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A review: Effectiveness of packaging materials treated with insecticide and plant extract against *Tribolium castaneum* and *Trogoderma granarium*

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ABSTRACT

The quantitative and qualitative losses in all commodities occurred due to stored product insect pests. Insects are responsible for causing a lot of damage to stored products and stored grains, they cause up to 5-10% damage in stored products of temperate zone and about 20-30% damage in tropical zone. These insects are very significant in causing post-harvest losses, which leads up to 36%. These insects also act as a vector of various diseases that are dangerous for the health of animals and human beings. In world annually about 25% losses has been observed during post-harvest process which ranges from 600-800 million tons of cereals. There are 24% of the reduction reported in grains storage due to attack of insect pest, which estimated a cost of $25.8 billion USD. In the developing countries there are 1 to 5% more post-harvest losses as compared to developed country, but it depends on the product or crop. Insects of stored grains caused losses including: reduced nutritional value; damage seed embryo; poor germination of seed; weight loss of grains; changes of flavor and mould formation. Throughout the world the most injurious and damaging pests of stored products are *Tribolium castaneum* and *Trogoderma granarium*. *T. castaneum* (Herbst) red flour beetle is one of the most important pest of stored grain. Grain and its quality is greatly affected by the attack of *T. granarium*. Pest control in stored products is a very major problem in developing countries. During the storage of wheat *T. granarium* (Everts) is responsible for causing both quantitative and qualitative losses. *T. granarium* larvae stage is the most damaging stage whereas the adult stage of *T. granarium* is unable to cause damage. The product packaging is the final step of the protection against insect infestation by the processors. Around the globe, especially in developing countries, there is no need to use bulk bins or elevator silos, bags can also be used to stored grains. Instead of using direct treatment of grains the approach of using insecticide-treated bags greatly capturing the interest of stakeholders. To prevent from infestations in stored product of grains, there is used to develop alter-native strategies such as botanicals. These are ecofriendly, pest specific, nontoxic to humans, non-phytotoxic, less pesticide resistance and locally available. For the storage of cereals different

kinds of packaging material like cloth bags, PICS bags polyethylene, polypropylene and jute bags are used. PICS bags are very important because they have low cost of input and also prevent the penetration of insects due to its hard surface. To evaluate the resistant packaging material against different insects of stored product keeping in view packaging type, thickness or insecticide-included bags for safety of stored-product. Application of repellents is very important because it needs a lot of research work. The efficacy of repellents is still questionable because they can penetrate packaging surface and damage food stuffs and only few chemicals are approved by EPA or FDA.

Key words: Packaging materials, insecticide, plant extract, *Tribolium castaneum, Trogoderma granarium*

INTRODUCTION

Insects are responsible for causing a lot of damage to stored products and stored grains, they cause up to 5-10% damage in stored products of temperate zone and about 20-30% damage in tropical zone (Nakakita, 1998). These insects are very significant in causing post-harvest losses, which leads up to 36% (Tefera, 2012). These insects also act as a vector of various diseases that are dangerous for the health of animals and human beings. For example, (Larson *et al.*, 2008) shows the evidence of enterococci in insects of stored products, which basically act as a reservoirs for various active genes and antibiotic resistant genes.

In Africa women produce "soumbala" by fermentation and cooking of seeds which is used in preparing various sauces. In the rainy season production of *Hibiscus sabdariffa* grain takes place, starting from the month of June and extends till October. Grains which are stored by producers are the main source throughout the whole year, and can be stored from three to ten months. They can be attacked by pests and insect during storage, if they are not properly secured. In Sub-Saharan Africa efforts have been made to increase the production of food during recent years by research and development (Anankware *et al.*, 2012).Throughout the world the most injurious and damaging pests of stored products are *Tribolium castaneum* (Sarwar *et al*., 2018) and *Trogoderma granarium* (Burges, 2008). *T. castaneum* (Herbst) red flour beetle is one of the most important pest of stored grain (Shafique *et al.*, 2006; Hulasare *et al.*, 2003). Grain and its quality is greatly affected by the attack of *T. granarium* (Ahmedani *et al.*, 2009). Pest control in stored products is a very major problem in developing countries. During the storage of wheat *T. granarium* (Everts) is responsible for causing both quantitative and qualitative losses (Prasad *et al.*, 1977). *T. granarium* larvae stage is the most damaging stage whereas the adult stage of *T. granarium* is unable to cause damage (Parashar, 2006).

According to literature the *Trogoderma granarium* is very dangerous for our food. The sections of insect in wheat flour cause reduction in sale of milling industries (Perez-Mendoza *et al.*, 2003). Among the international pests of cereals, stored grains, fruit and nuts the red flour beetle, *Tribolium castaneum* (Herbst) are most important (Fedina and Lewis, 2007). Use of woven bags is one of the low-cost method of storing grains but this method needs to apply the insecticide (De Groote *et al.*, 2013; Kamanula *et al.*, 2010; Maina *et al.*, 2016). In Sub-Sahara region for storing maize and some other crops hermetic storage bags were used for past ten decade (Baoua *et al.*, 2014; De Groote *et al.*, 2013).

Many companies have applied package-testing programs in order to develop resistance against insect attack (Mullen, 1994). Purdue Improved Crop Storage (PICS) bags contains two layers of high density polyethylene (HDPE) surrounded by a polypropylene bag, they give an excellent protection against bruchid seed beetles to cowpea grain in West Africa (Baoua *et al.*, 2013; Baoua *et al.*, 2012; Murdock *et al.*, 2012).

Repellents, means having the ability to repel insect to enter or move across a surface which is treated with these repellents. The use of coating of these repellent on packages is helpful in order to prevent insect infestation at that portion where further research is to be conducted (Mullen *et al.*, 2012). Highland (1978) recorded the progress of repellent treatments as a priority. Different repellent formulations have been tested through the years. Natural and synthetic combinations were used in the studies of senior authors. They include insect growth regulators neem oil, methyl salicylate and DEET derivatives (Mullen *et al.*, 2012). EPA was accepted as Provision Gard™ in 2009, in which IGR methoprene was used and it is also used in many package applications now a days. Provision Gard™ is very useful in order to prevent the Indian meal moth entry.

For the stored-product insects present in mills and warehouses insecticides with various liquid formulations and aerosols were applied for managing pests (Toews *et al.*, 2005; Peckman *et al.*, 2006; Arthur and Campbell, 2008)

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Malathion, pirimiphos-methyl (Actellic) and chlorpyrifos-methyl plus deltamethrin were used in Unites States for protection against insects of stored grains for long periods (Subramanyam *et al.*, 2012).

Spinosad is an insecticide with reduced-risk and have low mammalian toxicity, it is basically the fermentation products of an *Actinomycete bacterium* (Mertz and Yao, 1990; Thompson *et al.*, 2000). The United States Environmental Protection Agency permitted spinosad to be used on stored grains in 2005 (Anonymous, 2005). Scientific data having enough volume was collected from trails of field and laboratory having various formulations for field crops which show spinosad effective to control insect pests of stored grains (Fang *et al.*, 2002; Toews *et al.*, 2003; Getchell and Subramanyam, 2008; Athanassiou *et al.*, 2010; Kavallieratos *et al.*, 2010; Vayias *et al.*, 2010).

Deltamethrin and b-cyfluthrin are pyrethroid insecticides, these two insecticides are registered by US-EPA for surface application (Allahvaisi, 2012). When the insects are open on treated grains immediate death of these insects take place, and if they are removed their death may be delayed (Getchell and Subramanyam, 2008; Athanassiou *et al.*, 2010).

Now spinetoram, was presented as a different spinosyn insecticide which have more effectiveness and its speed of action is faster as compared to spinosad (Dripps *et al.*, 2008; Sparks *et al.*, 2008). Natural spinosyns are used for preparing Spinetoram (spinosyn J and spinosyn L) which is produced by *Saccharopolyspora spinosa* and used to make two artificial modifications. Mode of action of spinosad and Spinetoram is same and it is also active by the contact method and ingestion (Dripps *et al.*, 2011). Broad research with spinetoram in contradiction of field pests shows that spinetoram is very usefull against a number of pest species. In fact,(Sparks *et al.*, 2008) and (Jones *et al.*, 2010) noticed that the effectiveness of spinetoram was greater as compared to spinosad in controlling insect pest of stored grains.

Plant extracts are more effective in the way as they do not cause pollution, they produce less toxicity and are bio-degradable. Some plants naturally have the repellent effect against many stored grain pests (Ahmed and Eapen, 1986; Nawrot, 1982; Behal, 1998). In many studies it was observed that *Eucalyptus camaldulensis* have fumigant potential which help in the control against *Tribolium castaneum* (Tunc *et al.*, 2000; Channoo *et al.*, 2002; Negahban and Moharramipour, 2007).

According to the studies of last 20 years, in order to control some insect pests and pathogens by *Azadirachta indica* extract along with its compounds was proved best (Mwangangi and Mutisya, 2013). Different developmental stages of larvae can be controlled by *A. indica* especially after emergence from the eggs, but it is not too much effective in controlling the mid stage and late stage instars (Xie *et al.*, 1995). The *A. indica* was proved too much effective by the researchers from various parts of the world, they experienced and noticed the various features and parts of the plant, used them to control *Tribolium castaneum* and then recorded the data that shows the success of *A. indica* plant extract to control the *T. castaneum* without causing any adversative effect on the surrounding environment (Saeed *et al.*, 2016).

Eucalyptus camaldulensis essential oil shows a wide range of biological activity against pathogens including fungi, insects, bacteria, mites and also some weeds. It also provide a very simple, cheap and environmentally friendly (non-polluting and less or no toxicological concerns) alternate in order to control pest. Although its vapor forms are too much toxic towards a number of microorganisms as well as insects, hence they could commercially misused as fumigants for stored products and packaging materials, thus help in the prevention of insect infestation (Batish *et al.*, 2008).

REVIEW OF LITERATURE

Cline (1978) conducted an experiment on the ability of larvae to enter in packaging materials that were flexible. He determined large as well as small larvae of two species of stored-product insects. These insects were limited with or without availability of food. They were present in pouches made of polyethylene, cellophane, paper, aluminum foil, polyvinylchloride, polyester, or polypropylene. Larvae of *Oryzaephilus mercator*, *Cathartus quadricollis* and *Cryptolestes pusillus* do not show penetrations. *Tribolium castaneum* larvae show less penetrators. Only *Tenebroides mauritanicus* as well as *Trogoderma variabile* Ballion larvae have ability to penetrate to all 7 materials. Larvae of some other species were also observed and it was noticed that they penetrate 5 of the 7 materials. Polypropylene, Foil and polyester, resist penetration. Penetration mostly take place within 24 hours and highest within one week. Some larvae converted to adults and made more penetration in adult stage as compared to larvae.

Mullen (1994) developed a technique to evaluate the beneficial aspects of odor barriers and to know about the package content effect in consumer size packages along with its resistance against the insects. *Plodia interpunctella* helps to know about the difference between non-food and food products. For oviposition it provides a suitable site. By using this technique less time was needed for evaluation of new methods and materials that help in packaging that were insect free.

Arthur (1997) treated plywood, tile panels and concrete which were 0.094m2 with deltamethrin which was 0.05%, it was dusted at the rate of 3.45 grams per m^2, it was bio assayed every week with *Tribolium confusum* and *Rhyzopertha dominica* for 21 weeks. He exposed the insects for about 24 hours and then either kept for additional 96 hours on the surface which was treated or may be removed and are held for 96 hours. It was observed that average survival at 24 and 120 hours of morality assessment was 3.8% and 2.8%. The experiment shows that *T. confusum* survival for three different type of surfaces was greater in residual study as compared to recovery study. The LT_{95} in case of 24 and 120 hours was 0 and 0.2 weeks for plywood and for concrete it was 3.2 and 4.3 weeks while for tile it was 6.0 and 6.4 weeks. Deltamethrin dust helps to control both *R. dominica* and *T. castaneum,* there were not a very clear difference between the two methods of exposure and also between these three surfaces.

Ahmedani *et al.* (2007) worked on Khapra beetle and came to know that it cause serious damage to safety and security of global food. It is responsible for causing serious threat to stored grains by heating and feeding grains. It has the ability to withstand low moisture content and may withstand starvation for about three years in larval stage. *Trogoderma granarium* is concerned with quarantine measures the main reason is its international trade spread. The entry of pest is restricted due to inspection at ports. Economic importance of this pest was aggravated due to its resistance against various insecticides. The study helps to know about the quarantine importance, biology, economic losses, habitat and IPM of this beetle.

Ali *et al.* (2007) worked on six strains of stored grain pest adults including *Rhyzopertha dominica* viz. Chichawatni , Karachi , Sialkot ,Wazirabad , Lahore , and Multan and treated them with an organophosphate malathion, and a deltamethrin , synthetic pyrethroid, separately and also in two combinations. It was observed that C strain proved to be most resistant against Malathion, while M strain was less resistant. On the other hand, most resistant strain to deltamethrin was M strain, whereas most susceptible was L strain. A mixture of malathion and deltamethrin was proved to be effective against K, M and S strain with LC_{50} having 4.71, 5.33 and 8.38 ppm, while mixture of 10:1.5 and 9:2 proved most effective for W strain and M strain. *R. dominica* do not have any specific pattern which shows susceptibility to both mixtures. The results shows that mixture 10:1 with LC_{50} having range between 4.53 to 24.94 ppm, mixture 10:1.5 with LC_{50} having range between 4.52 to 8.74 ppm and mixture 9:2 with LC_{50} having range between 3.13 to 61.53 ppm were most effective for all the strains.

Athanassiou *et al.* (2008) examined the effect of insecticides of spinosad, against lesser grain borer adults, the rice weevil, the confused flour beetle, on wheat and larger grain borer, on maize. Doses used includes 0.01, 0.1, 0.5 and 1 ppm. At three temperatures, 20, 25 and 30°C bioassay was done with relative humidity levels of 55 and 75%. Mortality rate of *Sitophilus oryzae* and *Rhyzopertha dominica* was recorded more after exposure of 21 days. Mortality of *R. dominica,* increased as temperature increased while for *S. oryzae* mortality increased with increase in temperature but with the decrease in relative humidity. Mortality was low at 20°C for *S. oryzae.* Mortality was low between 0.01 and 0.5 ppm dose for *Tribolium confusum*. Mortality exceeded 90% at 1ppm and 30°C after 21 days of exposure. In various combinations, spinosad efficacy changes in accordance with temperature and humidity. The results indicated that, *R. dominica* and *Prostephanus truncatus* were too much susceptible to spinosad, *S. oryzae* was also susceptible, whereas *T. confusum* was less susceptible.

Abdel-Sttar *et al.* (2010) worked on *Schinus molle* fruit and leaf essential oil that showed insecticidal activity and insect repellent activity against *Tribolium castaneum* and *Trogoderma granarium*. Almost 65 components were present in these oils by GC-MS analysis. Oil composition was dominated with hydrocarbons and monoterpenes present in the highest amount in leaves and fruits, 74.84 and 80.43%, respectively. The experiment shows that p-Cymene was a major constituent of both oils. The efficacy of essential oil against *T. castaneum* and *T. granarium* recommend that it provide leads for active insecticidal managers.

Athanassiou *et al.* (2011) conducted an experiment on two liquids and a dry pre-commercial release formulation of spinosad. It was applied at the rate of 1 ppm against five species of stored-grain insect on short-grain rice, wheat, maize and long-grain rice. Effect of spinosad was observed on all these grains expect maize and compared with a new protectant named as chlorpyrifos-methyl plus deltamethrin. After 7 to 14 days 99.0–100.0% mortality of lesser grain borer was observed on long-grain rice, wheat and short grain rice treated with and chlorpyrifos-methyl plus deltamethrin and spinosad. Adult progeny of *Rhyzoperha dominica* was decreased by 99.7–100.0% after 42 days in these products as compared to progeny production on wheat which was not traeted. It was observed that mortality and reduction in adult progeny was reached to 100% in the rice weevil, maize weevil, red flour beetle, only when treated with chlorpyrifos-methyl plus deltamethrin. Spinosad in liquid formulations was proved to be most effective against the *Plodia interpunctella,* Indian meal moth, on maize and wheat. The effectiveness of spinosad on the other species depends upon formulation, commodity and exposure time except in case of *R.domonica.* Chlorpyrifos-methyl plus deltamethrin was proved to be more effective against insect species.

Chung *et al.* (2011) conducted research to evaluate the different types of plastic films along with their barrier properties against two types of insects such as *Tribolium castaneum* adults and *Plodia interpunctella* larvae, the morphological damage found in these insects was also observed. They used four different types of plastic films by using penetration apparatus, these films vary in thickness and were used for tests of insects penetration these films includes casted polypropylene having range of 20 to 25 micrometer second one is oriented polypropylene having range of 20 and 30 micrometer, third is linear low density polyethylene of 40 and 50 micrometer and a polyethylene terephthalate of 12 and 16 micrometer thickness. The percentage of penetration varies depending upon the thickness and type of film in which they penetrates. It also depends upon the tensile strength and elongation factor. LLDPE was considered as best film for insect penetration and this film have lowest tensile strength and highest elongation factor. By the help of this penetration the mouthparts were observed clearly and it was found that shaper mandibles are present in *P. interpunctella* larvae as compared to *T. castaneum.*

Sutton *et al.* (2011) worked on various packaging surface and wheat flour and they were exposed to various aerosol formulations. The mixture was specific to the insecticide labels and give 100 to 1 ratio of active ingredients methoprene and pyrethrin. After every 2 weeks for 16 weeks bioassay was conducted by placing 4 weeks old red flour beetle larvae or the confused flour beetle on treated packaging surface having untreated flour and also on treated flour. Red flour beetle was more susceptible as only 2% of larvae were developed into adults and does not depend upon the concentration of pyrethrin. Mostly the larvae of red flour beetle was not emerged to pupa because they die. They have the ability to develop on treated packaging surface but still they were unable to emerge as adult. Whereas larvae of the confused flour beetle were able to emerge as adult or pupa hence they were somehow resistant. However when they were exposed to about 3% methoprene and pyrethine treated packaging surface or flour it results in reduced adult emergence.

Vassilakos *et al.* (2012) worked on a chemical insecticide named as spinetoram which belongs to class spinosyn. They demonstrated the effect of this insecticide on various insect species which attack on stored grains. Six stored products were used and this insecticide acts as grain protectant. Lesser grain borer, the confused flour beetle, the larger grain borer, the rice weevil, granary weevil and sawtoothed grain beetle were tested. Concentrations of spinetoram achieved were 0.01, 0.1, 0.5, 1, 2, 5 and 10ppm by using adult stages of these species on wheat. After the exposure of 1, 2, 7, 14 and 21 days mortality was recorded. For emergence of offspring wheat grains were observed after 65 days. Larger grain borer and lesser grain borer were proved to be more susceptible. They show 100% mortality after seven days of exposure with 0.1ppm spinetoram on wheat and maize. The confused beetle show 95% mortality after 14 days with 10ppm concentration hence proved to be least susceptible. Sawtoothed grain beetle show 95%mortality after 14 days exposure at 5ppm hence it was limited susceptible. The results shows that this insecticide proved to be effective for protection of stored grains but it depends upon the species of insect or pest, concentration and exposure time.

Kavallieratos *et al.* (2013) conducted an experiment on chlorantraniliprole which belongs to the group of chemicals called anthranilic diamides. It has a discrimination that it proved to be beneficial against arthropods and also have low mammalian toxicity. Different doses were used and exposure interval was 7 and 14 days, with formulation of various combinations. Progeny production was observed after 45 days of exposure in *Liposcelis bostrychophila* adults while after 60 days in case of *Sitophilus oryzae* and *Tribolium confusum* adults also for *Ryzopertha dominica*. The results indicated that after 7 days of exposure, mortality rate was less in maize and whole rice for *L. bostrychophila* as compared to other commodities. Increase in dose results in increased mortality rate. Same trend was observed after 14 days of exposure.

De Groote *et al.* (2013) worked on the knockdown activity of fourth stage larvae of both male and female *Plodia interpunctella* after 1, 24 and 48 hours and mortality after 24 and 48 hours, they were then placed on glass, porous and ceramic tile. In this experiment a groups of 20 larvae were placed for about 5 or 15 minutes in an environment which is artificially lighted at 25±2°C and 60±10% RH. After 24 hours of the treatment tests were carried 5 replicates were taken for each test and also for the control. The mean percentages of the knockdown activity for both sexes were observed after one hour from the contact with various surfaces. The highest mean percentage mortality was detected after about 15 mints in female larvae as compared to male larvae.

Saleem *et al.* (2014) studied the insecticidal activity of some essential oils against three major pests of four plants that were grown locally including *Eucalyptus camaldulensis, Datura stramonium*, *Moringa oleifera* and *Nigella sativa.* These insects includes *Tribolium castaneum, Cryptolestes ferrugineus* and *Trogoderma granarium* and they were responsible for causing economic loss to stored products. These insects were fumigated with different concentrations such as 5, 10, 15 and 20 µl/L. Kept at laboratory conditions with relative humidity of 30±2°C and 65±5%. Mortality was effected by essential oils at all concentrations and period of exposure. Most toxic essential oil against *T. granarium* and *C. ferrugineus* was *D. stramonium* while results also showed that *N. sativa* had the highest fumigant mortality rate against *T. castaneum*. It was proved that the most susceptible test insect having 23.79 % average mortality rate was *C. ferrugineus* then *T. castaneum* (17.11%) and at last *T. granarium* (12.27%).

Kavallieratos *et al.* (2015) conducted an experiment on insects of stored-product. They exposed these products to grain protectants for different time periods. They exposed adults of these species such as the lesser grain borer, the granary weevil, and the red flour beetle, for 1, 4, 8, and 24 hours on pyrethroid deltamethrin treated brown rice. They were labelled at rate of 0.5ppm, and then detached and positioned on untreated rice. Adults were exposed on treated brown rice mixed with some untreated rice. Initial and delayed mortality of these exposed adults was not more than 7% for any exposure period, but production of progeny for *T. castaneum* was lower as compared to the other species. The increasing amount of treated rice results in decreased production of progeny of *R. dominica* but not for *Sitophilus* species. They obtained mixed results for *T. variabile* and *T. castaneum*. It shows that it is necessary to exposure for long time and to treat the entire mass of rice to control stored-product beetles completely.

Amadou *et al.* (2016) conducted an experiment to protect *Hibiscus sabdariffa* from insects by using hermetic triple layer PICS bags. Bruchid belongs to *Spermophagus sp*. was a major pest of stored grains. When the grains infested with pest was stored for six months in special bags used by farmeres its population increased to about 33 time initially. During this time period number of holes per 100 seeds were also increased and reached from 3.3 to 35.4 holes. In PICS bags number of holes does not increased. Weight loss was also not observed in PICS bags while in woven bags weight loss was 8.6%. Within six months rate of seed germination dropped in woven bags while in PICS seed germination rate remains the same. Hence PICS bags were safe to store grains after harvesting.

Abdelghany *et al.* (2016) investigated the effect of pea protein, DE, methoprene and DEET in order to reduce the insect penetration in stored products. They measured the survival of *Lesioderma serricorne* young larvae and eggs. 27 to 67% mortality was observed due to application of insecticides. These insecticides were not too much different but all of them were responsible for causing more mortality as compared to control. The penetration ability of adults in jute and polyethylene material was measured by second test. It results in penetration of 85% of adults within 24 hours. Third test was conducted to measure the insecticide which prevent flour in polyethylene bags and jute. The results indicate that DEET was more effective.

Paudyal *et al.* (2017) used a specific technology to overcome losses of postharvest crops caused due to attack of insects. Pre-fumigation of maize was done by using some treatments including PP bags containing maize which was treated by Betallic super, Zerofly bags containing maize that was not treated and a control with PP bags having untreated maize. Time period for that experiment was from February to August, four different locations were selected for this experiment. Data was recorded on monthly basis which includes number of insects that were alive or dead and moisture content along with weight loss of maize and damaged kernels due to attack of insects. Betallic super and Zerofly bags help in reduction of damage caused by insects as compared to control. After 6 months IDK in control increased to about 36%. For about 4 months the Zerofly bags proved to be effective against *Cryptolestes* and *Tribolium spp*. During six months of storage average loss in Zerofly was more than 3.68%, while in PP bags weight loss was about 11.88%. The results proved that Zerofly proved to be more effective if grains used for storage was insect-free.

Nickolas *et al.* (2017) exposed seven stored products adults of beetle species on outside and inside surface of polypropylene polymer bags and integrated them with deltamethine. He exposed the beetles for about 60,120 and 180 minutes and placed at same treatment arenas for one, three and five days and after five days these insects were transferred to untreated arenas for more five days. After one hour *Trogoderma variabile, Rhyzopertha dominica,* the large grain borer. *Prostephanus truncatus and Tribolium castaneum* were found at outside and inside surface of bag. During exposure the mortality rate of *P. truncatus, T. castaneum*, *T. variabile* and *R. dominica* was increased. Mortality rate is lower at inside as compared to outside of the bag. After five days of exposure the highest mortality of *T. castaneum* and *T. variabile* was about 5.6%. After five days on both the surfaces all *Sitophilus oryzae* was found dead. By transferring *S. oryzae* there was a decrease in knockdown activity while mortality rate increase. There was no delayed mortality in case of hide beetle and the mortality rate was never more than 5.6%. It was clear from results that storage bags reduce the entry of beetles to stored grains.

Okonkwo *et al.* (2017) worked on efficacy of polypropylene storage bags that were long-lasting and then incorporated with insecticide which was developed by Vestergaard Frandsen in order to protect grains from damage caused by insects to stored products. They were compared to grains treated with Permethrin and stored in Polypropylene bags of laboratories in Nigeria in 2013. *Callosobruchus maculatus*, *Sitophilus zeamais*, *Rhyzopertha dominica* and *Tribolium castaneum* adults were used to determine the contact-sensitivity of all these pests against deltamethrin insecticide at various exposure times. Attack of pests on stored grains reduces grain quality. Storage bags treated with deltamethrin show 90% knockdown while untreated bags shows 0% after 72 hours and adults were unable to chew through the deltamethrin treated storage bags from outside or inside at 72 hours. He concluded that in the absence of feed, starvation results in 65 to 90% insect death in 7 days. Deltamethrin insecticide treated bags show low mortality of insects while grains treated with Permethrin and then stored in PP bags show greater percentage mortality. Moisture content, fiber, oil, crude protein, ash, carbohydrate of maize grains or cowpea stored in PP incorporated bags have no change after period of 6 months. As the bags treated with deltamethrin insecticide help to control target pests or insects hence they were mostly recommended.

Afzal *et al.* (2017) conducted an experiment on seeds stored in jute bags or porous polypropylene bags. Seeds in these bags fluctuate relative humidity along with temperature and also help to increase the growth rate of insects and mold. Moisture content of seeds increased in bags of polypropylene while in PICS bags it remain constant. Germination of maize seeds were not observed in PICS bags. In polypropylene bags germination was reduced to one half. Higher insect damage was observed in polypropylene bags with 35% weight loss, infestation was minimal in PICS bags with 3% weight loss. In polypropylene bags higher contamination with aflatoxin was observed as compared to PICS bags. PICS bags helps to prevent dryness and maintain seed quality.

Yan *et al.* (2017) used hermetic storage in order to protect grains against insect pests, but its use is not restricted to whole grains. Against population of red flour beetle he used sealed, polyethylene terephthalate (PET) bottles for preservation of wheat and maize flour. Sealed PET bottles with less weight loss for time period of three-month storage were used for flour affected by RFB as compared to flour kept in bottles that are unsealed. Population of RFB in wheat flour which was placed in sealed bottles did not increase, whereas in bottles that were unsealed population increases up to 50-fold during the same time period. Low levels of moisture and oxygen was observed in flour with sealed bottles as compared to flour which was stored in unsealed bottles. Similarly oxygen and moisture levels in maize flour placed in sealed bottles was low. Hermetically-sealed bottles were more useful in prevention of population growth of RFB and in prevention of maize and wheat flour. Farmers, food processors and consumers usually store grain flour in hermetic sealed bottles or containers.

Ahmad *et al.* (2017) worked on the population of *Tribolium castaneum, Trogoderma granarium* and *Sitophilus oryzae* at six, eight and ten pairs per 500 gm wheat per specie of insect infection at initial stage and calculated wheat losses under laboratory conditions during six months. Overall increase in number of insects is from 20 to 3900 insects. Weight loss, loss of germination and kernel damage were, 1.99 to 15.38, 2.49 to 50.0 and2.79 to 63.69 respectively. *S. oryzae* was responsible for causing higher weight loss, loss of germination and kernel damage in comparison with *T. castaneum* and *T. granarium.*

Islam (2017) conducted an experiment on stored grain and came to know that these grains were continuously attacked by pests. One of the major pest is red flour beetle, *Tribolium castaneum* (Herbst), which is responsible for causing damage to stored grains as have the ability to withstand diverse climatic conditions. Desirable management of a specific pest in most of the countries is by using synthetic chemicals, but it may also cause negative effects on human health and environment, now a days it is necessary to apply ecofriendly procedures. Phyto-extracts are safe alternate in this respect. This review mainly focuses on the botanical use against red flour beetle by briefing the aspects from predictable to modern approaches. Different stages of insect life starting from egg to adult have also been focused. The review also focuses on the research conducted now a day for the assessment of phyto-derivatives against red flour beetle.

Machekano *et al.* (2017) conducted two laboratory experiments, in first one they observed the effect of straight DEs and also two food grade formulations based on DE on *Prostephanus truncates*, *Sitophilus zeamais* and also on *Tribolium castaneum* along with shelled maize. In second experiment protect-It® and Chemutsi were tested with less dose of deltamethrin and spinosad having different combinations. After 21 days of exposure mortality of *S. zeamais* was caused at Chemutsi 1000ppm, food grade 150ppm and protect it 600ppm and this mortality rate was not much different from control. While formulations based on DE food grade and straight DEs do not effect *T. castaneum* and *P. truncatus* after same exposure time. Seven days mortality at low dose combinations proved *S. zeamais* more susceptible. After 21 days these treatments proved to be effective. F_1 progeny for three test species was suppressed by combinations of DE-deltamethrin and DE-spinosed. They are not suppressed by straight DEs and DE based food grade formulations.

Lane and Woloshuk (2017) conducted an experiment to prove that small hermetic bags were effective and low cost solution in order to prevent losses caused in stored grains due to insect attack. They worked on dry maize and compared the two factors such as temperature and humidity at two different areas in PICS bags and polypropylene bags. The result shows that for about three month of storage moisture penetration is prevented by PICS bags. While in woven bags moisture content increased. *Aspergillus flavus* growth was not observed in both bags. However other storage fungi was observed. Infected kernels increased in woven bags whereas in PCIS bags their number did not increased. In woven bags warmer environmental conditions results in higher insect population but insect population was not increased in PCIS bags.

Ghimire *et al.* (2017) worked on 10 larvae of 3-4 week of different species and exposed them on concrete arenas for 1,2,3 and 7 days and were then transferred to diet cups of 175ml for 30 days which contain 5% untreated rearing media to study delayed mortality. They studied the residual efficacy of deltamethrin, b-cyfluthrin and chlorfenapyr at 0 to 12 weeks at laboratory conditions and also field strain of *Trogoderma granarium.* 10 larvae and adults of each strain were exposed and then mortality was observed after 4 days of exposure in adults and 30 days in larvae. Delayed mortality of larvae was more than 26% in first study but when they were exposed to arena treated with *Tribolium inclusum* and two pyrethroids it was observed that larvae were less susceptible as compared to *T. granarium.* Across post treatment assay without insecticide application for both strains mortality rate was 90% to 100%. 100% mortality was achieved in laboratory strain only by use of insecticides in initial assay but with passage of time it was decreased. Field strain larvae tolerate insecticidal effect as compared to laboratory strain larvae and both the larvae are resistant to insecticides as compared to adults.

Williams *et al.* (2017) worked to control pests of stored grains by hermetic technologies. PICS bags were successful in control of cowpea postharvest pests in one approach of this technology. Due to this success farmers use PICS bags mostly for stored grains. In order to observe that maize can be safely stored in PICS bags without any quality loss or not, he conducted laboratory studies on maize grains that were infected with *Sitophilus zeamais* and stored them in PICS triple bags. After observation of eight months, temperatures in those bags was compared with ambient temperature of treatments. Inside the bags relative humidity does not change during that period whereas the large difference in relative humidity was observed in surroundings. While in the woven bags relative humidity was followed by ambient humidity closely. PICS bags having grains infected with *S. zeamais* show decline in concentration of oxygen as compared to other treatments. Moisture content of grains decreased in woven bags, but does not decrease in PICS bags. Germination of seeds was not affected for about 6 months, but decreased after eight months of infestation in woven bags. Low relative damage was observed across treatments and also between the treatments. No signs of deterioration was observed in maize in PICS bags as compared to the woven bags. Hence PICS bags proved to be more effective.

Baributsa *et al.* (2017) conducted an experiment in order to estimate the function of hermetic triple layer PICS bags to preserve shelled and unshelled groundnuts. For about 6.7 months the infested groundnuts were placed in woven and PICS bags. Oxygen level falls to about 20% to 18% in PICS bags for unshelled groundnuts and about 21% to 15% in shelled groundnuts. *Corcyra cephalonica*, *Tribolium castaneum* and *Cryptolestes ferrugineus* were commonly observed. Pest population was increased to a large extent in woven bags after 6.7 months and weight loss for unshelled groundnuts was 8.2% and for shelled groundnuts weight loss was 28.7%. While for PICS bags weight loss was not observed and there is no increase in pest population of pests and germination rate remains the same. Hence PICS bags are more cost efficient and beneficial.

AUTHOR CONTRIBUTIONS

All authors contributed equally.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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