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Utility of magnetic fields in pest control and effects on quality of stored dates

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Abstract

The present study aimed to use a non-traditional method of controlling *Ephestia cautella* (Walker) (Lepidoptera: Pyralidae) and *Oryzaephilus surinamensis* (Linnaeus) (Coleoptera: Silvanidae) known pests of stored date. The magnetic apparatus (Patent 1663/2018) at the Plant Protection Research Institute was used to apply a magnetic field to *E.cautella* and *O.surinamensis* for varying durations. Biological parameters (Egg incubation duration, larval stage duration, pupal duration, adult longevity and life cycle duration from egg to adult) were measured in *E. cautella* to determine the utility of magnetic fields for protection dates during storage. Exposure of *E. cautella* eggs and larvae to a magnetic field for 40 minutes completely inhibited adult emergence. Further, the life span of treated eggs was longer than untreated eggs. The application of a magnetic field reduced the infestation ratio in treated dates from 80.82 % to 50.29 %. In addition, magnetic fields increased the quality and chemical composition of treated dried dates.

Introduction

Phoenix dactylifera (L.) is a significant date palm crop that has been cultivated around the Persian Gulf and in North Africa for millennia (Hussain, 2014). During the holy month of Ramadan, Middle Eastern countries become the greatest producers and consumers of palm dates worldwide (Abdelfattah *et al*., 2021). The farming of the date palm in ancient times led to the foundation of resourceful oasis agro-systems which are artificially created fertile regions maintained and harvested by the local population (Chi Cheng and Robert , 2007). A total of 23 species of pests is known to damage date fruits during harvesting and storage, predominantly Coleoptera and Lepidoptera (El-Shafei *et al*., 2019).

Almond moths *Ephestia cautella* (Walker) (Lepidoptera: Pyralidae) are a major pest of date fruits in Egypt. Infestations begin in the field and are transferred to storehouses through infested dates over several generations (Howard *et al*., 2001). Other than date palm fruits, the almond moth is also considered a pest of dried fruits, cereals, nuts, beans, flour, chocolate confectionaries, peanut and processed foods (Rees, 2007). Additional damage to stored products may occur during the removal of abundant almond moth webbing containing faecal pellets, cast skins and eggshells, with reported losses exceeding 60% of the stored commodity.

The saw-toothed grain beetle, *Oryzaephilus surinamensis* (Linnaeus) (Coleoptera: Silvanidae), is a secondary pest of stored grain due to its ability to damage the whole grain. Mechanical damage during harvesting and drying may lead to the transport of broken and damaged grain to storage facilities which may then precipitate serious saw-toothed grain beetle infestations (Pricket *et al*.,1990). The saw-toothed grain beetle is a tiny insect that can hide in a variety of locations in storage facilities and has developed resistance to a number of insecticides (Wallbank and Collins, 2003). Adult and larval saw-toothed beetles may also attack flours, breakfast cereals, feed, copra, nuts and dried fruits, particularly packaged foods (Mowery *et al*., 2002).

There is increasing interest in the use of magnetic fields (MF) in pest control due to their biological effects, low cost and safety. However, previous studies on the effects of MF have predominantly been conducted in vertebrates, with comparatively few studies in insects and crop storage facilities (Starick *et al*., 2005). Accordingly, the application of MF is considered a promising method of insect control (Hussein *et al*., 2014 and Gonil and Sajomsang, 2012) reporting a direct effect of magnetic fields on the chitin of the insect cuticle.

Materials and methods

All experiments were conducted at the Stored Product Pest Department, Plant Protection Research Institute, Agricultural Research Center and the Control of Stored Products Pests Laboratory.

1. Insect rearing and date type:

E. cautella and *O. surinaminsis* were obtained from naturally infested dried dates. Adults were obtained from cultures. Once collected, insects were placed in glass jars (1L capacity) containing semi-dried, sewa dates. Jars were maintained in an incubator at 28°C ± 2°C and 65% ± 5% relative humidity. Newly emerged adults were collected daily using a vacuum pump and placed in glass cages with screen bottoms to obtain eggs. The colony was maintained in the same conditions for six generations before experiments.

2. Bioassay test and apparatus:

The eggs, larvae and pupae of *E. cautella* and larvae and adults of *O. surinamensis* were used in the present study. Each stage was exposed separately in replicates: 30 fourth instar larvae and 30 pupae (2–4 days old) of *E. cautella,* in addition to 30 eggs were separately added to crushed dates in tube tests and subjected to a magnetic field at 180 milli-tesla between the two poles of the magnetic apparatus at PPRI (Patent 1663/2018; Figure 1) for varying durations (0, 10, 20, 30 and 40 minutes). Mortality rates were recorded after treatment. Immature stages were transferred into glass jars, covered with a muslin cloth, and fixed with a rubber band before incubation in rearing conditions until adult emergence. Jars were examined daily to record adult emergence until no further emergence of adults. All experiments were replicated four times.

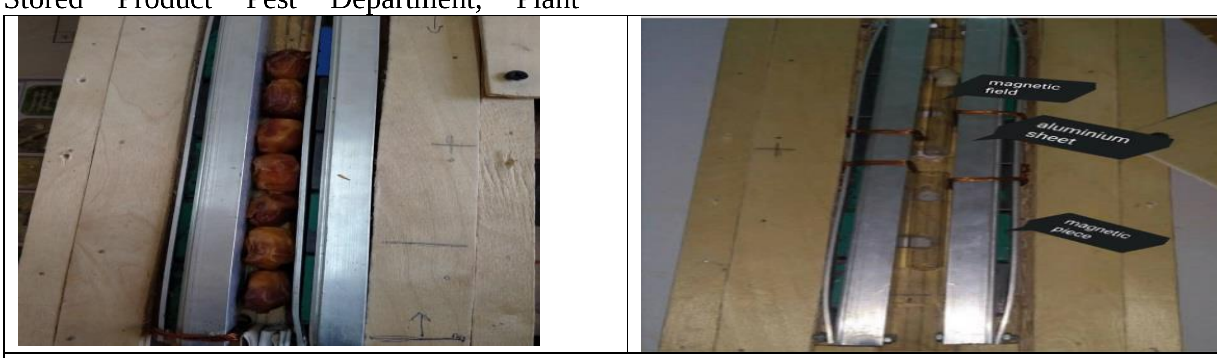

Figure (1): Magnetic apparatus (Patent 1663/2018).

3. Biology experiments:

Only *E. cautella* was used for biology experiments. The durations of egg incubation, larvae, pupae duration and adult longevity were recorded for eggs exposed to a 180 milli-tesla magnetic field for varying durations (0, 10, 20, 30 and 40 min.). The time from egg incubation to adult emergence was also recorded. Experiments were conducted with 30 eggs in triplicate. After exposure to the magnetic, eggs were returned to normal conditions (28 ± 2ºC and 65 ± 5% relative humidity) and examined daily to measure the durations of egg incubation, larval development, pupal development and adult longevity.

4. Dates storage:

Four kilograms of mature dates were stored in a cubic plastic container (25 cm × 10 cm × 30 cm). Dates were arranged in four layers alternating with three layers of magnetic pieces of similar size. The first layer was put in the bottom of the plastic container and then covered with 16 magnetic pieces horizontally arranged above the first layer of dates. Each magnetic piece had a magnetic flux density of 14–18 m tesla. The second layer of dates was then arranged above the first layer of magnetic pieces. A similar weight of dates was stored in a similar plastic container without the magnetic pieces as a control. Three replicates were conducted. The samples used for each replicate were examined at every 45 days of treatment. The experimental duration was 9 months in normal conditions from the end of February 2020 to the end of November 2020. In each experiment, the total number of all stages of *O. surinamensis* and *E. cautella* was counted. The numbers of dead and live insects and the developmental stage were recorded prior to removal. The numbers of infested and non-infested dates were also recorded.

5. Biochemical analyses:

Carbohydrate, iron, calcium and potassium content was measured in control, untreated and treated, (Magnetic field (Patent 1663/2018) for 40 min.) dates (Three dates for each measurement). Carbohydrate, iron, calcium and potassium amounts were measured using a colorimeter and Biodiagnostic kits (info@bio-diagnosytic.com).

6. Statistical analyses:

Data were analysed by ANOVA and T test using Proc ANOVA in SAS (Anonymous, 2003) . Means were compared by least significant difference (LSD; P = 0.05) in the same program. The data were subjected to probit analysis (Finney, 1971) and analyzed by the computer program Ldp Line **(Noack and Reichmuth,1978)**.

Results and discussion

1. Bioassay of magnetic field:

The three immature stages of *E. cautella* (Eggs, larvae and pupae) were exposed to a magnetic field for 20, 30, or 40 min. The effects of exposure were evaluated using two parameters: mortality (%) and adult emergence (%) for each stage (Table 1). These values were also compared to the control treatment (Without exposure to the magnetic field). Mortality in control eggs was 16% and increased to 25.3 %, 56 % and 65.3 % after exposure to the magnetic field for 20, 30 and 40 minutes, respectively. This finding suggests adult emergence decreased when eggs were exposed to the magnetic field. Adult emergence was 60.32% in control eggs and decreased to 42.86 % and 34.28 % after exposure to the magnetic field for 20 and 30 min respectively. Of note, adult emergence was 0 % after exposure for 40 min. Mortality in the larval stage increased linearly with increasing duration of exposure to the magnetic field from 20 % in control larvae to 40 %, 66.67 % and 80 % after exposure of larvae to the magnetic field for 20, 30 and 40 min, respectively (Table 1). The same trend was observed for the pupal stage, with mortality rates of 23.33 %, 36.67 % and 59.36 % after exposure to the magnetic field for 20, 30 and 40 min, respectively, compared to 0 % in control pupae (Without exposure to the magnetic field,Table 1). We next evaluated mortality in larval and adult *O. surinamensis* after exposure to the magnetic field for 10, 20 and 30 min. (Table 2). Mortality in the larval stage increased linearly with increasing duration of exposure from 0 % in controls to 56, 81.33 and 100 % when larvae were exposed to the magnetic field for 10, 20 and 30 min, respectively. The same trend was observed following exposure of the adult stage to the magnetic field, with mortalities of 30, 56.67 and 85% after exposure for 10, 20 and 30 min., respectively, compared to 0 % in controls (Without exposure to the magnetic field). Adult emergence for the larva stage was 78% in controls and decreased to 16.67 and 4 % after exposure to the magnetic field for 10 and 20 minutes, respectively. Of note, adult emergence was 0 % in larvae exposed to the magnetic field for 30 min. These results corroborate the findings of Pandir *et al.* (2013) who studied the effect of MF on the adult longevity, fertility and daily egg-laying habits of female *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) and reported increasing mortality rates with increasing magnetic field strength, reaching 100% mortality at 10 mT with complete inhibition of larval emergence at the maximum magnetic field strength. The observed mortality may be attributable to the effects of the magnetic field on enzyme levels and activity during insect development (Hussein *et al*., 2015).

Table (1): Effect of magnetic field on mortality % and adult emergency % of immature stages of *Ephestia cautella*

Stage	Egg		Larva		Pupa	
Time	Mort. %	Adult Emerge %	Mort. %	Adult emerge %	Mort. %	Adult emerge %
20 min	25.3±1.33	42.86±5.60	40±0.0	26.67±6.66	23.33±3.33	76.67±3.33
30 min	56±0.58	34.28±1.11	66.67±6.66	0±0.0	36.67±3.33	63.33±3.33
40 min	65.3±0.66	0.0±0.0	80±0.0	0±0.0	59.36±0.0	0±0.0
Control	16±0.58	60.32±4.91	20±0.0	70±5.8	0±0.0	90±5.8

***Mean ± stander error**

Table (2): Effect of magnetic field on mortality % and adult emergency % in larvae stage; mortality % and reduction % in adult stage of *Oryzaephilus surinamensis*.

Time	Larva		Adult	
	Mort. %	Adult emerge%	Mort. %	Reduction%
10 min	56±3.05	16.67±2.90	30±3.85	30±3.85
20 min	81.33±1.67	4±2.31	56.67±1.92	56.67±1.92
30 min	100±0.00	0±00	85±6.67	85±6.67
Control	0±00	78±4.16	0±00	-

***Mean ± stander error**

Data in Table (3) shows that the LT50 and LT90 in *E. cautella* were 29.52 and 67.45 min for eggs, 23.28 and 52.13 min for larvae, and 35.33 and 89.62 min for pupae. In the case of *O. surinamensis* LT50, LT90 was 9.08, and 25.06 min for larvae, 15.54 and 40.32 for adults. According to LT90 values, the pupae were more tolerant to the magnetic fields than all stages, while the larvae were more sensitive to treatment in both insects.

Table (3): LT_{50} and LT_{90} values and their confidence limits for different stages of *Ephestia cautella* and *Oryzaephilus surinamensis* exposed to different time of magnetic field.

Insect	Stage	LT_{50}(min)			LT_{90}(min)			Slope ± SE	χ2	P
		Value	Confidence limits		Value	Confidence limits				
			Lower	Upper		Lower	Upper			
Ephestia cautella	Egg	29.52	26.74	32.72	67.45	53.64	105.64	3.57±0.61	1.57	0.2
	larvae	23.28	20.11	25.70	52.13	43.71	72.74	3.66±0.62	0.07	0.7
	Pupae	35.33	31.64	42.01	89.62	64.91	182.86	3.17±0.62	1.23	0.2
Oryzaephilus surinamensis	larvae	9.08	6.85	10.80	25.06	21.34	32.17	2.90±0.44	0.95	0.3
	Adult	15.54	13.61	17.41	40.32	33.14	55.02	3.09±0.40	3.11	0.07

2. Effect of magnetic fields on life cycle duration:

Exposure of eggs to MF had a substantial effect on the total life cycle duration of *E. cautella* (Table 4). The total life cycle duration increased to 64.67, 70 and 71.67 days following exposure of eggs to the magnetic field for 10, 20 and 30 min, respectively, from 54 days in control eggs (Normal eggs without exposure to the magnetic field). Of note, eggs exposed to the magnetic field for 40 min had complete cessation of the life cycle with no eggs hatching, indicating the potential benefits effects of the application of a magnetic field to stored dates. Puja *et al.* (2018) reported that all biological parameters (Larval weight, larval length and mortality) were negatively affected by application of a magnetic field for 4 hours during the rearing of the larvae of the rice moth, *C. cephalonica*; however, the application of the magnetic diet field for 2 hrs. had beneficial effects. Regarding the effect of the magnetic field effect on immature larval stages, the egg duration (Incubation period) was 6.67, 6.33 and 6.67 days in eggs exposed to the magnetic field for 10, 20, 30 and 40 min, respectively, compared to 5 days in control eggs. The larval stage of development lasted 36.67, 49 and 54.67 days after eggs were exposed to the magnetic field for 10, 20 and 30 min, respectively, compared to 28.33 days for control. The application of the magnetic field increased the duration of the pupal stage of development to 11 days from 6 days in controls. Further, the duration of the adult stage of development increased to 10.33 from 5 days in controls, possibly due to the effect of the magnetic field on enzymatic activity in insects during this period, as posited by Husain *et al.* (2015).

Table (4): Effect of treated *Ephestia cautella* eggs with magnetic field on life cycle durations.

Time	Duration [Day]				
	Egg	Larvae	Pupa	Adult	Total life cycle
10 min	6.67±0.33^{a}	36.67±1.76^{c}	11±0.58^{a}	10.33±0.33^{a}	64.67±1.85^{b}
20 min	6.33±0.33^{a}	49±1.15^{b}	7.67±0.33^{b}	7±1.15^{b}	70.00±2.31^{ab}
30 min	6±0.0 ^{ab}	54.67±2.18^{a}	6±0.58^{c}	5±0.58^{b}	71.67±2.18^{a}
40 min	6.67±0.33^{a}	0±0.0^{e}	0±0.0^{d}	0±0.0^{c}	-^{d}
Control	5±0.58^{b}	28.33±1.45^{d}	9±0.58^{b}	11.67±1.45^{a}	54±1.00^{c}
F value	3.58	203.71	78.85	27.54	248.91
LSD	1.1506	4.7441	1.4854	2.779	5.3968

***Mean ± stander error, means with the same letter are not significantly different in the same column.**

3. Storage and survey of date under magnetic fields:

The presence of the two main insect pests was compared between the treated (Three layers of magnetic pieces between 4 layers of stored dates) and control samples (Stored dates without magnetic pieces). Two main pests were found; *O. surinamensis* and *E. cautella*. The numbers of adults, larvae and pupae were recorded (Table 5). The total number of *O. surinamensis* adults were 153.5, 426.3 and 205 individuals the fourth, fifth and sixth investigations, respectively, with a total of 785.8 found in the magnetised dates over the entire storage period. An average of 0.75, 74.25, 81 and 152 individuals were observed at the third, fourth, fifth and sixth investigations, respectively, with a total of 308 individuals found in the control samples (Without any magnetic layer). Regarding the magnetised stored dates samples, the average numbers of *O. surinamensis* larvae found in the fourth and fifth investigations were 10 and 3.75 individuals, respectively, compared to 17.5 and 34.75 individuals in the fourth and sixth control investigations. Accordingly, the total number of *O. surinamensis* larvae was 13.75 individuals in the magnetised date samples compared to 52.25 individuals in the control samples. This finding indicates 785.8 *O. surinamensis* adults produced only 13.75 larvae, representing 1.74 % of all *O. surinamensis* individuals in the magnetised date samples. In comparison, a total of 308 adults produced 52.2 larvae representing 16.96 % of all individuals in the control samples (Table 5 and Figure 2 a). Many studies on the use of magnetism and MF hazardous insect populations (Hussein *et al*., 2014). These data demonstrate a considerable decrease in the number of laid eggs following the application of a magnetic field. These results support the findings of Hussein *et al*. (2014), who reported magnetic field strength had a linear negative relationship with the hatchability percentage of exposed eggs in *Sitotroga* sp., with hatchability reduced to 22 % in MF with 11 magnet units.

Regarding *E. cautella*, the application of a magnetic field reduced larvae and pupae densities in stored palm dates at the end of the study period to 9.5 and 2.75 individuals, respectively, compared to 14.25 and 5 individuals, respectively, in control samples (Table 5 and Figure 2 b). Most larvae and pupae in treated samples were found more than 6 months after the application of the magnetic field, while both larvae and pupae were observed throughout the study period in control samples. Further, the application of the magnetic field decreased the proportion of dates infested with insects to 50.29 % compared to 80.82 % in control samples (Without magnetic field) (Table 5 and Figure 3). This finding indicates the considerable benefits of storing palm dates in a magnetic field to reduce infestation by insects. According to a previous study by Doaa and Hussein (2019), MF is particularly efficient in protecting stored wheat harvests from pest infestation for up to eight months compared to untreated seeds that became infested within three months. The use of the magnetic apparatus at PPRI, (Patent 1663/2018) resulted in greater protection of dates from a range of developmental stages of *E. cautella* and *O. surinamensis.*

Table (5): Effect of magnetic field on pest survey produced during date storage and infested date % during 9 months under normal conditions.

Treatment	Investigation	*Oryzaephilus surinamensis*			*Ephestia cautella*			
		Adult	Larva	Pupa	Adult	Larva	Pupa	Infested %
Magnetic	1 st. investigation	0±0	0±0	0±0	0±0	0.25±0.25	0±0	0.58±0.60
	2 nd. Investigation	0±0	0±0	0±0	0±0	0.5±0.28	0.25±0.25	1.17±0.70
	3 rd. investigation	1±1	0±0	0±0	0.5±0.5	0±0	0±0	1.75±0.6
	4 th. Investigation	153.5±6.17	10±3.53	0±0	6.25±5.26	6.75±1.93	1.75±0.63	50.29±8.76
	5 th. Investigation	426.25±59.21	3.75±1.25	0±0	0±0	0±0	0±0	50.29±8.76
	6 th. Investigation	205±32.40	0±0	0±0	0.25±0.25	2±1.68	0.75±0.25	50.29±8.76
	Sum	785.75[a]	13.75[b]	6.25[a]	7[a]	9.5[a]	2.75[a]	50.29[b]
Control	1 st. investigation	0±0	0±0	0±0	0±0	0.5±0.5	0±0	1.4±0.70
	2 nd. Investigation	1±1	0±0	0±0	0±0	0.5±0.25	1.25±1.25	2.05±0.71
	3 rd. investigation	0.75±0.48	0±0	0±0	0.5±0	0.25±	0±0	2.05±0.71
	4 th. Investigation	74.25±17.12	17.5±4.92	0±0	6.25±1.31	6.25±2.62	2.75±0.25	80.82±10.15
	5 th. Investigation	81±12.25	0±0	2.25±2.25	0±0	5.25±2.78	0.75±0.48	80.82±10.15
	6 th. Investigation	152±83.32	34.75±23.61	0±0	2.25±2.25	1.25±1.125	0±0	80.82±10.15
	Sum	308[b]	52.25[a]	2.25[a]	8.5[a]	14.25[a]	5[a]	80.82[a]

*Mean ± stander error, sum with the same letter are not significantly different between magnetic and control in the same column.**

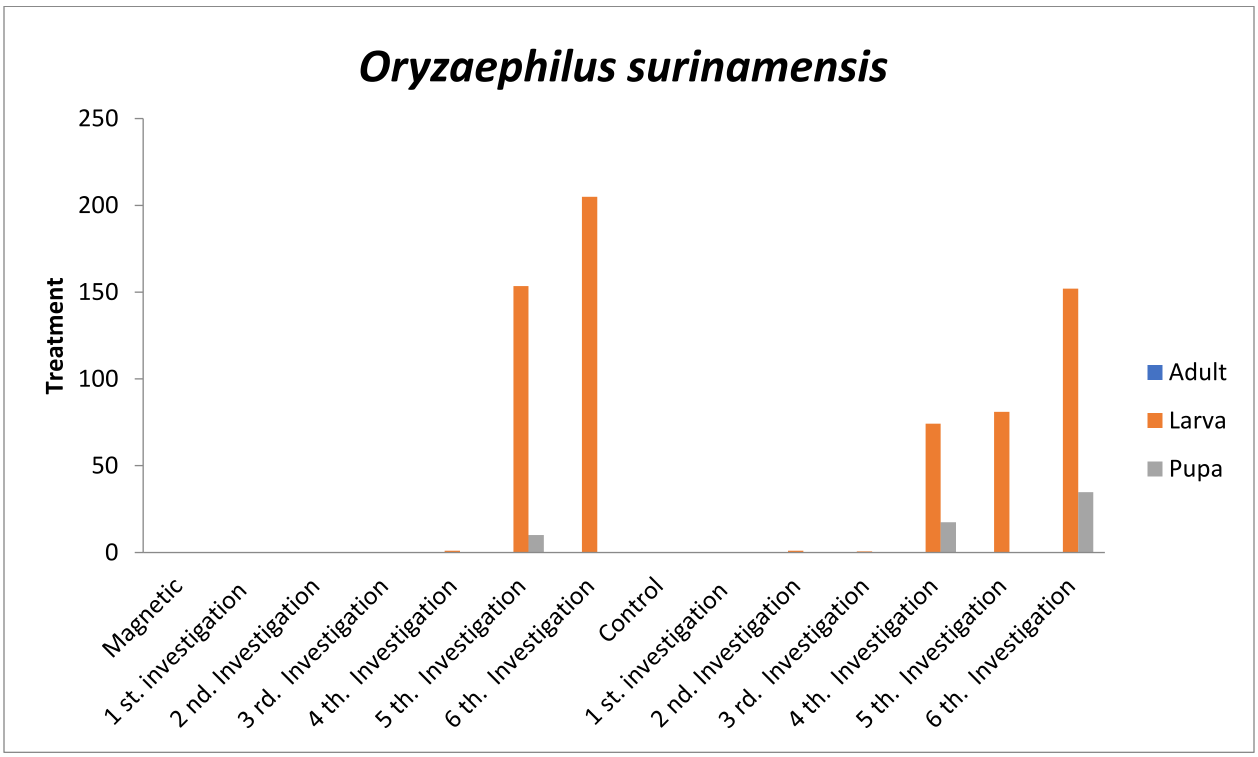

Figure (2 a): Effect of magnetic fields on survey of stored dates under normal conditions.

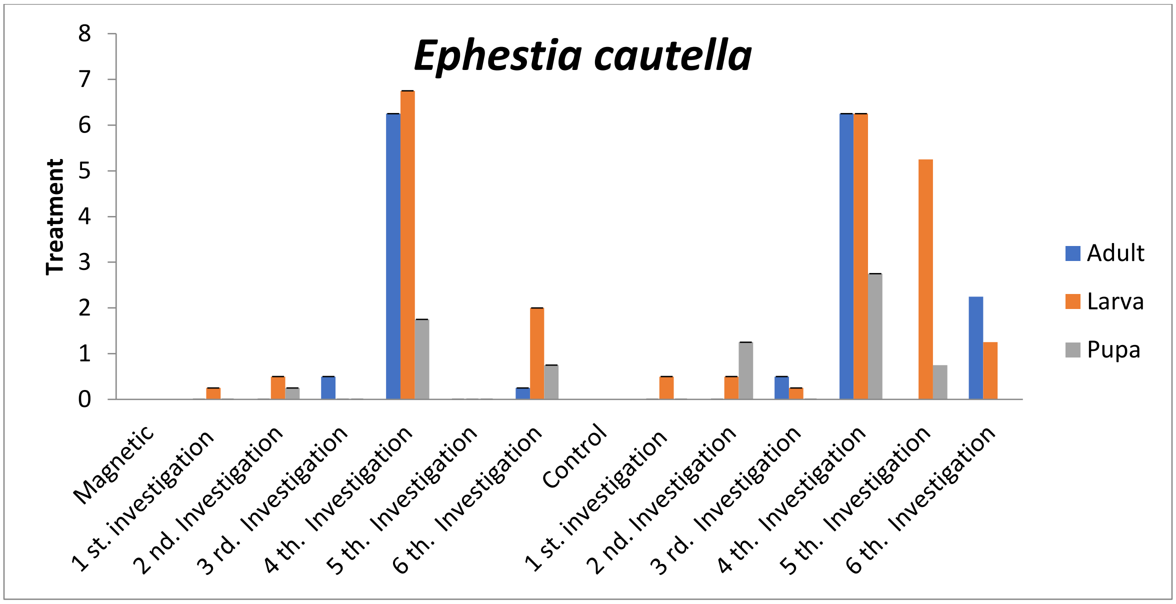

Figure (2 b): Effect of magnetic fields on survey of stored dates under normal conditions.

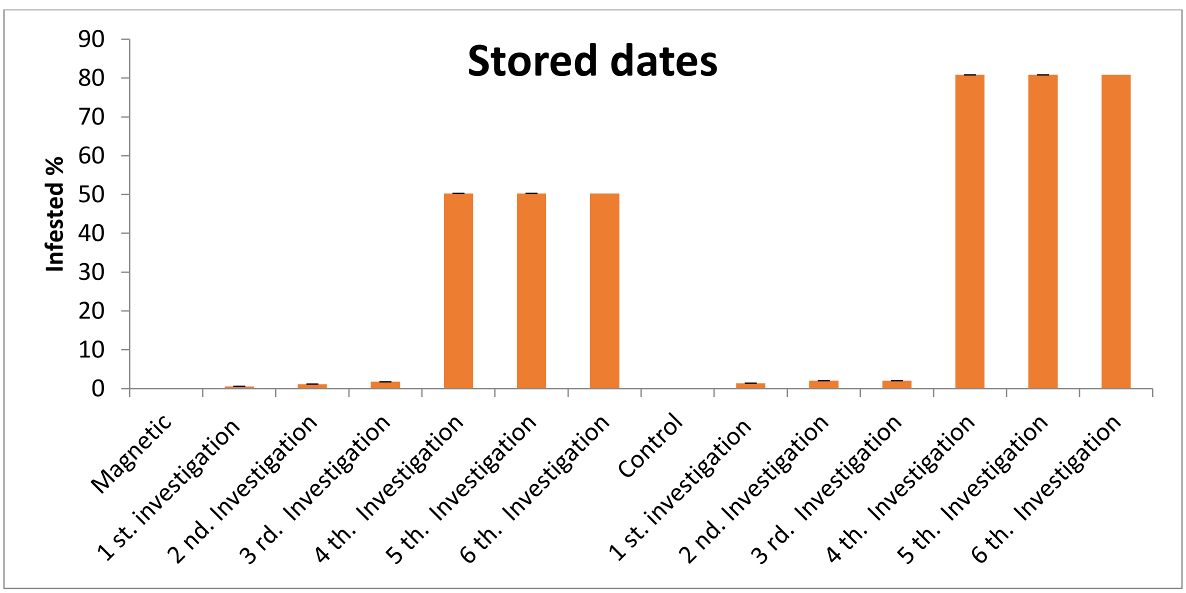

Figure (3): Effect of manetic feilds on infestation of stored dates during 9 month under normal conditions.

4. Biochemical composition of treated dates:

Table (6) shows the carbohydrate, iron, calcium and potassium content of dates exposed to MF for a maximum period of 40 min. compared to untreated dates (Control). Carbohydrate, calcium and potassium content were higher, while the iron content was lower, in dates exposed to the magnetic field increased compared to control samples. These findings indicate the use of MF is a suitable non-chemical alternative for controlling pests in stored food products and has potential applications in agriculture, pest control and food security. On the other hand, the accumulation of iron in stored dates was affected by the application of a magnetic field. MF has been shown to promote nutrient uptake in immobile plants and may therefore, increase the nutritional value of stored dates (Dhawi *et al*., 2009).

Table (6): Biochemical analysis of palm date exposed to magnetic field.

Treatment	Carbohydrate (g %)	Iron (mg %)	Calcium (mg %)	Potassium (mg %)
Magnetic field	63±2.36[a]	12.6±0.11[a]	63.56±1.85[a]	1017±13.89[a]
Control	57.5±1.26[a]	13.13±0.29[a]	55.23±1.63[b]	980±11.55[a]
F value	4.22	11.43	2.81	4.20
L.S. D.	7.43	0.88	6.84	50.15

***Mean ± stander error, means with the same letter is not significantly different in the same column. L.S.D. = Least Significant Difference.**

The findings of the present study demonstrate that MF has utility as a safe method of controlling pests in stored date fruits without adversely affecting fruit quality. Further studies are required to determine the effect of MF on pests of stored dates.

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