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ORIGINAL RESEARCH ARTICLE

Cellophane packaging treated with nano silica is superior to polyethylene in reducing stored irradiated flour from *Tribolium confusum* infestation

T. S. El sayed[1] · **S. A. Rizk**[1] · **R. M. Sayed**[1]

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Abstract

Most packaged food products are attacked and penetrated by insects. Causing reducing food quality. Since, different ways are investigated for controlling stored-product pests without application of chemical methods. So, the present study included laboratory methods to evaluate the effectiveness of two packaging materials, polyethylene and cellophane with silica nano particles to prevent or minimize the insect infestation and grain wastage resulting by the attack of wheat grain by confused flour beetle, *Tribolium confusum*. Studies made to determine the protecting capacity of the two packaging materials through assessing some parameters, number of adults infested poly ethelene and cellophane bags, percentage weight loss of grains, the results revealed that cellophane was the better packaging material than polyethelene, so polyethylene was the susceptible packaging material because it had maximum number of holes as a result penetrations by insects into them. Also, treatment the two types with packaging materials with different concentrations of nano silica protect the treated packaging materials from insect infestation and the protection increase with the increase of the concentration of silica nano particles

Keywords *Tribolium confusum* · Silica nano particles · Insect infestation · Cellophane · Polyethelene

Introduction

Insect pests cause considerable damage to cereal and other food grains, which recently have come to dominate human diets. Most of the countries, particularly in the developing world, are directing their efforts to increase grain output as one of the strategies to cope with increasing food requirements. One of the practical methods to manage these requirements is to decrease losses related to insect infestation (Bakr and Gad 2021)

Stored-product insects can be put into one of two groups with respect to their ability to penetrate packaged goods; penetrators that can chew into packages and invaders that only can enter packages through existing holes (Newton 1988; Highland 1991; Mullen et al. 2012). The products stored in warehouses or retail stores are infested by stored-product insects causing hidden infestations. The type of packaging greatly effects the insect infestation of finished products. There are several types of packaging material used; paper, plastic, aluminium foil or jute. Some materials, such as polymers and paperboard are used in high-value products such as snack foods, and are excellent in preventing insects from entering into packages, but are expensive. Cellophane or polyethylene are used around the world to bag seed and botanicals, however, they are ineffective for preventing insects from entering bags.

The confused flour beetle, *Tribolium confusum* (Herbst) (Coleoptera: Tenebrionidae), is a serious pest of stored products and grain commodities, especially in warmer climates. It has been discovered to be one of the species that is most prevalent in granaries and flour mills in Egypt (Attia et al. 2020). Its presence negatively affects the quantity and the quality of stored grains and grain products (Khanzada et al. 2011). Since the 1950s, chemical approaches have been the mainstay of the treatment of storage insect pests. However, a variety of issues, such as those relating to human safety, environmental effects, chemical residues, and insect pesticide resistance limit the use of these techniques (Yao et al. 2019).

Flour beetles are among the most common pest insects found in stored grain and milled products. Both adults and

✉ T. S. El sayed
taamy2010@yahoo.com

[1] Natural Products Research Department, National Centre for Radiation Research and Technology, Egyptian Atomic Energy Authority, Cairo, Egypt

larvae fed on flour, bean, cereals, spices, pasta, and many other products. They cause serious economic losses by contaminating the product, lowering its nutritive value, and generating favorable conditions for mold and other fungi sp. growth. Some fungi secreate toxic metabolites like mycotoxins (Abbas et al. 2002), which resulted in numerous toxic effects on animal and human health including carcinogenic and immunosuppressive activity (Eaton and Gallagher 1994). In addition, some of the beetles have the ability to produce benzoquinones (BQs) (Yezerski et al. 2000, 2004; El-Desouky et al. 2018), which have a carcinogenic effect (Lis et al. 2011) and give grain a characteristic, unpleasant odor, and infested flour has a pinkish color.

The creation of nanoparticles using nanotechnology has sparked a lot of interest in the food packaging industry. It makes a commitment to the creation of food packaging with improved qualities that aid in extending the shelf life of food goods. In order to maintain food quality and traceability along the supply chain, better packaging, active packaging, and intelligent packaging are developed using nanoparticles. Nanoparticles are useful for creating nanocomposites because of their antibacterial activity, capacity to scavenge oxygen, UV impermeability, and a variety of other features. It is crucial to research nanoparticle migration and interactions with polymer matrix while creating packaging materials since the high surface area to volume ratio might occasionally lead to nanoparticle toxicity (Ashfaq et al. 2022).

Due to its low density, outstanding processability, and low cost, polyethylene is one of the most adaptable polymers (Park et al. 2009). Flexible food packaging frequently uses low-density polyethylene (LDPE) and linear low-density polyethylene (LLDPE), in particular. Because they are heat-sealable and sturdy, tough, clear, good moisture barriers (Stadler et al. 2010). Poor heat resistance and a weak gas barrier, however, make it impossible to keep food. Thus, polyethylene nanocomposites with various organic nanofillers were created in order to overcome these disadvantages and create materials with improved characteristics. Due to the unique advantages of its particles, nano-silica (nano-SiO2) is one of the most popular nanofillers utilised in the creation of nanocomposites.

Cellophane, a multipurpose, non-plastic film created in 1900, is the most popular cellulose-based food packaging material. The 1970s and 1980s saw a boom in the number of publications on cellophane. The films used for commercial cellophane wrapping are transparent and clear (Paunonen 2013)

The aim of this study was to evaluate the effect of preserving flour sterilized by gamma irradiation from infestation with *Tribolium confusum*. And investigate the effect of different packaging materials treated with nanosilica material.

Materials and methods

Insect rearing

Tribolium confusum was reared at 28±2°C and 65±5 R.H. on wheat flour in the Natural Control Laboratory, Natural Products Research Department, National Center for Radiation Research and Technology (NCRRT), Egyptian Atomic Energy Authority, Cairo, Egypt.

Gamma-irradiation

Wheat was gamma irradiated with 1KGy for sterilization using an Indian Gamma cell with dose rate of 0.717 KGy/h located at the National Center for Radiation Research and Technology, Cairo, Egypt.

Evaluation of the ability of *Tribolium confusum* to penetrate polyethylene and cellophane bags treated with different concentrations of nanosilica

Serials of four concentrations of nanosilica were prepared from their stock (0, 6, 9, and 12 ppm) by diluting them with water. Polyethylene and cellophane bags with thickness 4 millimeter was treated with 3 cm^3 of nano silica and left for complete dryness then bags were filled with 20gm of sterilized irradiated crushed wheat after that the bags exposed to 20 adult *Tribolium confusum*. Bags were inspected after 2, 4 and 8 weeks for each

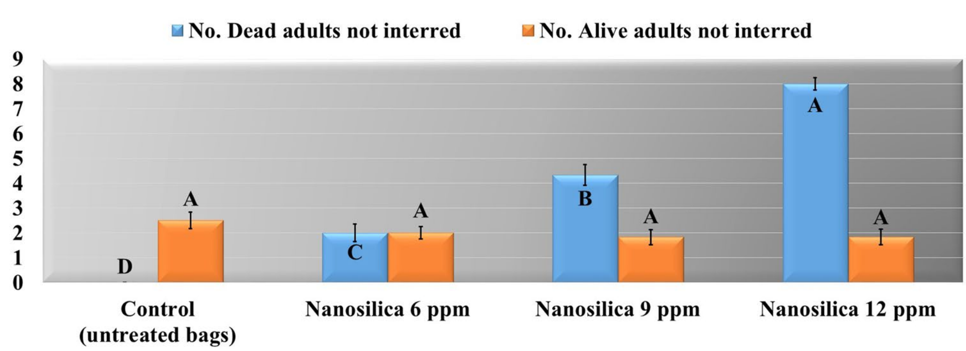

Fig. 1 Effect of polyethelene bags treated with different concentration of nanosilica on number of dead and alive insects around bags treated with nanosilica after 2 weeks. Values represent the mean ± S.E of 6 replicates. Column of the same color that do not share a letter are significantly different (Tukey Pairwise Comparisons)

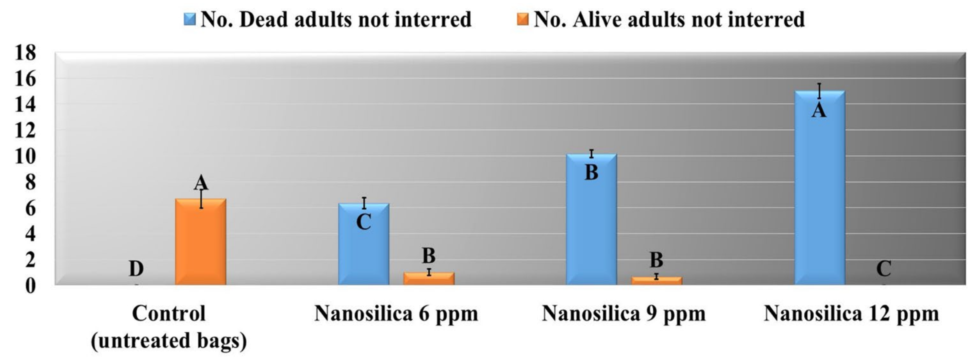

Fig. 2 Effect of cellophane bags treated with different concentration of nanosilica on number of dead and alive insects around bags treated with nanosilica after 2 weeks. Values represent the mean ± S.E of 6 replicates. Column of the same color that do not share a letter are significantly different (Tukey Pairwise Comparisons)

treatment and control. Number of penetrating holes, percent of dead and alive insects around and inside the bags were calculated also the weight loss of wheat.

Statistical analysis

Results were evaluated by analysis of variance using statistical Minitab program followed by different Comparisons' tests (one way and 2-way) to examine the significant differences between the treatments.

Results

Results reveal that we noticed that the number of dead insects around bags increase with the increase of concentration of nanosilica which being 0, 2, 4.33 and 8 for the concentrations 0, 6, 9 and 12 ppm respectively. Statistical analysis showed significant difference between control and different concentrations, as well as between different concentrations with each other. On the other hand, the number of alive insects failed to infest bags were decrease by increasing the concentration. There were no significant differences between control and different concentrations as well as among the different concentrations (Fig. 1).

Data show that the number of dead insects around bags increased with the increase of concentration of nanosilica bags being 0, 6.33, 10.16 and 15 for the concentrations 0, 6, 9 and 12 ppm respectively. Statistical analysis showed significant difference between control as well as different concentrations and also among different concentrations with each other. On the other hand, the number of alive insects failed to infest bags were decreased by increasing the concentration and significant difference were found between control and different concentrations (Fig. 2).

Data indicate that cellophane bags were more efficient than polyethelene bags which exposed to lower LC_{50} of nano silica, in addition resistance ratio, as presented in Fig. (3).

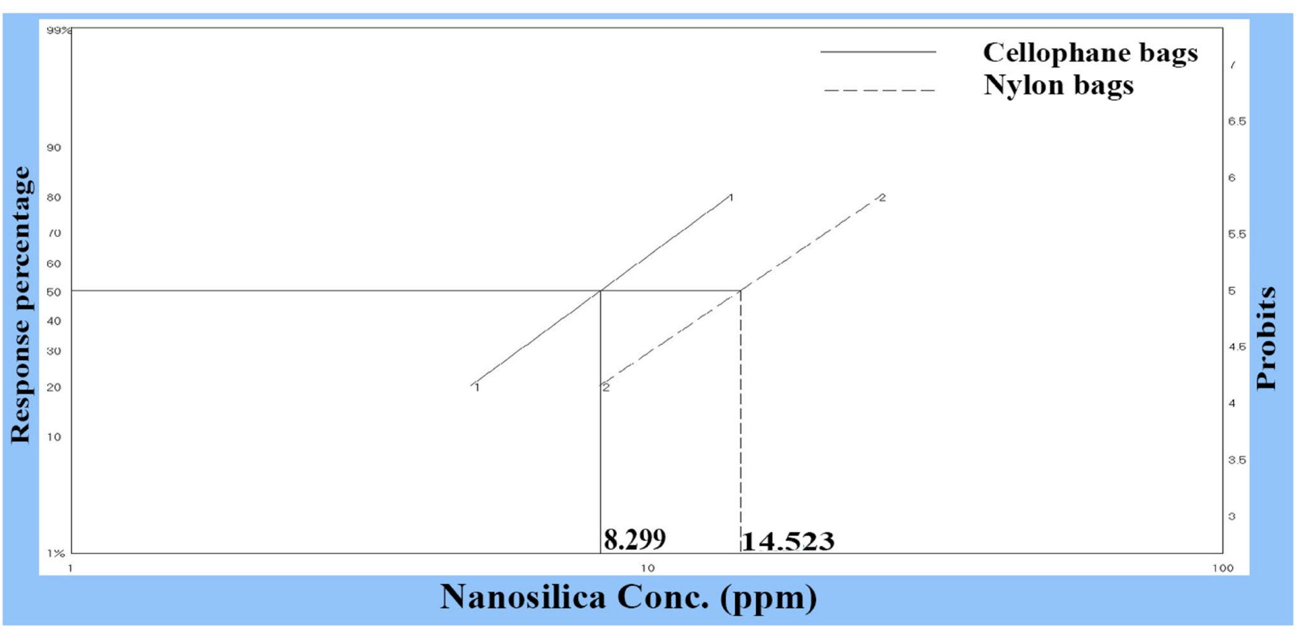

Fig. 3 LC_{50}/LC_{90} levels of nanosilica against *Tribolium confusum* after 2 weeks on different packaging materials

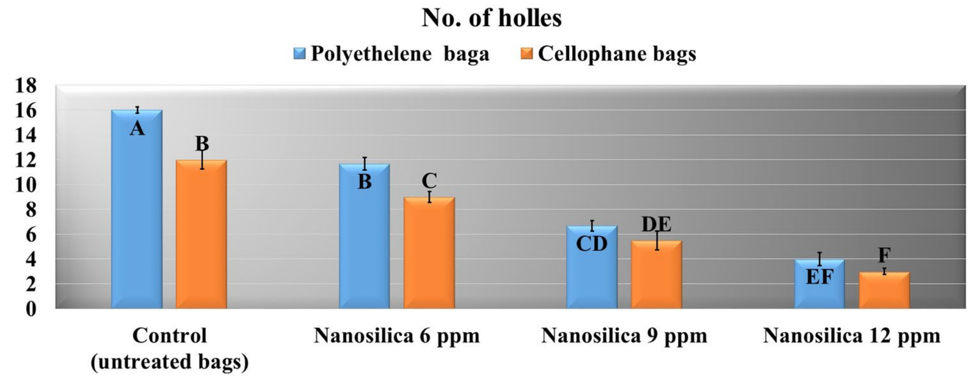

Fig. 4 Effect of nanosilica concentrations on the No. of holes on different bags after 2 weeks stored with *Tribolium confusum*. Values represent the mean ± S.E of 6 replicates. Columns that do not share the same letter are significantly different (2way Analysis Followed by Tukey Comparisons)

The number of holes in polyethelene bags were more in polethelene bags than in cellophane bags and also the number of holes decreased with the increase of concentration that being 16, 11.67, 6.67 and 4 for polyethylene bags and 12, 9, 5.5 and 3 for cellophane bags for the concentrations 0, 6, 9 and 12 ppm respectively. Statistical analysis showed significant difference between different concentrations in case of both polyethylene and cellophane bags (Fig. 4).

The number of infested insects decreased with increasing of concentrations and increase with the increase of the time (2, 4 and 8 weeks) at the two types of packaging materials and at all-time intervals of the different treatments. Statistical analysis showed significant difference between the concentration 12 ppm and all other concentrations in polyethylene bags at two weeks while at four weeks significant difference was found between the concentrations 12 ppm compared with control; whereas at 8 weeks significant difference was found between all concentrations. On the other hand, in cellophane bags statistical analysis showed significant difference between the concentration 12 ppm and all other concentrations at two weeks, while at four weeks statistical analysis showed significant difference between all the concentration except between the control and concentration 6ppm. Also, in case of polyethylene bags at different concentrations at different time significant difference was found between 8 weeks and other time (2 and 4 weeks) in cellophane bags statistical analysis showed significant difference between the number of infested adults at 8 weeks and those at other time (2 and 4 weeks) in cellophane bags (Fig. 5).

Results reveal the effect of nanosilica different concentrations on number of *T. confusum* larvae produced in different sac materials after different intervals time (2, 4 and 8 weeks) for both polyethylene or cellophane bags from the fig. in all treatments the number of produced larvae were zero at the first two weeks but after 4 weeks the number of produced larvae were 128.5, 105.83, 91 and 62.17 for polyethylene bags and 116.83, 75, 32.17 and 11.83 for cellophane bags After 8 weeks the number of produced larvae were 79.83, 48.17, 29.33 and 11.83 for polyethylene bags and 88.67, 19.83, 11.17 and 0for cellophane bags for the concentrations 0, 6,9 and 12 ppm respectively. Statistical analysis showed significant differences between different concentrations polyethylene bags and cellophane bags at 4 and 8 weeks (Fig. 6).

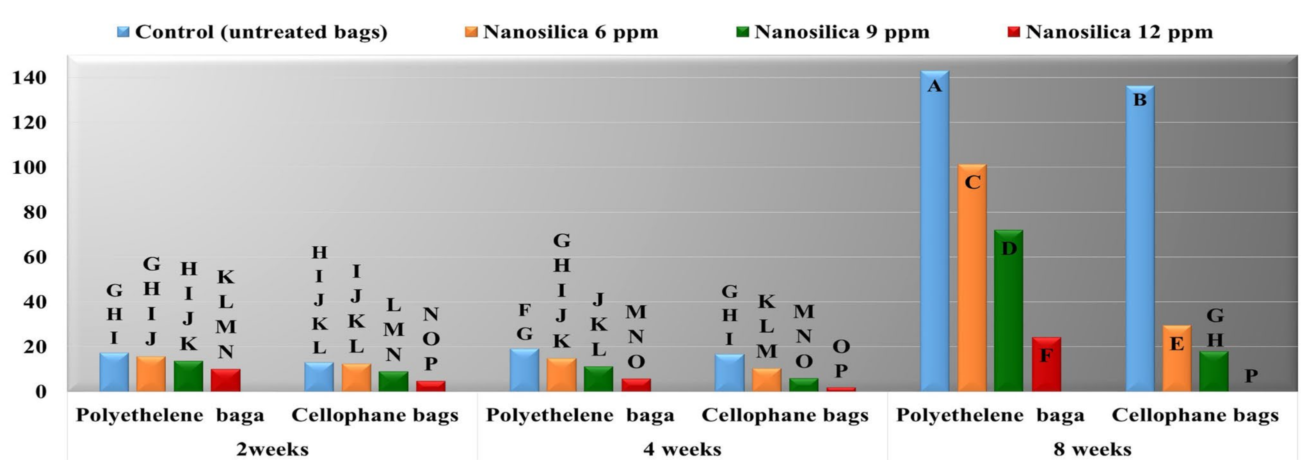

Fig. 5 Effect of nanosilica concentrations on number of *Tribolium confusum* infested different bags materials after different intervals time. Values represent the mean of 6 replicates. Columns that do not share the same letter are significantly different in Comparing to Control after 2 Weeks (3way Analysis Followed by Tukey Comparisons)

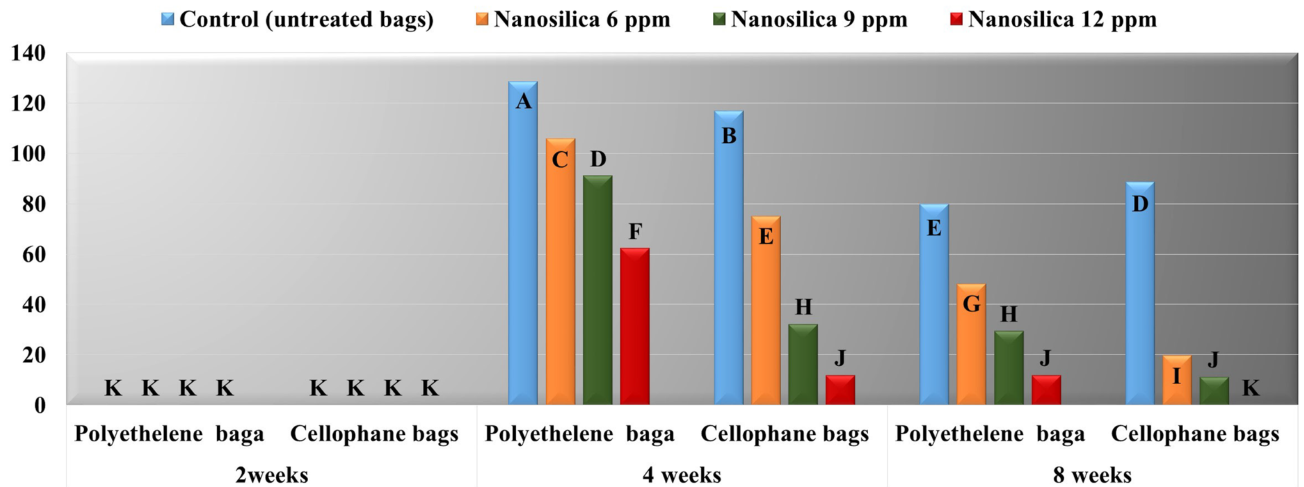

Fig. 6 Effect of nanosilica concentrations on number of produced larvae of *Tribolium confusum* inside different bag materials after different time intervals. Values represent the mean of 6 replicates. Columns that do not share the same letter are significantly different in Comparing to Control after 2 Weeks (3way Analysis Followed by Tukey Comparisons)

Effect of nanosilica concentrations on % wheat weight loss by *T. confusum* after different time intervals from the table it was noticed that percent weight loss in polyethylene bags were 1.44, 1.25, 1.01 and 0.68 for 0.69 and 12ppm, respectively. While in case of cellophane it was less than in polyethylene being 1.21, 0.95, 0.62 and 0.27. By increase the time to 4 and 8 weeks the percent weight loss increase in both polyethylene and cellophane bags also weight loss decrease with the increase of the concentration. Statistical analysis showed significant differences between control and conc. 9 and 12 ppm in polyethylene bags after 2 weeks and between different concentrations in cellophane bags. After 4 and 8 weeks significant differences were found between different concentrations in both types of bags when compared percent weight loss in the two types of bags cellophane was better than polyethylene (Fig. 7).

Discussion

Reducing grain and food product losses during storage can help strengthen food security more effectively than an increase in production can (Kumar and Kalita 2017). Our results showed that nano silica protect grains from infestation these agree with Dash et al. (2022) who found that Nanoparticles (NPs) have acquired significance in technological

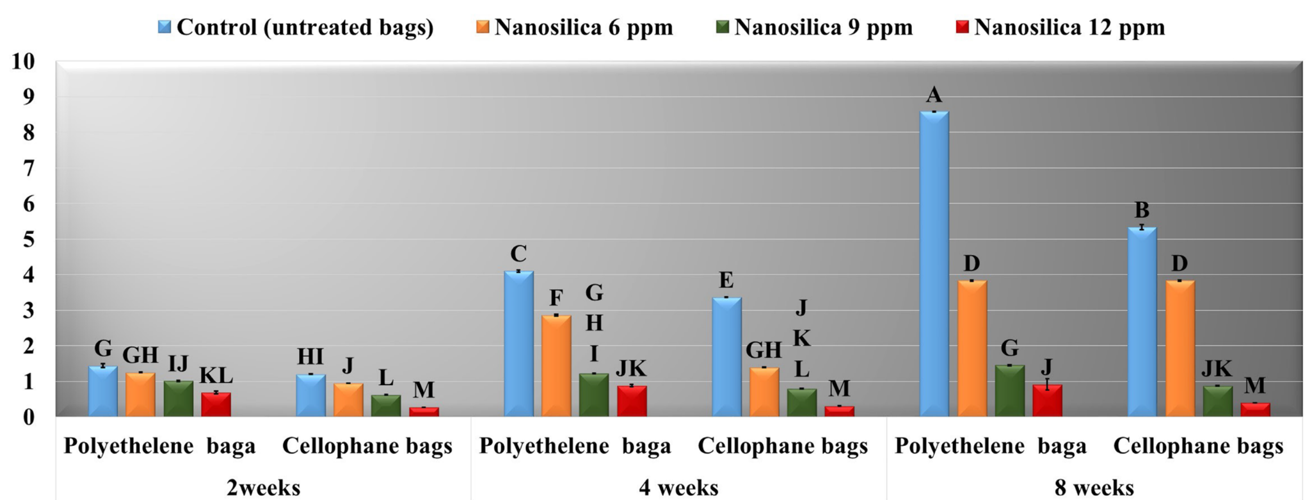

Fig. 7 Effect of nanosilica concentrations on %wheat weight loss by *Tribolium confusum* after different time intervals. Values represent the mean ± S.E of 6 replicates. Columns that do not share the same letter are significantly different in Comparing to Control after 2 Weeks (3way Analysis Followed by Dunnett Comparisons)

breakthroughs due to their unique properties, such as size, shape, chemical composition, physiochemical stability, crystal structure, and larger surface area.

The incorporation of nanoscale fillers in the polymer matrix would assists in the alleviation of packaging material challenges while also improving functional qualities. These polymers incorporating nanocomposites all have increased barrier properties, thermal properties including melting point and glass transition temperatures, and altered functions like surface wettability and hydrophobicity.

The current findings demonstrated the efficacy of SiO2-NPs against insects that feed on stored goods. These findings are consistent with those of Benhalima et al. (2004), Stadler et al. (2010), and Debnath et al. (2011) who reported the effectiveness of nanomaterials as an alternative pesticide against insects that feed on stored grains.

Our findings indicated that nanoparticles might contribute to the development of novel insecticides, and Onyeka et al.'s (2008) assertion of the same fact was supported by our data. There haven't been many studies done to examine the toxicity of nanoparticles on insects, particularly storage insects.

According to Yang et al. (2009), nanoparticles containing garlic essential oil are effective against *T. castaneum* (Herbst). In order to tackle pests that have developed a resistance to chemical conventional pesticides, a new strategy has been developed using nanoparticles as an unconventional pesticide.

Under laboratory conditions, silica nanoparticles have a wide range of applications as insecticides on several insects, including *Sitophilus oryzae* L., *T. castaneum* (Herbst), and *Rhizopertha dominica* F. (El-Samahy et al. 2015).

Insect control mechanisms rely on the cuticular lipids' structural integrity to protect their water barrier and thwart dehydration-related mortality. In the meantime, silica nanoparticles cause insects to die by physically sorbing into the lipids of the cuticular.

Moreover, Barik et al. (2008) announced that higher concentrations of silica nanoparticles in our study reduce penetration of insects through packaging materials this agree with Salem et al. (2015) who found that, aluminum oxide (Al_2O_3) and zinc oxide (ZnO) were used as stored product insect protectants compared to malathion as standard reference. Results obtained showed that malathion had the highest adverse effect on the all parameters studied of *T. castaneum* adults viz, mortality, offspring and weight loss percentage. Data obtained indicated that the increasing of concentration and exposure period caused increasing in mortality (%) and decreasing in weight loss (%). Also results accentuated that the two nanoparticles (Al_2O_3 and ZnO) significantly inhibited the number of progeny and weight loss (%) and the concentration of 2 g/kg wheat grain had the highest effect based on the LC_{50} values ZnO was had the most effect compared to Al_2O_3 nanoparticles.

Our results showed that cellophane was more effective than polyethelene, this agree with Allahvaisi (2016) when found polymers in here rank generally from easiest to most difficult to penetrate: polyethylene, Cellophane, Polyvinylchloride and Polypropylene. Also, Cline (1978) stated that penetration of large larvae and adult insects of many species of stored pests to polyethylene and cellophane polymers with a thickness of less than 29 µm is possible.

Acknowledgement We confirm that this work is original and has not been published elsewhere, nor currently under consideration for publication elsewhere. We confirm that the results should be presented clearly, honestly, and without fabrication, falsification or inappropriate data manipulation. Also, no data, text, or theories by others are presented.

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Availability of data and material All data and materials are available if requested.

Declarations

Ethics approval and consent to participate Not applicable

Consent for publication All authors declared that there is no any issues relating to journal policies.

Competing interests The authors declare that they have no conflict of interest.

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