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ORIGINAL ARTICLE

Ability of magnetic field to protect wheat crops during storage

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Abstract

The current research aimed to use non traditional methods to control some stored grain insects. The effects of 180 millitesla (mT) magnetic field (MF) for six different exposure periods (3 min, 30 min, 1 h, 12 h, 24 h and 48 h) on mortality (%) of two stored grain insects, *Tribolium casteneum* adults and *Trogoderma granarium* larvae, reduction in F_1-progeny (%), seeds germination (%) and seed components (%) after 8 months storage period were studied under laboratory conditions. According to results, the mortality (%) of tested insects increased with increasing of MF time exposure. *Trogoderma granarium* was more resistant than *T. casteneum* in which mortality reached 56 and 75%, respectively 14 days after from exposure period. Without any negative effect on seeds germination (%) the MF was very effective in protecting stored wheat from insect infestation up to 8 months compared to non-magnetic seeds which became infested after 3 months of storage. Furthermore, the germination (%) was accelerated by 6 h compared to non-magnetic seeds. The MF level caused a slight increase in the percent of total carbohydrate, crude protein and ash while slightly decrease the percent of moisture, total fats and crude fiber.

Keywords: magnetic field, seeds germination, *Tribolium casteneum*, *Trogoderma granarium*

Introduction

Wheat suffers heavy losses during storage due to insect infestation. According to Food and Agriculture Organization (FAO) approximately 10 to 25% of harvested food worldwide is destroyed annually by insects and rodent pests (Anonymous 1980). The damage arising from insects in grain is the result of the direct feeding of insects on the endosperm, grain embryos and the pollution caused by their droppings and flayed skins. Also there is increased exposure of grain to rot because of scratches and damage which create unpleasant odors. The rot can infect the grain delivered which cannot be accepted by humans and animals (Ismail 2014).

Pest control in Africa has mostly depended upon the use of synthetic chemical pesticides. However, repeated use for decades has led to outbreaks of other insect species and sometimes has resulted in the development of resistance (Uma 2014). It has had undesirable effects on non-target organisms and has fostered environmental and human health concerns (Champ and Dyte 1976; Subramanyam and Hagstrum 1995; White and Leesch 1995). Therefore, there is an urgent need to develop environmentally friendly alternatives such as magnetic field (MF) to replace the highly toxic chemicals.

Other than a source of radiation, MF has attracted the attention of researchers due to their biological effects, low cost and safety. Most of the studies about MF effects have focused on vertebrates and relatively fewer studies have been done on insects and their stored-product environment (Starick *et al*. 2005). Magnetic fields have been shown to affect the orientation (Jones and Macfadden 1982), oviposition and development (Ramirez *et al.* 1983), fecundity and behavior (Starick *et al*. 2005) of a wide variety of insects.

The present study was conducted to determine the efficiency of a magnetic device of 180 mT in controlling two of the most important stored grain insects, *Trogoderma granarium* and *Tribolium castaneum* infesting wheat seeds.

The khapra beetle, *T. granarium* (Everts) is one of the world's most destructive stored-product pests. In fact, it has been recognized as an A2 quarantine organism for EPPO (OEPP/EPPO 1981) and ranked as one of the 100 worst invasive species worldwide (Lowe *et al.* 2000). Losses caused by *T. granarium* (Everts) have been reported to range from 0.2 to 2.9% over a period of 1 to 10.5 months (Irshad *et al.* 1988).

Tribolium castaneum is a polyphagous, cosmopolitan pest, feeding mostly on stored flour and other milled cereal products, broken wheat and stored farm products. In severe infestation the flour turns grayish and moldy and has a pungent, disagreeable odor making it un-fit for human consumption (Suresh *et al.* 2001). Both insects are known for their highly resistance against many alternatives.

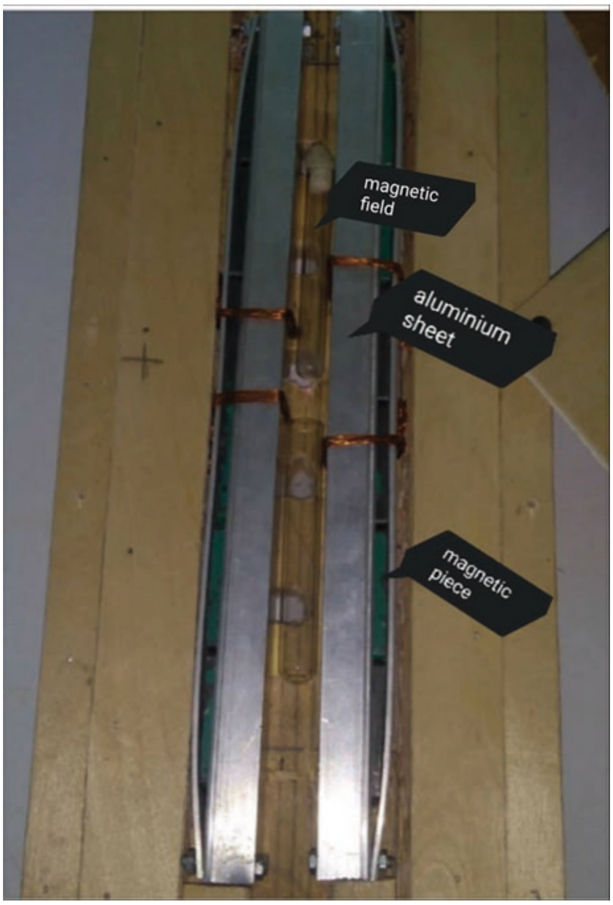

Fig. 1. The magnetic field apparatus of 180 mT

Materials and Methods

This study was conducted at the Plant Protection Research Institute, Agriculture Research Center, Egypt from February to November 2018.

Insect culture

For starting a culture of tested insects, larvae of *T. granarium* (Everts) (Coleoptera: Dermestidae) were reared on wheat seeds while adults of rust red flour beetle, *T. casteneum* Herbst. (Coleoptera: Tenebrionidae) were reared on wheat flour in 500 ml glass jars. Each jar was covered with muslin cloth and fixed with rubber bands for egg laying to obtain large numbers of adults needed for the tests and incubated at 30 ± 2°C and 65 ± 5% relative humidity (RH). These insects were selected because of their economic importance as harmful and destructive pests to stored cereals and other food products worldwide.

Bioassay experiment

A magnetic field apparatus of about 180 mT was designed and measured in the faculty of engineering/ Menoufia University (Fig. 1). Twenty adults of *T. casteneum* and twenty larvae of *T. granarium* (1–2 weeks old) infesting 10 gm of wheat seeds were exposed to 180 mT magnetic field for different times (3 min, 30 min, 1 h, 12 h, 24 h and 48 h). Each treatment was replicated 3 times. After the exposure period, the mortality percentage was recorded after 2, 4, 6, 8, 11 and 14 days then the live adult insects of *T. casteneum* were removed and the replicates were incubated at 30 ± 2°C and 65 ± 5% RH to investigate the reduction in F_1-progeny after 60 days. The live larvae of *T. granarium* were incubated until adult emergence. Percent of insect mortality was calculated using the corrected Abbot's formula (Abbot 1925). Reduction percentage in progeny of offspring was calculated according to (El-Lakwah *et al.* 1996).

Storage experiment

A laboratory experiment was conducted to study the efficiency of magnetic field in protecting wheat seeds for 8 months of storage. Five hundred g of wheat seeds were exposed to MF at the 180 mT level for 48 h then stored for 8 months. Five hundred g of non-magnetic seeds were used as the control. The first emergence of insects in treated and untreated seeds was recorded.

Seed germination experiment

A germination test was conducted on magnetized wheat seeds after 8 months of storage. For this assay, 30 seeds were randomly picked from treated and untreated groups and placed on moist what man filter paper No. 1 inside disposable Petri dishes at the rate of 10 seeds per plate. The treatments were arranged in a completely randomized design with three replicates. Seven days later the germination percentage was calculated according to Ileke and Oni (2011) and Ojiako *et al.* (2013).

Seed component analysis

This experiment was carried out at the Soil, Water and Environment Research Institute to study the effects of 180 mT magnetic field for 48 h exposure on wheat seed components (moisture, crude fats, crude protein, ash and carbohydrates percentages) after 8 months of storage. The control seeds were used for comparison.

Total ash content

Two grams of sample were put in a previously weighed porcelain crucible, placed in a muffle furnace at 600°C for 2 h, and then placed in desiccators, cooled and weighed. The weight of the residue was calculated and expressed as percent ash (AOAC 2000).

Crude fat (ether extract)

Ten grams of each powdered sample were extracted using a continuous extraction apparatus (Soxhlet) with a solvent of petroleum ether [boiling range (b.p.) 60–80°C] for 16 h. Each extract was dried over anhydrous Na_2SO_4 and evaporated to dryness. The residue was dried at 80°C for 10 min, cooled, weighed and expressed as percent lipid (AOAC 2000).

Crude fiber content

Two grams of the defatted powder of each sample were boiled with 200 ml of 1.25% sulphuric acid under reflux for 30 min and filtered. The residue was washed with distilled water then transferred back to the flask with 200 ml of 1.25% NaOH solution. Then it was boiled for 30 min under reflux, rapidly filtered and washed with distilled water. The residue was dried at 100°C to a constant weight. The difference between the weight of residue after drying at 110°C and the weight of powder represents the weight of crude fiber (AOAC 2000).

Crude protein

According to AOAC (2000), the crude protein of each sample was calculated by multiplying the total nitrogen by the factor 6.25.

Moisture content

Five grams of each air-dried powder sample were accurately weighed in a porcelain crucible, and then dried in an oven at 105°C until a constant weight was obtained. The loss in weight was calculated and reported as moisture percent (AOAC 2000).

Determination of total carbohydrate

The carbohydrate percent was given by: 100 – (percentage of ash + percentage of moisture + percentage of fat + percentage of protein) (Shumaila and Mahpara 2009).

Results and Discussion

Bioassay experiment

The mortality percentage of *T. granarium* larvae and *T. casteneum* adults after exposure to 180 mT (MF) for different times (3 min, 30 min, 1 h, 12 h, 24 h and 48 h) are shown in Tables 1 and 2. According to the results, mortality (%) increased with increased exposure period. The most effective exposure time against

Table 1. Effect of 180 mT magnetic field on mortality (mean ± SE) and adult emergence of *Trogoderma granarium* larvae infesting wheat seeds under laboratory conditions of 30 ± 2°C and 65 ± 5% RH

Exposure time	Mortality [%] of *Trogoderma granarium* larvae after indicated days						Adult emergence [%]
	2	4	6	8	11	14	
3 min	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	5 ± 0.0	8.3 ± 1.7	8.7 ± 3.3	72
30 min	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	8.3 ± 1.7	16.6 ± 1.7	19.3 ± 1.7	65
1 h	0.0 ± 0.0	0.0 ± 0.0	5 ± 0.0	11.6 ± 1.7	16.6 ± 1.7	22.7 ± 1.7	63
12 h	0.0 ± 0.0	5 ± 2.9	10 ± 2.9	16.7 ± 1.7	28.3 ± 2.9	29.8 ± 4.4	58.2
24 h	1.7 ± 17	10 ± 2.9	11.7 ± 1.7	23.3 ± 4.4	30 ± 2.9	43.8 ± 1.7	7
48 h	11.7 ± 3.3	25 ± 2.9	35 ± 2.9	43.3 ± 4.4	45 ± 5.0	56 ± 4.4	7

Table 2. Effect of 180 mT magnetic field on mortality (mean ± SE) and reduction in F_1-progeny of *Tribolium casteneum* adults infesting wheat seeds under laboratory conditions of 30 ± 2°C and 65 ± 5% RH

Exposure time	Adult *Tribolium casteneum* mortality [%] after indicated days						Reduction in F_1-progeny [%]
	2	4	6	8	10	14	
3 min	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	5 ± 2.9	8.3 ± 3.3	10.5
30 min	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	3.3 ± 1.7	8.3 ± 1.7	11.6 ± 1.7	13.0
1 h	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	8.3 ± 2.9	18.3 ± 3.3	18.3 ± 3.3	15.7
12 h	0.0 ± 0.0	1.7 ± 1.7	5 ± 2.9	11.6 ± 1.7	15 ± 3.3	26.6 ± 1.7	17.7
24 h	0.0 ± 0.0	3.3 ± 3.3	8.3 ± 1.7	16.6 ± 1.7	23.3 ± 4.4	36.6 ± 1.7	37.5
48 h	28.3 ± 4.4	41.6 ± 4.4	58.3 ± 8.8	61.6 ± 7.3	63.6 ± 6.0	75 ± 5.8	88.5

both tested insects was 48 h. *Trogoderma granarium* was more resistant than *T. casteneum* in which mortality reached 56 and 75%, respectively, 14 days after the exposure period.

Magnetic field caused moderate mortality percent with *T. casteneum* adults. It affected the insects' mating and female fertility, leading to a good reduction percentage in F_1– progeny which ranged from 10.5 to 88.5%.

Magnetic field was effective against *T. granarium* larvae which have high resistance against most alternatives. It caused reduction in adult emergence of up to 7% after 48 h exposure.

The advantage of magnetization as a pest control method that does not leave undesirable residues has been studied by a few other researchers on stored grain insects. Pandir *et al.* (2013a) investigated the effect of MFs from a DC power supply on the longevity of adults, fecundity and daily egg laying patterns of female *Ephestia kuehniella* and found that mortality increased with increased MF levels and complete mortality was achieved at the level of 10 mT. Pest longevity was significantly reduced with increasing levels of MF. There was no significant difference in the longevity of males and females. Exposing adults to increasing levels of MF significantly influenced daily egg laying patterns and fecundity of magnetized females. Larval emergence from these eggs was completely prevented at the highest level of MF. Pandir *et al.* (2013b) investigated the insecticidal effect of strong magnetic fields on *E. kuehniella* larvae (1 to 2 days) exposed to 1.4 Tesla (T) magnetic fields from a DC power supply at 50 Hz for different time periods (3, 6, 12, 24, 48 and 72 h). Results showed that a level of 1.4 T at 72 h completely prevented the development of the larvae. There was no significant effect on larval survival at 1.4 T at 48 and 72 h. Pandir and Sahingoz (2014) showed that MF caused oxidative stress and cDNA damage as revealed by the comet assay. Magnetic field may be used to determine potential toxic effects as a control agent against *E. kuehniella* larvae. Hozayn *et al.* (2016) studied the effect of magnetic field periods (1 min, 6 and 12 h) exposure of some infected wheat seed varieties (Masr-1, Sids-12 and Sakha-93) with two stored grain insects, *Sitophilus oryzae* (L.) and *Rizopertha dominica* F., to low static magnetic field (30 and 60 mT on mortality (%), and reduction in F_1– progeny (%) under controlled laboratory conditions. Results showed that, the mortality percentage of both insects increased with increasing MFs levels and time exposure. A magnetic field level at 60 mT for 12 h was the most effective against tested insects in which mortality percentage of *S. oryzae* was 56.60, 53.30 and 50.00% with Masr-1, Sakha-93 and Sids-12, respectively, 10 days after the exposure period. At the same level and time, the mortality percentage of *R. dominica* was 45.00, 36.60 and 33.30% with Sids-12, Sakha-93 and Masr-1, respectively. Puja *et al.* (2018) recorded that rearing rice moth larvae on a magnetized diet for 4 h had a negative effect on all biological parameters (larval weight, larval length and mortality) while a magnetized diet for 2 h had a positive effect. A magnetic field, below a certain limit value of intensity, which is hard to define for various organisms, causes an increase of enzyme activity, accelerating their metabolism. Increased enzyme activity under the effect of magnetic fields is observed also in the organisms of animals. It is assumed, therefore, that this can be considered as a general rule of nature. It should also be emphasized that in the effect of magnetic field on living organisms there is an absence of any selectivity of that field. Magnetic field acts on all molecules, and thus also on those that do not require its effect (Wadas 1991).

Storage experiment

A laboratory experiment was conducted to study the efficiency of MF at 180 mT level in the protection of wheat from insect infestation during storage.

According to observed results, MF was very effective in protecting stored wheat crops from insect infestation up to 8 months compared to non-magnetic seeds which were infested after 3 months of storage.

These results indicated that MF represented a safe, powerful alternative in protecting stored seeds. Only a few researchers have investigated the efficiency of MF during the storage period. Hussein *et al.* (2018) used a magnetic field among and between stored grains and seeds for 9 months in which each treatment was provided with 80 similar small magnet pieces. Each magnet was 1.5 cm long with a 14–18 mT magnetic power. These magnets lowered insect and mite infestation by four fold compared to the control seeds.

Seed germination experiment

The effect of magnetic field on plant seed germination has been researched over a very broad range of values of magnetic induction. This experiment was conducted to study the effect of magnetic field on the germination of wheat seeds after 8 months storage.

Results showed that magnetic field had no negative effect on the percent of seed germination. It accelerated the germination percent by 6 hrs compared to non-magnetic seeds. Similar results have been reported by many other researchers such as a study by Aksenov *et al.* (2001). It was demonstrated that a magnetic field of 50 Hz, 30 mT, applied on wheat seeds stimulated the growth of roots and sprouts. Cakmak *et al.* (2010) observed that the application of magnetic field doses of 4 mT and 7 mT promoted germination ratios of bean and wheat seeds. Florez *et al.* (2014) concluded that magnetic treatment improves the germination rate of triticale seeds. In general, most of the parameters recorded for all the doses applied to triticale seeds were better than control values. Furthermore, seedlings from magnetically treated seeds grew taller than the control. Hozain *et al.* (2016) concluded that magnetic field positively affected all germination parameters (seed germination %, seed and seedling vigor traits) compared to untreated seeds.

Seeds components analysis

The effect of MF level at 180 mT for 48 h after 8 months storage on means of wheat seed components including moisture content, crude fats, crude protein, ash and carbohydrates percentages are shown in Table 3. Control seeds were used for comparison.

Results showed that MF level slightly increased total carbohydrate, crude protein and ash percentages which are important for seed germination while it slightly decreased the percentages of moisture, total fats and crude fiber. Decreased seed moisture content was useful for safe storage. Based on certification standards it is recommended that for good quality, long duration storage, prior to storage, the seeds should not have a moisture content above 14 or below 5% (Copeland and McDonald 2004). Seeds stored at a moisture content above 14% begin to exhibit increased respiration, heating and fungal invasion that destroy seed viability more rapidly while below 5% causes seed deterioration.

Table 3. Effect of 180 mT magnetic field on wheat seed components after 8 months storage

Components	Treatment [%]	Control [%]
Moisture	9.92	12.09
Crude protein	10.60	8.95
Crude fats	2.41	3.17
Ash	1.45	0.84
Total carbohydrates	75.62	74.95
Crude fiber	3.21	4.66

Conclusions

Based on the results, magnetic field could provide a good alternative in controlling stored grain pests. It can also protect stored crops from insect infestation for long storage periods without affecting seed germination percent or seed components.

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