aid in identifying optimal conditions; these were experimentally verified and proved to be adequately reproducible. Thus, the mechanical exclusion devices used in the study could exploit the wandering behaviour of the insects and help in timely detection in stored produce leading to timely control.

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AUTHOR CONTRIBUTION STATEMENT

All authors equally contributed.

CONFLICT OF INTEREST

No conflict of interest.

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