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Eco-Friendly Tools for Early Detection of Insects in The Stored Wheat Grains Under Egyptian Conditions

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ABSTRACT

The quality and quantity of stored food grains may be highly reduced by insects attack. Applying protective actions can be performed by technology transfer and monitoring the stored grains for timely detection of insect attacks. Two experiments on stored wheat kernels in the warehouse and retail stores were performed using two methods of international traps across the Sharkia Governorate in 2020 for early detection and monitoring of the insects that attack the wheat storage ecosystem in Egypt. The applied technologies are related to stack probe and insect probe traps which were transferred from India to Egypt via the author. The stack probe traps were tested in the first experiment on the warehoused wheat structure and compared with spear sampling, whereas insect probe traps were applied in the second experiment on the retail stores. The detected insect species by stack probe trap in the warehoused grains were *Oryzaephilus surinamensis, Sitophilus oryzae, Tribolium castaneum*, and *Rhyzopertha dominica.* The detection frequency of *T. castaneum* achieved 98.5% using trapping and 16.3% by spear sampling within seven days before fumigation treatment. The detection frequency ratios of trapping: spear sampling were 6:1 and 5:1 for *T. castaneum* and *S. oryzae*, respectively. The insect distribution of warehoused wheat kernels indicated the traps of the top layer have the well-trapped highest population of *T. castaneum* and *R. dominica* while the bottom layer of grain stacks was dominated with *S. oryzae* and *O. surinamensis*. Concerning the second experiment, the insect probe traps have captured four insect species in the open wheat stacks of retail stores. The trapped insects were *Sitophilus oryzae, Tribolium castaneum, Rhyzopertha dominica*, and *Oryzaephilus surinamensis*. The collection unit of the insect trap was dominantly filled with *T. castaneum* and *S. oryzae*. Ultimately, the more effective eco-friendly tool to catch the insect species in the warehouse before and after fumigation was non baited stack probe trap than the spear sampling methods, and the insect probe trap was the vital detector of insects inside the open wheat stacks in the retail stores. The study demonstrated that the tested traps of India can be effectively used as physical methods and eco-friendly techniques for early detection and monitoring the stored insects without any harm to human health and the environment under Egyptian conditions through the technology transfer from abroad.

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INTRODUCTION

Wheat grain (*Triticum aestivum*) is a very vital and strategic grain crop for all Egyptian people (ElFetyany *et al.,* 2021). The total cultivated area of wheat in Egypt is going to be increased by the governmental authorities to achieve food security (FAO, 2017). Wheat grain production represents about 10% and 20% of agrarian production and agrarian imports, respectively (FAO, 2017). The cereals occupy 62.3% of calorie intake per day and wheat is considered a strategic product for the food chain in Egypt (Hafez et al., 2021). Wheat is the main food staple for the Egyptian people (Matouk *et al*., 2017). The wheat consumption per capita is about 146 kg/year (ElFetyany *et al.,* 2021). Egypt is the biggest wheat purchaser in the world, particularly from various countries such as Russia and Ukraine (ElFetyany *et al.,* 2021). It is thus understandable that wheat product is very important for Egyptians because it is directly linked to the bread that is the backbone of Egyptian food (Matouk *et al*., 2017). Egyptian food security is the major challenge due to the rapid Egyptian population (ElFetyany *et al.,* 2021). Wheat crop is facing major challenges and losses where about 45% losses may occur in the field and storage processes. Among these losses, more than 57% of losses may arise during grain storage (Wicochea-Rodríguez *et al.,* 2021). Insect pests are the major enemy of cereals in Egypt and could cause the main loss in stored food grain products (ElFetyany *et al.,* 2021). Moreover, the activities of insect pestilential in stored grain products and processing food can affect the marketability and the nutritional values of stored grains (Parfitt *et al.,* 2010; ElFetyany *et al.,* 2021). For instance, a rice weevil insect can consume about 15 mg out of 21 mg of rice kernels during storage processes (Wicochea-Rodríguez *et al.,* 2021). Commercially, this leads to loss the quality and reduces the quantity of the grain product (Mohan and Rajesh, 2016; Wicochea-Rodríguez *et al.,* 2021).

The study of movements and distributions of insect pests in the stored products are very beneficial for ecological properties and insect infestation (Wang *et al.,* 2018). The populations of insects in stored grain ecosystems are commonly examined and monitored through grain sampling or by using scientific traps (Wicochea-Rodríguez *et al.,* 2021). The sampling plans may be designed by using the derived information from insect distribution (Athanassiou *et al.,* 2016). The monitoring program may be applied to early detect and estimate insect populations in the storage structure ecosystem. Furthermore, insect densities and populations in the stored ecosystem are traditionally determined by sampling (Wang *et al.,* 2018). Probe traps could be used to detect, monitor, and determine the activities of insects in the stored grain ecosystem for a long time (Zhang *et al.,* 2020). The trapping techniques have the potential to control the insect distribution inside stored product bulks. They can give higher results in storage entomology than the traditional sampling procedures. In the traditional grain sampling methods, the processes of sieving and counting of stored-product insects are time-consuming process and laborious (Wang *et al.,* 2018). Furthermore, both the sizes of the grain sample and the unit of sampling aren't large enough to characterize the population and density of insect species in warehoused kernel bulks (Wang *et al.,* 2018). Moreover, the sampling method is a higher problematic procedure than the automatic detection tools of insects in the warehouses. The trapping frequency of *Cryptolestes ferrugineus Stephens* was significantly linked to the density and population of insects inside the warehoused kernels (Mori and Evenden, 2013). However, the trapping frequency was affected by numerous challenges such as the growth stages of insect species and their environments (Athanassiou *et al.,* 2016).

Applying corrective actions to prevent infestation of stored products by insect attack may be accomplished through early detection of stored pests and protecting the stored grain from insect infestation (Hafez *et al.,* 2021). Insect traps, visual lures, pheromone devices, probe sampling, and visual inspection are well-known methods used in grain storage establishments and commercial granaries (Banga *et al.*, 2018). The physical methods of inset detection are valuable in the diagnosis of infestation, locating the insects in the storage ecosystem for early monitoring (Papadopoulou and Buchelos, 2002; Hawkin, 2008). Traps may be used as physical methods without any harm to the environment compared to the treated grains with fumigation or other control measures (Abd El-Aziz, 2011). Severe contamination and quantitative loss of stored products may be caused in the case of any delay in pest detection and therefore pest outbreaks and heavy populations can build (Athanassiou *et al.*, 2016).

Advanced techniques and modern trapping tools in storage entomology (Fig. 1) always lead to better results in stored products (Mohan and Rajesh, 2016; Banga *et al.*, 2018). Trapping methods are considered the best detection of insects in the stored ecosystem (Fig. 1). These traps assist in reducing pesticide contamination in food commodities through time-consuming, labor-intensive, and non-baited measures (Toews *et al.*, 2005; Mohan and Rajesh, 2016). Trapping methods have higher importance in monitoring the insect infestation than other traditional methods of spear sampling or sieving (Reed *et al.*, 2001; Banga *et al.*, 2018). Grain products may be damaged, and also contaminated by the metabolic of insects and their products and body fragments (Neethirajan *et al.*, 2007; Zhang *et al.*, 2020). Insects' detection at the early period of the infestation and estimation of their density are considered the first step in developing an integrated program for effective insect control. Adults of insects can easily move in the warehoused grain structure and therefore, these mobile insects may be captured and trapped using the trap techniques (Neethirajan *et al.*, 2007; Banga *et al.*, 2018).

Besides early detection by trapping, it may be used to determine its location and degree. Pest management is targeting the location of pests in or outside the storage structure ecosystem (Rajendran, 2005). Prior investigations by Loschiavo and Atkinson (1973) were among the first scientific efforts for detecting and trapping beetles by probe trap. Trap tools are also attempted and introduced by Mohan (2007) that are considered as physically probe traps for early detection of insects in the storage ecosystem under different conditions (Mohan and Rajesh, 2016; Banga *et al.*, 2018) (Fig. 1). These traps are insect probe trap, pitfall trap, two in one model trap, indicator device, egg removal device, UV light trap, stack probe trap in the warehouse, and automatic insect removal bin (Fig. 1). An Indian patent was given for insect probe trap, pitfall trap, and stack probe as TNAU patents (Mohan, 2007; Mohan, 2010; Mohan and Rajesh, 2016; Banga *et al.*, 2018). Therefore, the spatial distribution of these traps from the top passing the middle to the bottom layers of kernel stacks in the warehouse could be a better guide for the timely control of warehoused pests (Fig. 1).

Information about the environment of storage structure and knowledge of the ecology of warehoused pests are very vital for controlling insect pests by retailers or store managers. The kernels of mature wheat spend on the plant without insect attack for only many days to a few weeks (Abd El-Aziz, 2011). Furthermore, the wheat seeds may remain numerous months to a year in the storage ecosystem before processing into food products (ElFetyany *et al.*, 2021). Insect attack for stored wheat kernels is a very serious challenge in the Egyptian ecosystem. Management of insects in stored food products by chemical pesticides or semiochemicals are very dangerous for food security and human health, and also put the environment at high risk. Therefore, this current research aimed at evaluating some used international traps in the wheat storage ecosystem in Egypt as eco-friendly techniques for storage entomology management through technology transfer from abroad (India) to Egypt. These traps were transferred from India to Egypt via the author. The traps used in the current research were stack probe trap and insect probe trap. The specific objectives of this work were (1) to early detect insect species in the warehoused stored wheat grains using the non-baited stack probe trap concerning fumigation treatment and spear sampling method and (2) to estimate insect population and density of insects in the retail stores using the insect probe trap across Zagazig city, Sharkia Governorate, Egypt. This study is considered as the first attempt to transfer this technology from abroad for storage grain management of Egyptian cereals.

Fig. 1. Eco-friendly techniques for technology transfer and integrated pest management in stored ecosystems (After Mohan and Rajesh, 2016; Banga *et al.*, 2018).

MATERIALS AND METHODS

Trap Tools Used:

Stack Probe Trap in the First Experiment:

The first experiment was conducted in 2020 using the stack probe trap in a warehouse at Zagazig city, Sharkia Governorate, Egypt. The tested warehouse and bag stack have standard criteria of 50 × 10 × 5 m and 10 × 5× 3 m (length x width by height) respectively. An Indian Patent (No. 1733/CHE/2008) was given for the stack probe trap of TNAU on 24/7/2008 (Mohan and Rajesh, 2016) as shown in Fig. (2). This trap is designed by Mohan (2010) at Tamil Nadu Agricultural University of South India (Mohan and Rajesh, 2016; Banga *et al.*, 2018). It has stainless steel that contains a major hollow tube with a 1.8 to 2.0 cm diameter and 1.8 to 2 mm of equal perforation in the upper portion. This trap has two ends, one is a closed-end, and the other is open and has a white plastic cone that is transparent and considered as a collection unit for capturing the pest insects from bag stacks in the tested warehouse (Mohan, 2010; Mohan and Rajesh, 2016; Banga *et al.*, 2018) (Figs. 1 & 2).

Insect Probe Trap in the Second Experiment:

The second experiment was done in 2020 using the insect probe trap in some retail stores at Zagazig city, Sharkia Governorate, Egypt. The insect probe trap was also designed in TNAU, India (Mohan, 2010; Mohan and Rajesh, 2016; Banga *et al.,* 2018). It comprises a top red cap, detachable cone as shown in Fig. (3). The long tube of this trap has perforations with a diameter size of two mm for allowing the air to enter and therefore the insects are attracted and then trapped and captured. A detachable cone is made of transparent white plastic at the bottom of the trap as shown in Fig. (3). The insect trap was kept in the open wheat stacks in a vertical form where the white plastic cone is inserted inside the grain stacks and the top red cap was at the level of the surface of the grains. Insects were trapped by their moving towards the holes searching for air. They are entering through the tube and may be fallen into the plastic cone and they couldn't escape. The plastic cone containing trapped insects can be detached and separated one time per week and the trapped insects can be destroyed by special treatment (Mohan, 2010; Mohan and Rajesh, 2016; Banga *et al.,* 2018) (Figs. 1 & 3).

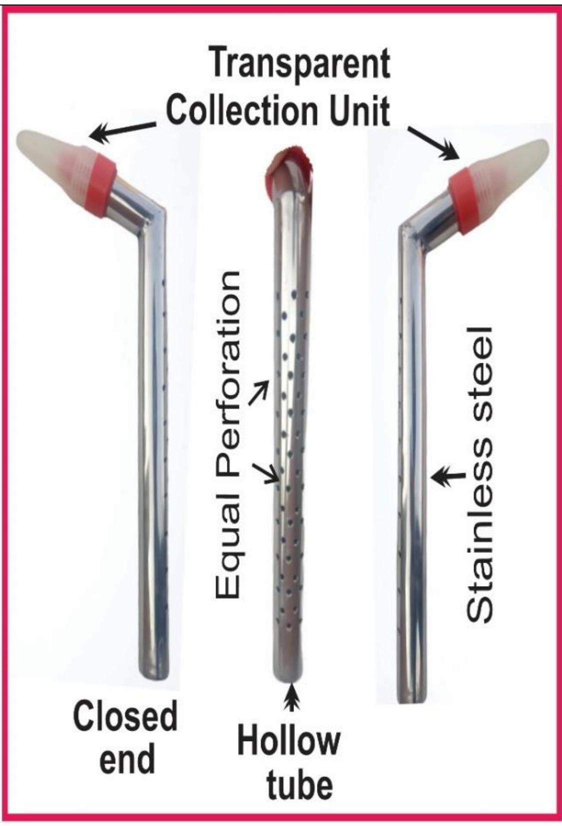

Fig. 2. Stack probe trap used in the warehouse of Sharkia Governorate, Egypt.

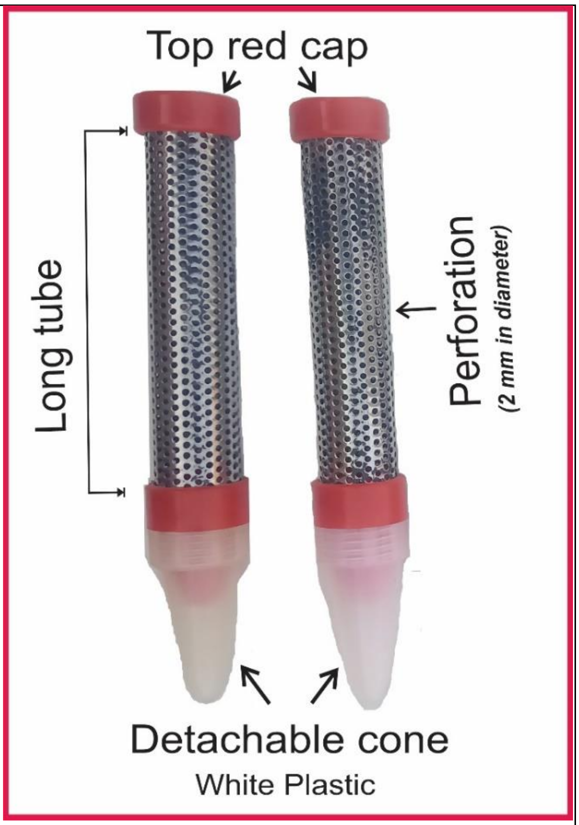

Fig. 3. Insect probe trap used in the retail stores across Zagazig City, Egypt.

Procedures of the Two Experiments:

First experiment using stack probe trap:

Eighteen stack probe traps were vertically introduced and inserted between the grain stacks over eighteen locations at the standard measures of the top, middle, and bottom bulk layers in the studied warehouse as shown in Fig. (4). The standard measures of stack layers were shown in Fig. (4). Each trapping treatment has been replicated five times. Additionally, the treatment of spear sampling was in parallel conducted at each step of trapping in the corresponding sites. Daily, the samples of tested grain were taken as one-kilogram grains from a standard wheat stack within seven days. The trapping technique is shown in Fig (4) and covered all stack sides from top passing the middle to bottom. A comparison between the insect trapping by stack probe trap method (Fig. 2) and the method of spear sampling was performed in five bag stacks in the warehouse. The trapping explanations and observations using the stack probe trap were done before fumigation treatment by seven days. The number of trapped insects was calculated daily and spear sampling was also taken daily for a week. The configuration of the traps and removal of the trapped and captured insects have followed the standard procedures given by Zhang *et al.* (2020). Removing the trapped insect adults from the white cone of the traps was done per day over the trapping period. Furthermore, the detection frequency of trapping was determined by following the methods concerning the captured insect number over the trapping period and treatments (Zhang *et al.,* 2020). The efficiency index of the tested trap was calculated based on the detection frequency and the ratio between the numerical values of trapping sites and the total number of treatments and observations (5×18=90). Regarding the fumigation treatment, the fumigation validation was made in the tested warehouse to protect the wheat grain stacks and prevent cross-infestation between wheat bulks. The fumigation with phosphine was treated at the standard rate once the wheat stocks reached the warehouse. The treated grains with phosphine were covered during the treatment period (seven days).

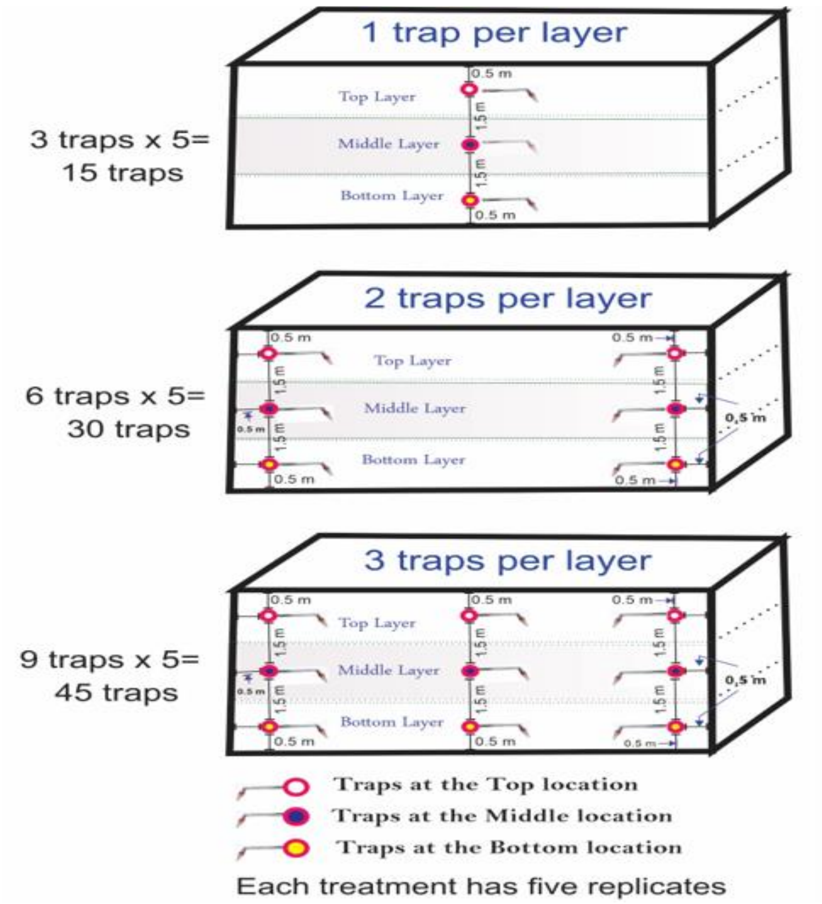

Fig. 4. The diagrammatic strategy for insect trapping treatments using stack probe trap is followed in the present research work.

Distribution of the Stack Probe Trap in Stored Wheat Grains:

The diagrammatic plan for insect trapping treatments using stack probe trap (Fig.3) across different layers of wheat grain stacks is shown in Fig. 4. The stack probe traps were put in between wheat stacks at three layers (Fig. 4). The study of the first experiment was performed in 2020 under storage conditions of the warehouse in Egypt. During the experiment, the conditions of the tested warehouse environment were the same for all treatments. Each treatment has five bag stacks and each bag was considered as a replication. The trapped insect number was counted at each stack layer. The distribution of the stack probe traps per layer (one trap/layer, two traps/layer, and three traps/layer) was done as per Fig. (4) For each layer, five replications were also done. The bottom traps were introduced at 0.5 m above the ground, the middle traps at two m from the ground, and the top trap at 3.5 m from the ground (Fig. 4). The distance between the top and middle layers was 1.5 m, and so on for other layers. Furthermore, 0.5 m was considered from the right and left of treatments as shown in Fig. (4). Furthermore, the effect of the number of stack probe traps on the caught insects was investigated at each layer of grain stacks. The total captured insects' number in a week for each layer was determined compared with the spear sampling method.

Second Experiment Using Insect Probe Trap

The insect probe traps were fixed at the midpoint of open wheat bags in some retail stores at Zagazig city during 2020. The investigations on the monitoring and detection of insects in the storage wheat bags were conducted after six months as a storage period. The insects were captured and trapped in the white cone of the insect probe trap for seven days. This collection unit was unscrewed at the end of the seventh day. The captured insect pests inside the collection unit for each trap were removed and collected daily for up to 7 days. The removed and trapped insect species from wheat bags were registered as a trapped number. The captured adults were kept in killing and preserving agents of ethyl alcohol (70%). The killed insects were separated from the glass container containing the applied agent. The trapped insects were recognized with the aid of an available hand lens and then each insect species were separated and counted.

Data Analysis:

Data of two experiments related to the trapped insects collected from tested trap techniques were processed per trap by Excel program and then were subjected to statistical analysis. Data of insect distributions were processed and transformed by log transformation before the variance analyses. SPSS software was used to implement the ANOVA analysis. The Least Significance Difference (LSD) test was carried out to identify the significant variance among the obtained mean values of trapped insects using two tested traps across two experiments.

RESULTS AND DISCUSSION

Trapping and Detection Using Stack Probe Trap:

The results of the first experiment using stack probe trap are presented in the Tables (1 & 2) and Figs. (5, 6, 7 & 8). Investigations were performed in the Egyptian warehouse to detect the insect species at the early stages of infestation and also study the efficiency of stack probe trap in early detection of wheat infestation due to insect attack. These trials were compared to spear sampling results of warehoused wheat grains. Findings of the first experimental work showed the presence of many insects that attack wheat commodity during the storage, namely *S. oryzae*, *R. dominica*, *O. surinamensis*, and *T. castaneum* (Table 1). The stack probe trap method over 18 sites has observed *T. castaneum* in 98.5 % of sites compared to 16.3 % of sites was detected by spear sampling. At the same time, stack probe trap can detect the species of *S. oryzae* in 92.3 % of sites compared to 18.5 % of sites by spear sampling. The calculated ratios between the results given by both trapping and spear sampling in detection frequency were 6:1 and 5:1 for the insects of *T. castaneum* and *S. oryzae*, respectively (Fig. 5). The detection frequency of captured insects by spear sampling method after fumigation was lower than those captured by stack probe traps (Table

1). The detected insects in the warehoused wheat grains were *S. oryzae, R. dominica, T. castaneum,* and *O. surinamensis*. Hence, the method of stack probe trap may be suggested as a commercial model for effective early detection of insects in stored wheat commodities without any harm to the bag environment (Fig. 6). The obtained results of the current work were supported by Epsky and Shuman (2002) and Divya and Mohan (2009).

Table 1: The percentages of detection frequency and ratios per day of insect species in stack probe trap and spear sampling before and after fumigation with phosphine.

Detected insects	Before Fumigation			After Fumigation		
	Detection Frequency (%)		Detection ratio (Trapping: Sampling)	Detection Frequency (%)		Detection ratio (Trapping: Sampling)
	Stack trap	Spear sampling		Stack trap	Spear sampling	
O. surinamensis	41.3±3.5	4.7±1.3	9:1	4.3±2.8	0.3±0.6	14:1
R. dominica	51.7±3.4	10.7±2.3	5:1	6.8±1.8	2.8±0.8	2.5:1
S. oryzae	92.3±4.5	18.5±3.5	5:1	33.3±5.6	5.9±3.6	5.5:1
T. castaneum	98.5±4.6	16.3±3.7	6:1	37.3±7.4	7.8±4.1	4.5:1

The findings concluded that the investigated non-baited trap tool was effective in early monitoring the insects in the warehoused stacks. Concerning the quality of the stored wheat commodity, the studied tool was very safe where the tested wheat bags didn't damage during the study period compared to the baited traps. Furthermore, the tested stack probe traps were non-baited tools and were more accurate than a spear sampling method in both early detection of wheat insects and the captured number of insects during the storage before and after fumigation. The early studies on the use of other probe traps by Reed *et al.* (2001), Perez-Mendoza *et al.* (2004), and Neethirajan *et al.* (2007) have supported the current research views.

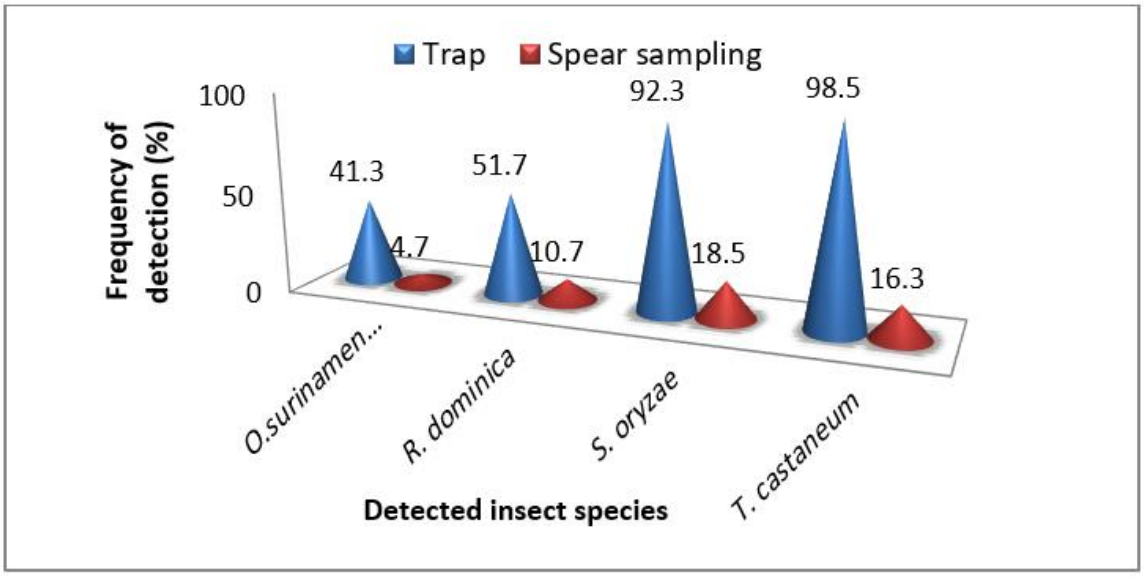

Fig. 5. A comparison between the obtained percentages of insect detection frequency by trapping/day and spear sampling/kg before fumigation.

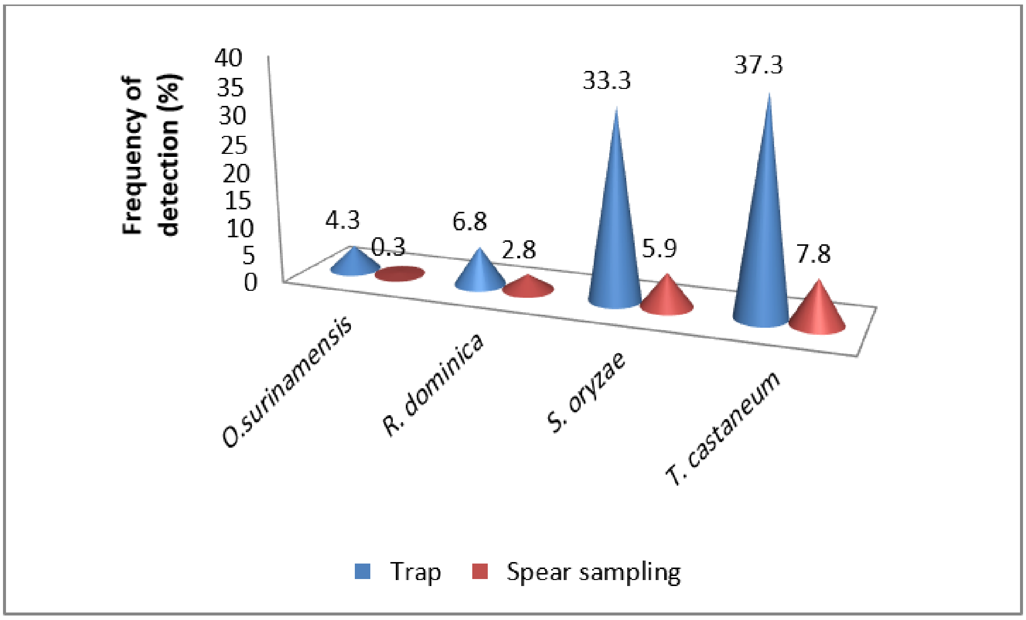

Fig. 6. The detection frequency percentages of captured insects by daily stack trapping and spear sampling after fumigation.

Distribution of the Warehoused Insects (Second Experiment):

The distributions of detected insect species at each layer of stacks are furnished in Table (2). Significant variations were found among the localization layers of warehoused stacks based on the detected insect distribution before fumigation, particularly for *S. oryzae* and *O. surinamensis* (Table 2). Except for *S. oryzae*, no significant difference was found among the captured *O. surinamensis* in the warehoused layers after fumigation (Table 2). Additionally, significant differences among the traps number per stack layer at three levels from top to bottom were observed for the detected insect species of *S. oryzae* and *O. surinamensis* before and after fumigation. The significant distribution of *R. dominica* and *T.castaneum* after fumigation was clearly observed for all stack layers. Before fumigation, there is a significant difference among the captured number of *T.castaneum* based on the number of traps at the studied layers. In contrast, there is no significant variation for the trapped R. *dominica* at all layers of wheat stacks. In general, there are significant differences among the captured insect species of *R. dominica* and *T.castaneum* in relation to traps number per layer.

A dispersion pattern was observed in the current work between the detected insects over their location in the wheat bags. The detected insects of *S. oryzae* and *O. surinamensis* were highly distributed at higher densities of insects in the bottom layer of the tested bags while the top layer of tested stacks was dominated by the insect species of *T.castaneum* and *R. dominica* as shown in Fig. (7). This pattern was supported by the findings obtained by Zhang *et al.* (2020).

Table 2: Insect distribution in the warehoused wheat stcks before and after fumigation.

Treatments	*O. surinamensis*		*R. dominica*		*S. oryzae*		*T.castaneum*	
	Before fumigation	**After fumigation**	**Before fumigation**	**After fumigation**	**Before fumigation**	**After fumigation**	**Before fumigation**	**After fumigation**
Warehoused grain stacks layers								
Top layer	0.6±0.1^{b}	0.5±0.4	6.9±1.5	3.6±1.4^{a}	10.5±2.3^{b}	8.1±1.4^{b}	48.3±3.7^{a}	35.7±1.8^{a}
Middle layer	0.8±0.1^{b}	0.6±0.2	3.6±1.3	1.4±0.6^{b}	17.9±1.4^{b}	11.5±1.3^{b}	22.5±1.3^{b}	11.5±2.8^{b}
Bottom layer	3.7±1.2^{a}	1.3±0.67	1.8±1.1	0.8±1.1^{c}	55.3±2.8^{a}	32.3±3.4^{a}	9.3±1.4^{b}	8.9±1.5^{b}
***P* value**	0.6	NS	NS	0.7	0.7	0.6	0.8	0.7
Traps number per layer								
1 trap /layer	0.3±0.1^{b}	0.3±0.1^{b}	6.5±0.8^{ab}	3.1±0.8	5.5±1.3^{b}	2.9±0.6^{c}	7.5±1.3^{c}	3.5±0.8^{c}
2 traps /layer	2.6±1.8^{a}	1.4±0.7^{ab}	4.7±1.3^{ab}	3.5±0.9	20.5±3.5^{a}	12.3±0.7^{b}	24.9±2.7^{b}	17.5±1.3^{b}
3 traps /layer	3.9±1.0^{a}	2.6±0.6^{a}	5.9±1.1^{a}	3.3±0.5	53.9±1.6^{a}	12.3±0.3^{b}	45.8±1.3^{b}	32.9±2.9^{a}
***P* value**	0.3	0.6	0.6	NS	0.6	0.5	0.5	0.5
The significance level was at P value=0.05; Same small character that followed the mean values indicated non-significant different values; NS (Not Significant).								

Concerning the trapped insects with the different number of traps, data in Table (2) showed a highly significant between the captured numbers of insect species per trap based on the fumigation treatment. The tested wheat bags were infested by four major species of insects. They were *S. oryzae, T.castaneum, R. dominica,* and *O. surinamensis.* The major infestation was mainly by *T. castaneum* followed by *S. oryzae* with little infestation with other detected species. The mean values of insect number of *O. surinamensis* before fumigation were 0.3 when one trap was used, and 2.6 for two traps, and 3.9 for three traps. After fumigation treatment, the trapped number of insects was also observed. This means that the treatment with phosphine didn't kill all species in the tested bags, whereas the tested traps have the potential to detect the insects after fumigation. Where the insect adults of *O. surinamensis* detected after fumigation were 0.30 using one trap, 1.4 for two traps, 2.6 for three traps. The trapped number of detected insects was slightly decreased after fumigation. Furthermore, the captured insects from warehoused stacks were increased in number with increasing the traps number of each layer. Since the captured insects by three traps per layer were significantly higher in number than those captured by one or two traps per layer. Regarding the *T. castaneum,* the detected number was varied based on the number of tested traps either before or after fumigation. The detected number of *T. castaneum* before fumigation was increased from 7.5 using one trap to 45.8 using three traps. Additionally, after fumigation, the detected number of *T. castaneum* didn't prevent but only decreased from 7.5 before fumigation to 3.5 after fumigation using one trap, 24.9 to 17.5 using two traps, 45.8 to 32.9 using three traps. Concerning the detected *S. oryzae,* the number of trapped insect adults was increased with increasing the used traps and not prevented but decreased after fumigation. Before fumigation, one trap has detected 5.5 of *S. oryzae,* while 20.5 and 53.9 were detected by two and three traps, respectively. These numbers were decreased after fumigation from 5.5 to 2.9 at one trap, 20.5 to 12.3 at two traps, and 53.9 to 12.3 at three traps (Fig.6). The results were agreed with the most earlier studies reported by Loschiavo and Atkinson (1973) and with the later investigation of Zhang *et al.* (2020). Ultimately, the tested traps have the ability to detect different species of insects before and after fumigation.

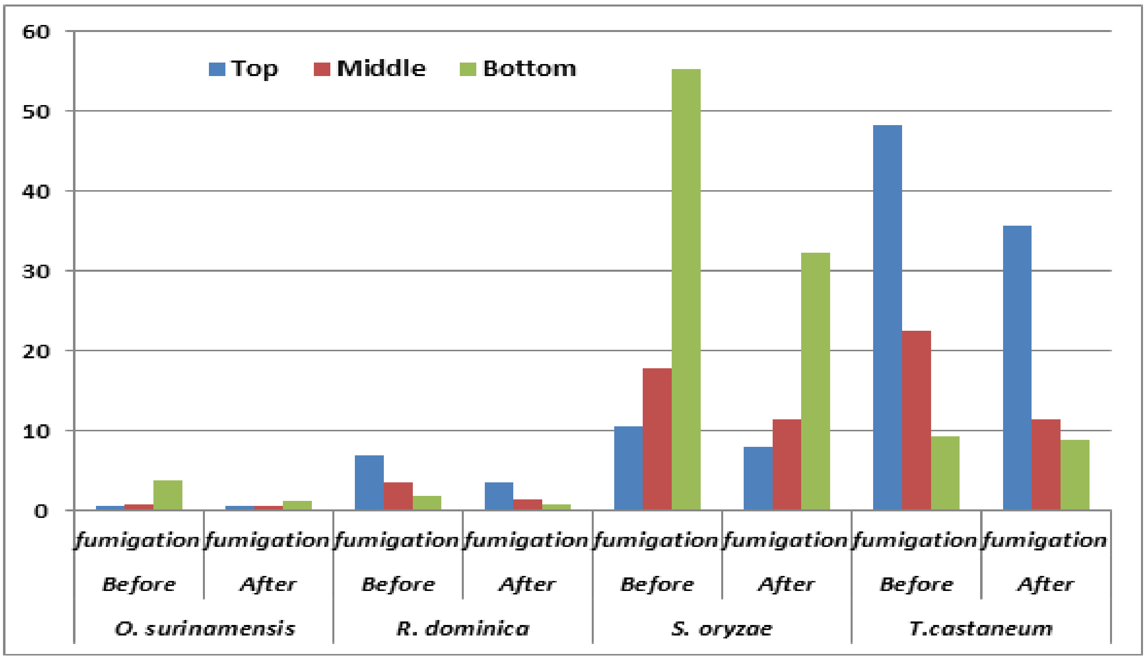

Fig. 7. Daily distribution of insects per layer position (top, middle, and bottom) in the warehoused grain stacks before and after fumigation treatment.

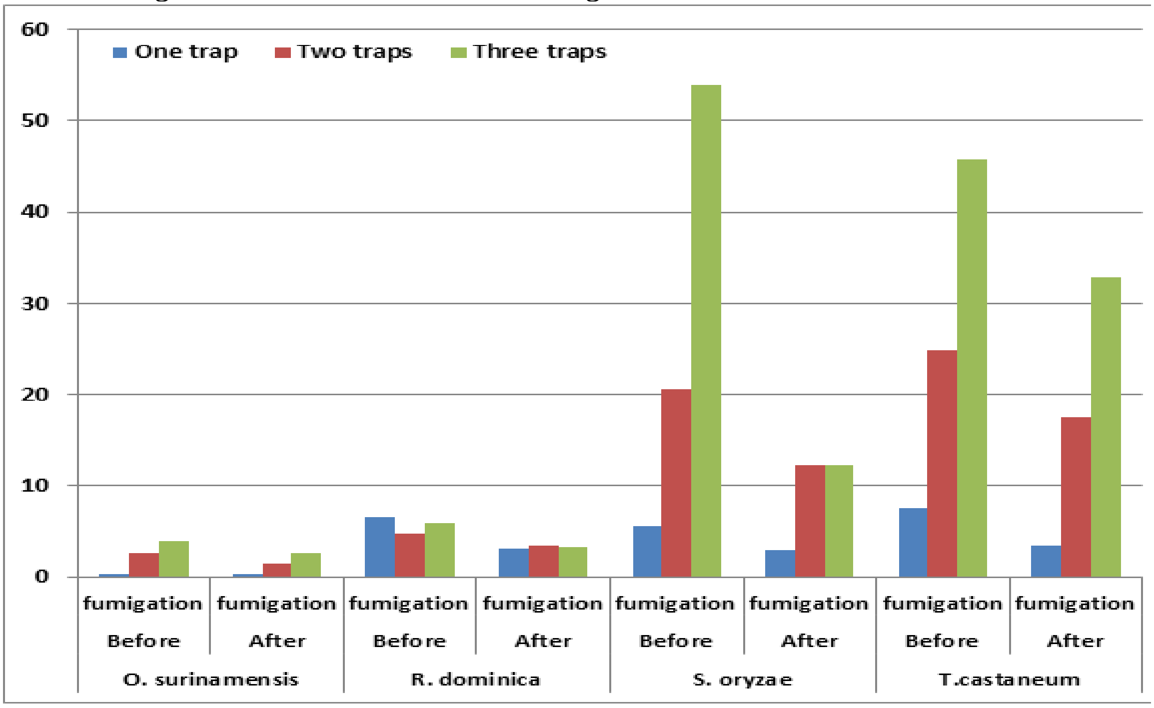

Fig. 8. Daily insect distribution per trap in each layer in the warehoused stacks before and after fumigation.

Insect Trapping and Detection Using Insect Probe Trap in the Second Experiment:

The most results of the second experiment using the insect probe trap are furnished in Table (3) and visualized in Fig. (9). The detected insect species by insect probe traps were dominated by rice weevil (*Sitophilus oryzae*), red flour beetle (*Tribolium castaneum*), lesser grain borer (*Rhyzopertha dominica*), and saw-toothed grain beetle (*Oryzaephilus surinamensis*). The findings of trapped *Rhyzopertha dominica* was significant compared to others. Furthermore, the collection unit of the trap was filled with the captured *T. castaneum* adult population from tested wheat bags. Moreover, the trapped pupating of *Rhyzopertha* *dominica* larva was found in the collection unit. The maximum population of trapped insect species achieved by the tested trap is increased based on the following order *T. castaneum* (390) > *S. oryzae* (221) > *R. dominica* (26) > *O. surinamensis* (17) (Table 3).

The total densities of trapped insects were 17, 26, 221, and 390 for *O. surinamensis, R. dominica, S. oryzae,* and *T. castaneum* , respectively. The mean numbers of trapped insect pests per week across four weeks (period of the experiment) *were the maximum values* (97.5) for *T. castaneum* in the open wheat bag stacks of retail stores followed by *S. oryzae* (55.25), *R. dominica* (6.5), and *O. surinamensis* (4.25) (Fig. 9). The tested open wheat bags were dominantly infested with *T. castaneum* in the third week (117) followed by the fourth week (96). The lowest values of captured *T. castaneum* were 90 and 87 in the 1st and 2nd weeks, respectively. The mean number of 163.5 was for all captured insects within the four weeks using studied insect probe traps. The findings of the second experiment were in line with those obtained by Epsky and Shuman (2002), Neethirajan *et al.*, (2007), Zhang and Wang (2007), and Divya and Mohan (2009). The tested wheat in the retail stores was mainly infested by *T. castaneum* and *S. oryzae* compared with *R. dominica and O. surinamensis* (Table 3). The total numbers of captured insects of all detected species were 158, 146, 179, and 171 in the 1st, 2nd, 3rd, and 4th weeks, respectively with a total density of 654 for all species across the full period of the experiment. The mean percentages of detected insects per week were 59.6% for *T. castaneum*, 33.9% for *S. oryzae*, 3.9% for *R. dominica*, and 2.6% for *O. surinamensis* (Table 3; Fig. 9).

Table 3: Detecting the insect species trapped by insect probe trap in the open wheat bags of some retail stores.

Week	Insect number captured in the retailer wheat bags per week				Total trapped insect number per week
	T. castaneum	***R. dominica***	***S. oryzae***	**O. *surinamensis***	
First Week	90	9	54	5	158
Second Week	87	7	48	4	146
Third Week	117	5	54	3	179
Fourth Week	96	5	65	5	171
Total trapped insect	390	26	221	17	654
Mean (± SE)	97.5 ± 3.87	6.5 ± 0.19	55.25 ± 2.65	4.25 ± 0.54	163.5 ± 10.2
Mean (%)	59.6%	3.9%	33.9%	2.6%	--

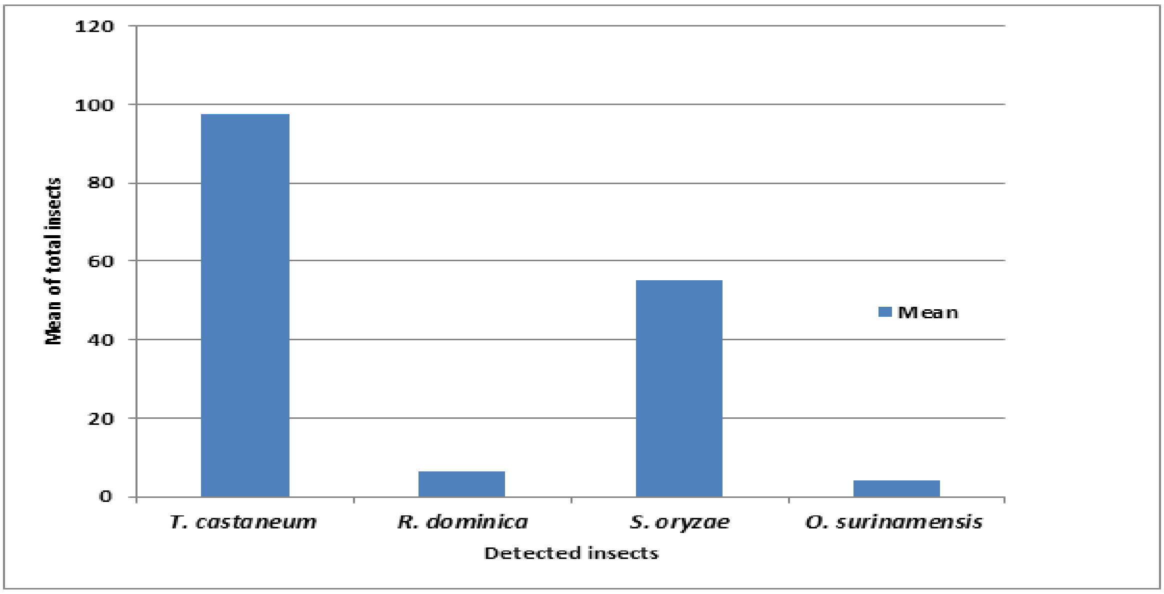

Fig. 9. Mean value of the total number for each insect species trapped over the entire trapping period of the experiment.

CONCLUSION

Two experiments on stored wheat grains in the warehouse and retail stores were conducted using methods of international traps across the Sharkia Governorate of Egypt for early detection and monitoring of the insects that attack the wheat storage ecosystem in Egypt. These trap technologies are stack probe and insect probe traps which transferred from the origin country (India) to Egypt. The stack probe traps were used in the wheat stored in the warehouse and compared with spear sampling, whereas insect probe traps were used in the retail stores. The insects in the tested wheat grains of the warehouse were effectively early detected using the stack probe trap device. It showed more operative results in the detection of stored insets and the identified species numbers of the caught insects than other spear sampling methods. This trap has timely detected the insect species in the warehoused wheat products more precisely than the used sampling method under fumigation. Therefore, the insects in the tested wheat grains were highly detected and monitored using the stack probe trap which is an eco-friendly tool for integrated pest management in the stored ecosystems in Egypt. The insect distribution before and after fumigation showed that the trapped insects were found from the top, middle, and bottom layers of treated wheat stacks. The results confirmed that the bottom layers were dominated by the insects of *O. surinamensis* and *S. oryzae* while the top layers of tested wheat bag stacks were dominated by the species of *R. dominica* and *T. castaneum*. The research work demonstrated that storage insects in small stockholders and warehouses inspectors can be timely detected and monitored using the stack probe trap in different commodities, particularly during the post-fumigation times.

Regarding the insect probe trap, the early detection of the insect species was timely done across the tested retail stores in Zagazig city, Egypt. The detected and trapped insects by insect probe trap were dominated by *T. castaneum* and *S. oryzae* followed by *R. dominica* and *O. surinamensis*. The findings showed that the highest tapped number of *T. castaneum* was 117 in the 3rd week and the lowest number was achieved in the 2nd week. The trapping technologies that are imported from India have the potentiality to timely detect and monitor the insects in the stored wheat ecosystem for sustainable integrated pest management in Egypt.

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ARABIC SUMMARY

أدوات صديقة للبيئة من أجل الإكتشاف المبكر للحشرات في حبوب القمح المُخزنة تحت الظروف المصرية

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تُهاجم الحبوب المخزونة في مصر وخاصة القمح، كونه محصول إستراتيـجي للمصريين، بالعديد من الآفات الحشرية التي قد تقلل من جودة وكمية الحبوب المخزونة. لذا فإن تطبيق الإجراءات الوقائية عن طريق نقل التكنولوچيا الحديثة من الخارج من أجل الاكتشاف المبكر لآفات حبوب القمح المخزونة ومراقبتها من أجل مكافحتها؛ سيؤدي بالضرورة إلى الحفاظ على منتجات الحبوب المخزونة في صورة جيدة للمستهلك. أُجريت الدراسة الحالية في مدينة الزقازيق ، محافظة شرقية ، مصر في عام 2020 باستخدام مصائد الحشرات التالية: TNAU stack probe and insect probe traps للاكتشاف المبكرلآفات الحبوب المخزونة وكذلك تقدير درجة وموقع الاصابة بهذة الافات في أكوام أكياس القمح بالمخازن الرئيسية Warehouse بإستخدام stack probe traps (كتجربة أولى)، وكذلك بالأكياس المفتوحة بمتاجر الحبوب المخزونة Retail stores بإستخدام insect probe traps (كتجربة ثانية). حيث تم توزيع المصائد stack probe traps في ثلاثة مواقع لاكوام اكياس الحبوب المخزونة (قمة الكومة، وسط الكومة، وقاع الكومة) وتم تزويد كل موقع بعدد معين من المصائد، حيث تبعد اكياس القمح عن الارض بحوالي نصف متر طبقة القاع ، والوسط على ارتفاع مترين من الارض، اما القمة فكانت على ارتفاع 3,5 متر من الأرض. اما بالنسبة للمصيدة الثانية insect probe traps فقد تم استخدامها لاكتشاف الإصابة في المتاجر المفتوحة بوضعها داخل أكياس القمح المفتوحة والمجهزة للبيع للمستهلكين. حيث تم الأكتشاف المبكر للآفات التالية بإستخدام Stack probe traps: ثاقبة الحبوب الصغرى (*Rhyzopertha dominica*) ، وخنفساء الدقيق الصدئية (*Tribolium castaneum*) ، وخنفساء الحبوب ذات الأسنان المنشار(السورينام) (*Oryzaephilus surinamensis*) ، وسوسة الأرز (*Sitophilus oryzae*). وخلال أسبوع واحد قبل التبخير Fumigation بلغ Detection frequency حوالي 98,5% في حالة *T. castaneum* عن طريق stack probe traps بالمقارنة بقيمة 16,3٪ عن إستخدام طريقة أخذ العينات Spear Sampling ونخلها لفصل الحشرات Sieving وعدها؛ وبالتالي فنجد أن stack probe traps فعالة في اكتشاف الإصابة بالافات الحشرية بمعدل حوالي ست مرات الطريقة التقليدية، وكذلك كانت هذه المصائد فعالة في اكتشاف الإصابة بسوسة الأرز بمعدل حوالي خمس مرات الطريقة التقليدية. وقد اتضح من خلال توزيع الحشرات المجمعة من المصائد *R.dominica* و *T. castaneum* كان باعداد كبيرة في الطبقة العليا من الأكياس عن طبقتي الوسط والقاع بينما كان انتشار *S. oryzae* و *O. surinamensis* في الطبقة السفلية والتي اكثر من الطبقتين الاخرتين. و فيما يتعلق بمصيدة insect probe traps التي تم إستخدامها بالتجربة الثاية، فقد ساهمت هذه المصيدة في الاكتشاف المبكر والدقيق للآفات التالية: خنفساء السورينام (*Oryzaephilus surinamensis*) ، وسوسة الأرز (*Sitophilus oryzae*) ، وثاقبة الحبوب الصغرى (*Rhyzopertha dominica*) ، وخنفساء الدقيق الصدئية (*Tribolium castaneum*). وكان متوسط أعداد الافات المسجلة أسبوعيًا كالتالي: 4,25 و 6,5 و 55,25 و 97,5 لكل من *O. surinamensis* و *R. dominica* و *S. oryzae* و *T. castaneum* على التوالي. مما سبق يتضح أن المصيدة المستخدمة في التجربة الأولى stack probe trap الأكثر فاعلية في اصطياد أنواع الحشرات قبل وبعد التبخير من الطرق التقليدية حيث أنها غير مزودة بطعم وبالتالي أكثر أمانا على صحة الانسان والبيئة، وكذلك المصيدة المستخدمة في التجربة الثانية وهي insect probe traps هي الاكثر ملائمة في أماكن البيع للمستهلك، وبالتالي فإن المصائد التي تم اختبارها من الهند يمكن استخدامها كأدوات صديقة للبيئة Eco-friendly tools بشكل فعال وآمن كوسيلة للاكتشاف المبكر والمراقبة لافات الحبوب المخزونة لحبوب القمح دون أي ضرر على صحة الإنسان والبيئة في ظل الظروف المصرية من خلال نقل التكنولوچيا من الخارج.