doi:10.14720/aas.2023.119.1.2707 Original research article / izvirni znanstveni članek

Bags impregnated with garlic (*Allium sativum* L.) and parsley (*Petroselinum crispum* (Mill.) Fuss) essential oils as a new biopesticide tool for *Trogoderma granarium* Everts, 1898 pest control

Alzahraa Abdelaty ELMADAWY [1], Ahmed Fayez OMAR [2, 3], Tamer ISMAIL [2]

Received May 28, 2022; accepted January 11, 2023.
Delo je prispelo 28. maja 2022, sprejeto 11. januarja 2023

Bags impregnated with garlic (*Allium sativum* L.) and parsley (*Petroselinum crispum* (Mill.) Fuss) essential oils as a new biopesticide tool for *Trogoderma granarium* Everts, 1898 pest control

Abstract: Stored product pests can cause significant damages and great economic problems in stored commodities and grain cereal. Using synthetic pesticides in the storage pest control has adverse effects on human health. In our study, the toxicity of garlic (*Allium sativum*) and parsley (*Petroselinum crispum*) essential oils (EOs) impregnating with three types of bags were assessed against *Trogoderma granarium* Everts, 1898 adults after different exposure intervals. GC-MS analysis of the investigated EOs revealed that the major components of parsley and garlic were 1, 3, 8-p-menthatriene (23.34 %) and di-allyl disulfide (27.9 %), with (1.40 %) alpha-terpinene and (1 %) of di-alyl tetra-sulfide as minor components respectively. Additionally, comparison the toxicity among the treated bags was assessed based on the LC_{50} values and a persistence efficiency of the tested EOs was carried out by the LC_{90} values for each bag type. In all bag types, garlic and parsley had mortality by 100 % for clothes, and 80 % for both plastic and paper bags after 7 days of exposure, respectively. After two and five days of garlic treatment, plastic bags were the most effective, but after seven days of exposure paper bags was more effective than the other two types. Finally, cloth bags treated with EOs were the most effective packaging for insect control, indicating that this approach could be considered as an additional tool to the concept of stored product management.

Key words: essential oils; stored grain; bags; *Trogoderma granarium*

Vrečke, impregnirane z eteričnimi olji česna (*Allium sativum* L.) in peteršilja (*Petroselinum crispum* (Mill.) Fuss) kot novo biopesticidno orodje za nadzorovanje indijskega žitnika (*Trogoderma granarium* Everts, 1898)

Izvleček: Skladiščni škodljivci lahko povzročijo znatno škodo in velike ekonomske probleme v skladiščih žit .Uporaba sintetičnih pesticidov pri nadzoru skladiščnih škodljivcev ima škodljive učinke na zdravje ljudi. V raziskavi so bili preučevani toksični učinki eteričnih olj česna in peteršilja na odrasle osebke indijskega žitnika s tremi tipi vrečk (plastične, papirnate in iz blaga), impregniranimi z eteričnimi olji obeh rastlin v različnih časovnih izpostavitvah. GC-MS analiza preučevanih eteričnih olj je pokazala, da sta bili njihovi glavni sestavini 1, 3, 8-p-mentatrien (23, 34 %) in dialil disulfid (27,9 %), z (1,40 %) alfa-terpinenom in (1 %) dialil tetrasulfidom v manjšem deležu. Dodatno je bila ocenjena primerjava strupenosti impregniranih vrečk na osnovi LC_{50} vrednosti. Trajnost učinka eteričnih olj je bila preiskušena na osnovi LC_{90} vrednosti za vsak tip vrečke. Primerjalno je impregniranost vrečk z eteričnimi olji česna in peteršilja povzročila 100 % smrtnost pri vrečkah iz blaga in 80 % smrtnost pri plastičnih in papirnatih vrečkah po sedemdnevni izpostavitvi. Po izpostavitvi za dva in pet dni v vrečkah impregniranih s česnom so bile najbolj učinkovite plastične vrečke, po sedmih dneh izpostavitve so bile najbolj učinkovite papirnate vrečke. Zaključimo lahko, da so vrečke iz blaga, impregnirane z eteričnimi olji najbolj učinkovite za uravnavanje škodljivih žuželk in bi jih lahko uporabili kot dodatno orodje pri ohranjanju shranjenih pridelkov.

Ključne besede: eterična olja; shranjena zrna; vrečke; *Trogoderma granarium*

1 Plant Protection Research Institute, Stored Product Pests Department, Agricultural Research Center, Ministry of Agriculture, Giza, Egypt
2 Pesticides Chemistry and Toxicology Department, Faculty of Agriculture, Kafrelsheikh University, Kafrelsheikh, Egypt
3 Corresponding author, e-mail: ahmed.foz.fayez9@gmail.com

1 INTRODUCTION

Stored commodities are vulnerable to insect attack. Major stored grain cereal crops can be attacked by more than 600 species of beetles, moths, and other insect pests and mites, causing a great economic problem either qualitatively or quantitatively deteriorating (Rajendra and Sriranjini, 2008). According to estimates, more than one-third of food products are lost during post-harvest storage due to pest infestation (Tripathi et al., 2009). *Trogoderma granarium* Everts (Coleoptera: Dermestidae), the khapra beetle, is one of the most important storage pests, which has economic importance under severe phytosanitary worries (Myers and Hagstrum 2012; EPPO 2013; Athanassiou et al., 2019). This species has been classified among the most harmful and intrusive outsider species on the planet (Lowe et al., 2000). The potential expansion of *T. granarium* is due to its ability to attack numerous stored cereals or related products and non-grain commodities. It feeds on 96 commodities and infests very dry food in a very dry environment with 2 % relative humidity (r. h.). In addition to its ability to shuttle from one place to another according to worldwide exchange and temperature tolerance, which ranged between (21 and 40 °C) with an optimum at 35 °C (Degri and Zainab 2013; Athanassiou et al., 2016; Kavallieratos et al., 2019). Their larvae may fall under selective diapause for a long and show resistance to insecticides (Edde et al., 2012; Myers and Hagstrum, 2012; Athanassiou et al., 2015). Due to the widespread overuse of synthetic pesticides in managing insect pests, including those attacking stored products, and the development of resistances, efforts to reduce environmental pollution represent a major issue of concern for environmental and health issues (Desneux et al., 2007).

Due to expansion instances of khapra beetle resistance against traditional insecticides such as phosphine, malathion and pyrethroids have more featured its monetary importance and raised another errand for the researchers to seek a new way to control it (Myers and Hagstrum, 2012; Honey et al., 2017; Khalique et al., 2018). In this way, the European Union supports a considerable decrease in the utilization of insecticides, by looking for less harmful substances under the Integrated Pest Management (IPM) models (Hillocks, 2012; Lucchi and Benelli 2018). During the last years, botanicals such as plant powder and essential oils have been evaluated as promising alternatives for the control of a huge range of pests on different-stored commodities (Athanassiou et al., 2014; Bohinc et al., 2020). Plant essential oils are complex natural mixtures of volatile organic compounds resulting as secondary metabolites in plants, constituted by terpenes, terpenoids, and phenol-derived aromatic components and, aliphatic components (Bakkali et al., 2008). They have been reported by many studies that essential oils have toxic effects such, as a repellent, antifeedant, antifungal, antibacterial, reproduction, and inhibitory development effects against varied insect pests (Ebadollahi and Jalali Sendi 2015; Tu et al., 2018; Hu et al., 2019).

Packing is one of the most common methodologies for the development of bioactive preservation tools. It is confirmed that packaging offers a basic point in food quality conservation and a definitive defense against insect pests. Active packaging is considered a promising innovation for food packaging. It consists of incorporating into the packaging material active compounds useful for food protection. Earlier studies mentioned that packages are one of the possible ways to protect stored products during storage until they reach consumers (Campbell et al., 2004). Furthermore, naturally derived compounds such as essential oils and plant extracts consolidated in active packaging can be used in place of commonly used chemical preservatives by consumers who prefer natural preservatives (Bazargani-Gilani et al., 2015). However, insect pests can infest packaged products in many ways (Mullen et al., 2012; Costa, 2014; Stejskal et al., 2017). Endeavors ought to be made not just towards the planning of successful frameworks, which might hinder the food quality rot, but also towards the improvement of insect-proof packages, ready to stand up against insect penetration and/or to repel their presence from the food package's environment.

Recently, many essential oils have been employed as promising natural preservatives in packaging. A lot of exhaustive research has developed numerous packaging material types that can offer different levels of protection for stored products at a low cost for either individuals or companies (Stejskal et al., 2017). Treated packages protect the stored grain commodities by blocking insect infestations resulting from the storage environmental conditions (Paudyal et al., 2017a). Similarly, a covering containing citronella oil is applied to the containerboard for insect repellence (Wong et al., 2005). Consequently, insecticides or other protective materials can be impregnated into the synthesis of the storage bags or treated straightforwardly on the packaging material (Scheff et al., 2016; Kavallieratos et al., 2017a, b; Paudyal et al., 2017a, b; Scheff et al., 2017; Scheff and Arthur 2018). Active agents consolidated in packing materials could be released through evaporation of the headspace or can migrate from the package to the product by diffusion through the packaging material prolonging the specific activity and reducing the migration to the preserved material. For instance, antimicrobial cellulose packaging was achieved through the laccase-interceded joining of phenolic compounds (Elegir et al., 2008). Therefore, the objectives of this study were to evaluate the immediate and delayed mortality of *T. granarium* adults exposed to three types of available and low-cost storage bags made of plastic, paper, and clothes material impregnated with two natural essential oils garlic and parsley addition to evaluating their storage long activity.

2 MATERIALS AND METHODS

2.1 INSECT

Trogoderma granarium Everts, 1898 (Coleoptera: Dermestidae) used in the bioassays were obtained from stock colonies maintained in the laboratory of Stored Product Insects of the Sakha Agricultural Research Station, Agriculture Research Center (ARC) Egypt. Adults of *T. granarium* < 24 h old and larvae having 2–4 mm long (Athanassiou et al., 2016) were used in the experiments, which were cultured on wheat at 35 °C, 65 % relative humidity (RH), and continuous darkness.

2.2 ESSENTIAL OIL

Garlic (*Allium sativum* L.) and parsley (*Petroselinum crispum* [P. Mill.] Nyman ex A.W. Hill) EOs are widely available in Egypt, and they were supplied by Hashem Brothers Company for Essential Oils and Aromatic Products (Kafr-Elsohby, Kalyoubeya, Egypt).

2.3 GC/MS ANALYSIS OF THE ESSENTIAL OIL

The chemical composition of the essential oils was analyzed by gas chromatography-mass spectrometry (GC/MS) using the model (HP5890- USA) provided by an HP column (60 m × 0.25 mm, 0.25 µm film thickness) (HP-5 ms). The initial temperature was 60 °C and the maximum temperature was 250 °C for 65.3 min. The injector temperature was 240 °C. Relative percentage amounts were calculated from the peaks' total area by apparatus software. The compounds were identified by matching the mass spectra data with those held in a computer library (Wiley 275. L), according to Swigar and Silverstein (1981) and Adams (1995). All analysis steps were carried out at the laboratory of Hashem Brothers Company, Egypt.

2.4 STORAGE BAGS

Three different types of bags were used in the experiments: polypropylene (BOPP) bags that are utilized for containing and moving products like food sources, produce, powders, ice, magazines, chemicals, and waste it is a common form of packaging. Kraft paper (KP) which are some of the most popular forms of packaging for consumers and finally clothes bags, which are considered a popular alternative to plastic and paper shopping bags, because cloth bags do not cause the environmental harm as plastic bags.

2.5 BIOASSAYS

2.5.1 Contact

The standard solution of each tested essential oil (EO) was obtained by diluting 1 ml of crude oil in 100 ml acetone then, four concentrations of each essential oil, (1.25, 2.5, 5, and 7.5 mg ml^{-1}) of garlic, & (7.5, 10, 12.5, and 15 mg ml^{-1}) of parsley were prepared from the standard solution of garlic and parsley then impregnated into tested bags. Each concentration was sprayed into the tested bags with 1 ml as a fine mist that contained the appropriate concentration of each oil. Bags were splashed with a brush on both sides. After treatment with each EOs, the brush was carefully cleaned with acetone and subsequently, the following treatment was applied to the other type. An additional series of bags were prepared without any treatment and served as controls. The sprayed bags were left to become dry for 24 h (h) at 30 °C and 65 % r. h. Then, in each type of bag, 20 g of wheat was placed, and ten adults of *Trogoderma granarium* were put in each bag and then closed with stapler staples. Each concentration was replicated three times for each type and placed in incubators set at 30 C and 65 % r. h. Accumulative mortality counts were recorded at 2, 5, and 7 days after treatment corrected by Abbott's formula (1925).

2.6 LONG-TERM EXPERIMENT

Long–term experiment was conducted to evaluate the persistence and long-active effectiveness of various concentrations of testing essential oils loaded with testes bags, this experiment was carried out as follows. After calculating the LC_{90} value of testing essential oil for each type of bag individually, 9 bags of each type were treated with the 2 days calculated LC_{90} value of garlic and parsley and stored treated until further investigation. After one month of storage three bags of each treated type (paper, plastic, and cloth) were infected with 10 adults of *T. granarium* insect and another three untreated bags served as a control, mortality was observed after 2 days. This experiment was repeated after three months as mentioned above and recorded mortality rate.

2.7 STATISTICAL ANALYSIS

The results were analyzed by one-way analysis of variance ANOVA followed by the Least Significant Difference test for mean separation. *p* values of ≤ 0. 05 were considered significant. The experiments were performed in triplicate, the data presented are the mean ± SE. The lethal concentration for 50 % mortality (LC_{50}) was determined by log-probit analysis (Finney, 1971), and the data were analyzed by determining chi-square values and degrees of freedom. The analysis of data was performed with SPSS program version 24.0 for Windows (SPSS Inc., IBM Corp.)

3 RESULTS AND DISCUSSION

3.1 CHEMICAL COMPOSITION TESTED ESSENTIAL OILS

The major components of testing essential oils are summarized in Tables 1 & 2. A total of 33 components were identified for parsley essential oil according to their retention indices in Table 1, the major constituents representing 84.63 % of the total component were trimethyl bicylo (13.01 %), beta pinene (8.28 %), beta myrcene (3.93 %), beta phellandrene (3.81 %),1,3,8-p-menthatriene (23.34 %), benzodioxole (11.67 %), apiol (12.72 %) and benzofuran (7.87 %). Whereas the minor constituents were chavicol (2.51 %), benzene-methyl (2.06 %), and alpha-terpinene (1.40 %). Where in Table 2 a total of 42 components were identified for garlic essential oil according to their retention indices, the major constituents representing 94.4 % of the total component were dimethyl disulfide (1.4 %), diallyl sulfide (9.5 %), allyl methyl disulfide (8.3 %), dimethyl trisulfide (2.9 %), diallyl disulfide (27.9 %), allyl (Z)-1 propenyl disulfide (2.2 %), allyl (E)-1-propenyl disulfide (3.7 %), allyl methyl trisulfide (17.7 %), 4-methyl-1,2,3-trithiolane (1.2 %), 2-vinyl-4H-1,3-dithiine (1.8 %), diallyl trisulfide (16.8 %) and diallyl tetrasulfide (1 %).

Essential oils from various plant species could represent an alternative way to existing synthetic pesticide agents, either by direct application or by loading on a carrier.

In our study chemical composition of parsley (EO) *P. crispum* agrees with earlier studies from different regions all over the world (Zhang et al., 2006; Soher et al., 2014) with some differences in component percentage due to climate change and environmental factors. Also, the chemical composition of garlic (EO) *A. sativum* is in agreement with those (Satyal et al., 2017; Mossa et al., 2018), who reported that garlic oil from different topographical areas has shown subjective similitudes, yet quantitative contrasts in the groupings of the organosulfur compound.

3.2 TOXICITY BIOASSAY

In the current study *A. sativum* and *P. crispum,* essential oils exhibited strong insecticidal activity against *T. granarium* adults with a significant difference between treated concentrations along the test period and within bag types. Where the results demonstrate that *A. sativum* oil showed high efficiency over *P. crispum* oil against khapra beetle with all tested bags. Mortality percentage for garlic increased as a function of time exposure, where the highest concentration of garlic recorded 100 % mortality in clothes bags, 86.66 % for plastic bags, and 96.66 % for paper bags after 7 d of exposure (Fig 1c). On the other hand, parsley recorded mortality by 80 % for plastic

Table 1: Main components of parsley (*Petroselinum crispum*) essential oil analyzed by gas chromatography-mass spectrometry (GC-MS)

Compounds	Percent Composition %	Molecular formula	Retention time (min)
Trimethyl bicylo	13.01	$C_{10}H_{16}$	6.20
Beta pienen	8.28	$C_{10}H_{16}$	7.52
Beta myrcene	3.93	$C_{10}H_{16}$	7.97
Beta phellandrene	3.81	$C_{10}H_{16}$	9.31
1,3,8-p-menthatriene	23.34	$C_{10}H_{14}$	12.85
Benzodioxole	11.67	$C_7H_6O_2$	30.05
Apiol	12.72	$C_{12}H_{14}O_4$	36.02
Benzofuran	7.87	C_8H_6O	12.08

Table 2: Main components of garlic *(Allium sativum)* essential oil, analyzed by gas chromatography-mass spectrometry (GC-MS)

Compounds	Percent Composition %	Molecular formula	Retention time(min)
Dimethyl disulfide	1.4	$C_2H_6S_2$	12.32
Diallyl sulfide	9.5	$C_6H_{10}S_2$	14.25
Allyl methyl disulfide	8.3	$C_4H_8S_2$	15.26
Dimethyl trisulfide	2.9	$C_2H_6S_3$	16.13
Diallyl disulfide	27.9	C6H10S2	18
Allyl (Z)-1-propenyl disulfide	2.2	$C_4H_8S_2$	18.21
Allyl (E)-1-propenyl disulfide	3.7	$C_6H_{10}S_2$	18.33
Allyl methyl trisulfide	17.7	$C_4H_8S_3$	18.96
4-Methyl-1,2,3-trithiolane	1.2	$C_3H_6S_3$	19.21
2-Vinyl-4H-1,3-dithiine	1.8	$C_6H_8S_2$	20.23
Diallyl trisulfide	16.8	$C_6H_{10}S_3$	21.68
Diallyl tetrasulfide	1	C6H10S4	25.66

Table 3: Toxicity assessment of garlic and parsley essential oils against *Trogoderma granarium* adults after different exposure periods in plastic bags

Tested oil	Time (d)	LC_{50} Value (mg kg^{-1})	Confidence Interval 95 % Lower	Confidence Interval 95 % Upper	Slope value	Chi-Square (X^2)
	2 days	19.26 a	24.06	15.39	1.165	0.035
Garlic	5 days	9.86 d	7.88	12.33	0.599	0.238
	7 days	1.240 f	0.99	1.55	0.107	0.874
	2 days	17.98 b	15.00	22.48	1.575	0.598
parsley	5 days	12.01 c	7.508	15.02	1.022	0.483
	7 days	3.65 e	2.92	4.56	0.257	0.325

Values in the row followed by the same letters are not significantly different ($p > 0.05$) according to ANOVA and Duncan multiple-comparison tests

Table 4: Toxicity assessment of garlic and parsley essential oils against *Trogoderma granarium* adults after different exposure periods in paper bags

Tested oil	Time (d)	LC_{50} Value (mg kg^{-1})	Confidence Interval 95 % Lower	Confidence Interval 95 % Upper	Slope value	Chi-Square (X^2)
Garlic	2 days	6.31 d	5.05	7.89	0.504	0.600
	5 days	5.21 e	4.17	8.08	0.641	2.085
	7 days	4.33 f	3.46	7.07	0.717	0.087
parsley	2 days	18.89 a	14.94	23.61	1.869	0.347
	5 days	16.14 a	12.91	20.18	1.22	0.086
	7 days	8.34 c	3.54	10.08	1.187	0.505

Values in the row followed by the same letters are not significantly different ($p > 0.05$) according to ANOVA and Duncan multiple-comparison tests

Table 5: Toxicity assessment of garlic and parsley essential oils against *Trogoderma granarium* adults after different exposure periods in clothes bags

Tested oil	Time (d)	LC_{50} Value (mg kg^{-1})	Confidence Interval 95 % Lower	Upper	Slope value	Chi-Square (X^2)
Garlic	2 days	6.13 b	4.68	9.65	1.013	0.214
	5 days	2.24 d	0.144	3.47	0.438	1.95
	7 days	1.211 f	0.76	2.18	0.366	2.685
parsley	2 days	6.63 a	4.52	8.29	0.732	0.828
	5 days	3.32 c	2.66	4.15	0.189	0.055
	7 days	1.47 e	1.17	3.59	0.162	0.183

Values in the row followed by the same letters are not significantly different ($p > 0.05$) according to ANOVA and Duncan multiple-comparison tests

bags, 80 % for paper bags, and 73.33 % for clothes bags at the highest concentration after 7 d of exposure as shown in Fig. 2 c.

In Table 3, *A. sativum* essential oil had the lowest LC_{50} values by 19.26, 9.86, and 1.24 mg kg^{-1} after two, five, and seven days respectively, opposite to 17.98, 12.01, and 3.65 mg kg^{-1} for *P. crispum* for plastic bags treatment. The same was in both paper and clothes bags (Tables 4 & 5), where LC_{50} values were 6.31, 5.21, and 4.33 mg kg^{-1} for *A. sativum* compared to 18.89, 16.14, and 8.34 mg kg^{-1} for *P. crispum* after two, five and seven days in paper bags treatment, while clothes bags recorded LC_{50} values by 6.13, 2.24, and 1.211 mg kg^{-1} for *A. sativum* oil compared to 6.63, 3.32, and 1.47 mg kg^{-1} for *P. crispum* after the same investigation period.

In this framework, our findings indicate that essential oils impregnated into different types of bags can contribute to managing one of the stored-product insect species with economic importance *Trogoderma granarium*. The EO of *A. sativum* was the most effective among the tested EOs against *T. granarium*, causing a higher mortality rate than *P. crispum* oil with all types of testing bags. Botanicals incorporate a wide scope of promising compounds used for developing novel, effective, and ecologically economical pesticides (Stevenson et al., 2017; Pavela et al., 2019a). Extracts and oils of garlic have already been advertised as pest control products. Yang et al. (2009) found that garlic essential oil loaded on coated polyethylene glycol (PEG) in the size of the nanoparticles could effectively control *Tribolium castaneum* (Herbst) insect. In addition, George et al. (2010) found that the garlic oil was highly toxic to the red poultry mite, *Dermanyssus gallinae* (De Geer, 1778). On the other side, the insecticidal activity of parsley has been demonstrated in some studies on arthropods (Bortolucci et al., 2015; Mansour et al., 2015). Whereat, Massango et al. (2016) reported that the essential oil of parsley showed low fumigant toxicity than phosphine against *Callosobruchus maculatus* (Fabricius, 1775). In addition, Kavallieratos et al. (2020) mentioned that eight essential oils could be considered grain protectants to manage adults and larvae of *T. granarium*. Janaki et al. (2018) showed that *T. granarium* adults were highly susceptible to the *Cyperus rotundus* L. EO when applied to filter paper at 0.04 µl cm^{-2}, causing 94 % repellence after 2 h of exposure.

A comparison between tested bags to illustrate the most powerful type of bags results in Fig. 3, showed that paper and clothes bags impregnated with garlic oil was the most effective one after two and five days post-treatment, but with increasing the investigation period to seven days clothes bags showed high effectiveness than the other two types. However, in parsley treatment, Fig. 4 clothes bags were the most effective one than the other two bag types during the tested period.

Coating is the most common methodology for the advancement of bioactive packing, our bioassay was established for the evaluation of insect control by oil-impregnated packaging through three types of bags. Bags are a trustworthy method of storage, due to the expansion of the assurance they can give against insect invasions is of high significance (Paudyal et al., 2017a). Previous studies have demonstrated the efficiency of loading different toxic agents against stored product insects. Wong et al. (2005) indicated that commercial citronella could reduce beetle infestation, initially by approximately 50 % when applied at 0.2 g m^{-2} of carton board in addition to its repellent effect for 16 weeks when applied directly as a coating into carton board in ethanol solution. Our results are in line with Kavallieratos et al. (2017a) who documented that deltamethrin impregnated into ZeroFly storage bags was very effective against larger grain borer *Prostephanus truncatus* (Horn, 1878) by 94.4 % after 5 d of exposure, the rice weevil *Sitophilus oryzae* (L., 1763) by 100 % after 1 d of exposure, and by 96.7 % on the ware-

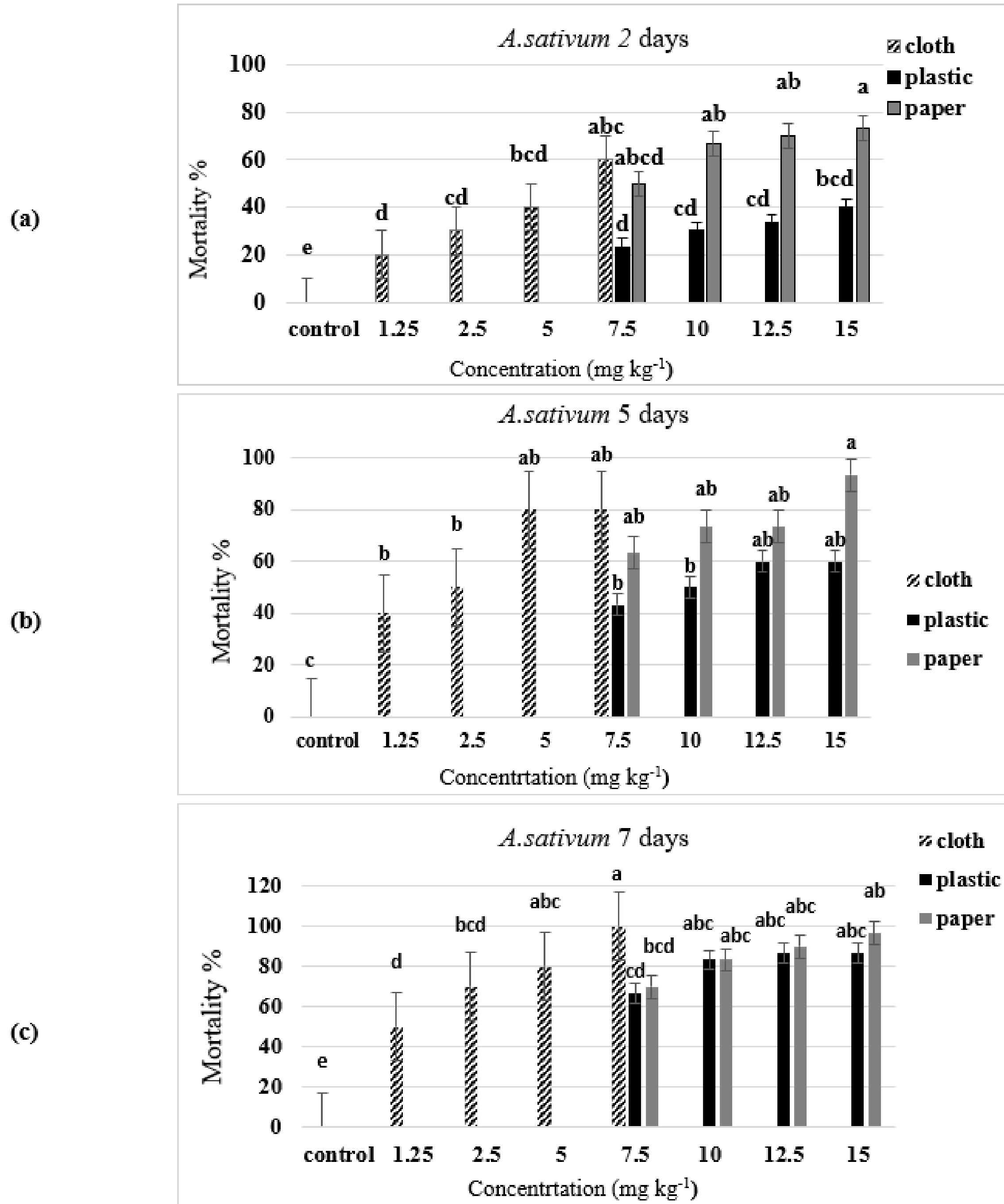

Fig 1: Mortality percentage of *Trogoderma granarium* adults in bags treated with garlic (*Allium sativum*) essential oil after different exposure periods (a, b and c)

house beetle, *Trogoderma variabile* (Ballion, 1878) after 5 d of exposure. In the same trend, Kavallieratos et al. (2017b) found that treated bags with chlorfenapyr and pirimiphos-methyl were effective to kill all adults of *P. trunactus* and the lesser grain borer, *Rhyzopertha dominica* (F., 1792) (Coleoptera: Bostrychidae) after 3 d of exposure. The same was reported by Paudyal et al. (2017a) on S. *oryzae* and the red flour beetle, *T. castaneum* (Herbst, 1797) (Coleoptera: Tenebrionidae) adults. Our results showed that all bag types had a mortality efficiency against tested insects, whereas Kavallieratos and Boukouvala (2018) in their studies reported that three tested types of bags showed equal mortality levels of *T. granarium*. In addition, Herrera et al. (2021) reported that the

(a)

(b)

(c)

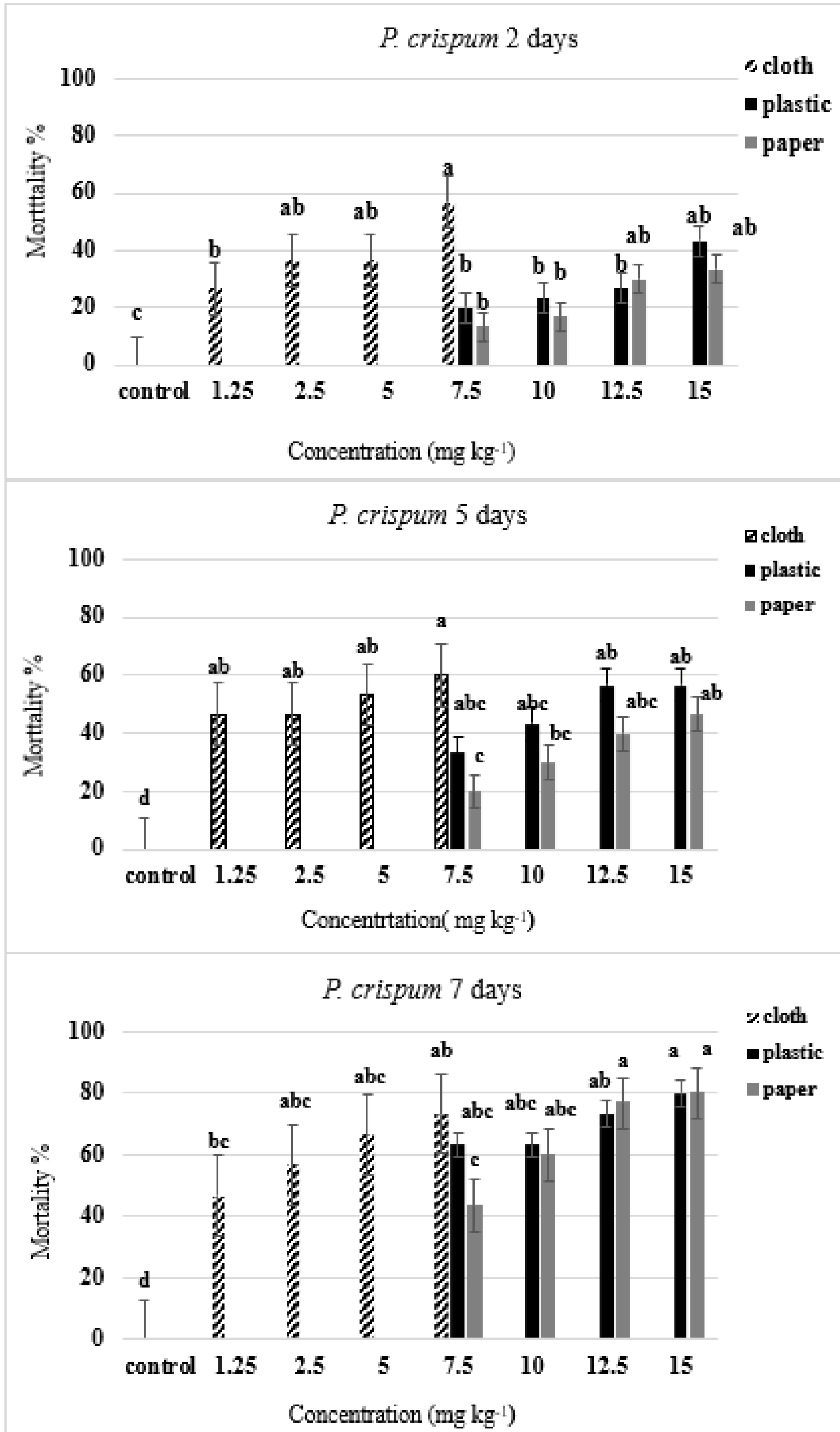

Fig 2: Mortality percentage of *Trogoderma granarium* adults in bags treated with parsley (*Petroselinum crispum*) essential oil after different exposure periods (a, b and c)

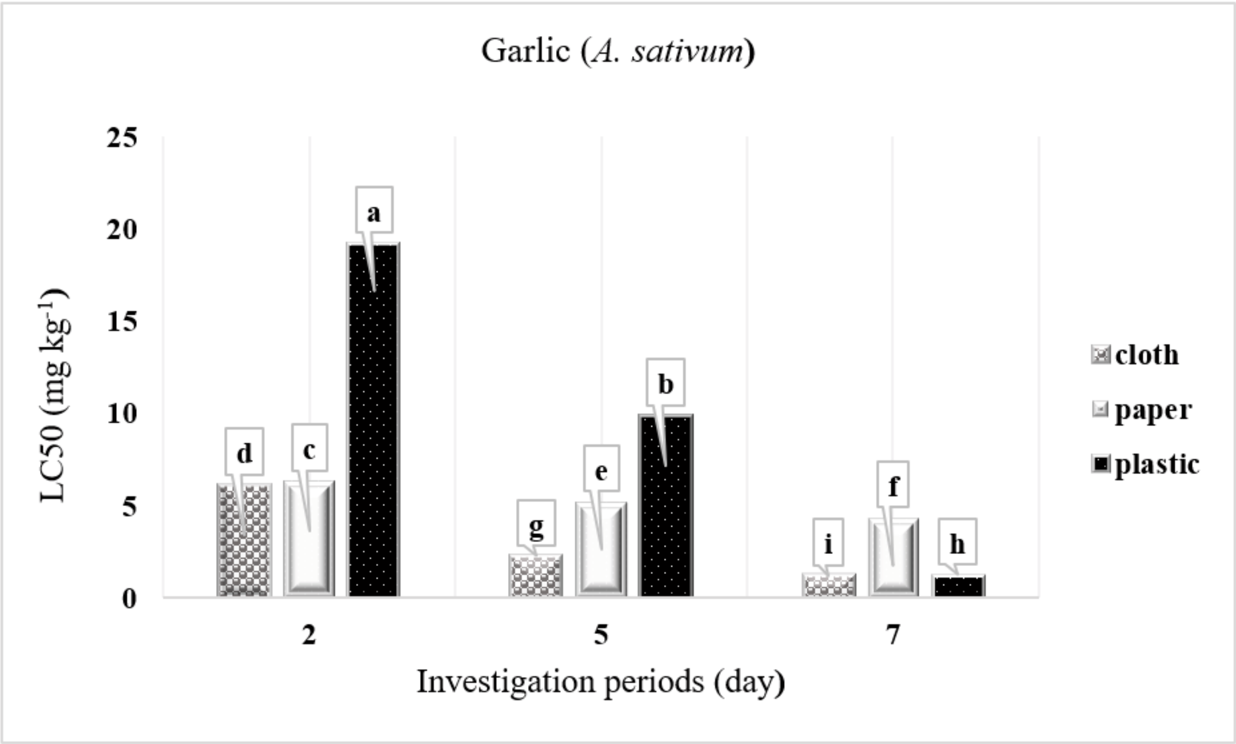

Fig. 3: Comparison between bags types treated with garlic oil (*Allium sativum*) according to LC_{50} value

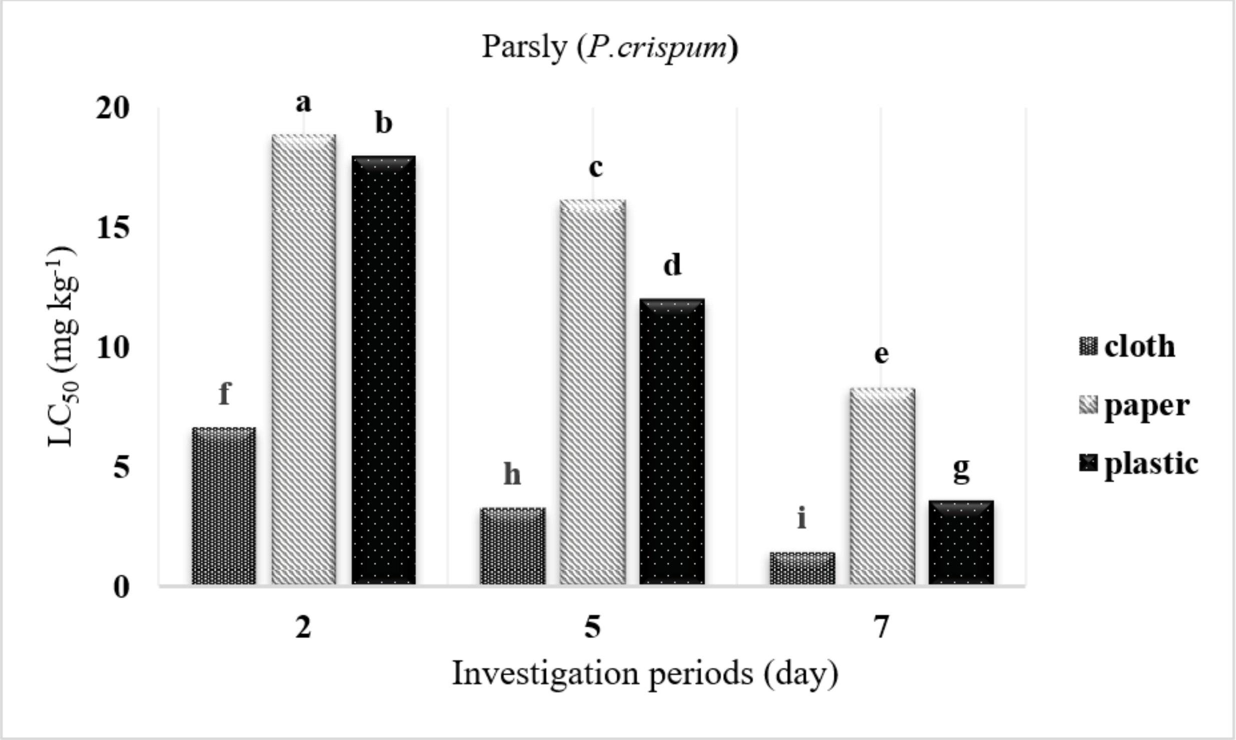

Fig. 4: Comparison between bags types treated with parsley oil (*Petroselinum crispum*) according to LC_{50} value

Table 6: Mortality percentage of *Trogoderma granarium* adults exposed to bags treated with LC_{90} value of garlic and parsley essential oils after different storage times

	Mortality (%) after 1 month of storage		Mortality (%) after 3 months of storage	
Bags	Garlic	Parsley	Garlic	Parsley
Paper	90 b	86.66 b	20 bc	16.66 bc
Plastic	73.33 b	70 b	40 b	30 b
Cloth	76.66 b	76.66 b	33.33 b	26.66 bc
Control	0 a	0 a	0 a	0 a

Values in the row followed by the same letters are not significantly different ($p > 0.05$) according to ANOVA and Duncan multiple-comparison tests

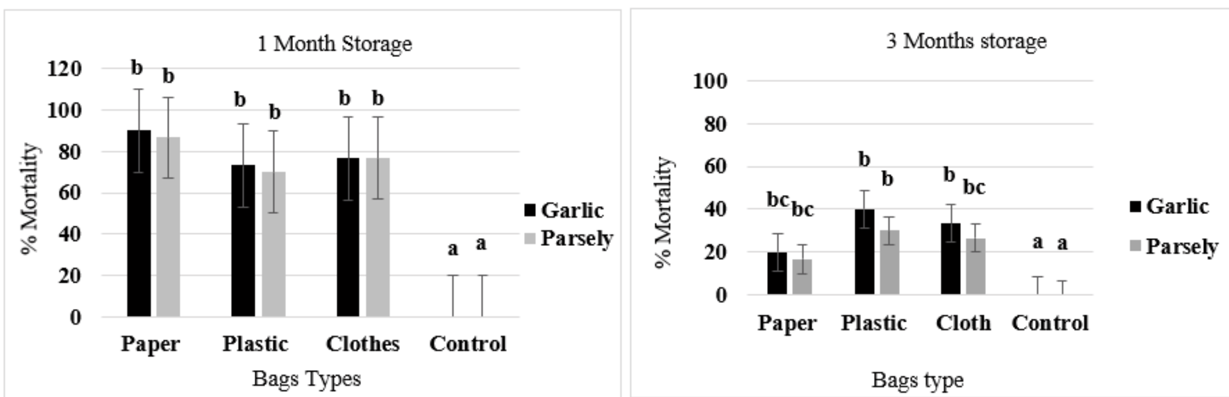

Fig 5: Storage efficiency of garlic oil (*Allium sativum*) and parsley (*Petroselinum crispum*) oil impregenated in different bags types after one and three months

insecticidal effect of the biopesticide of the silo bag with the added essential oil of *Mentha* x *piperita* L. released from the silo bag against *R. dominica* (F.) showed 100 % mortality during the time examined therefore silo bag could be used to control different pests in stored grain. Also, Vendl et al. (2021) mentioned that the treatment of different pieces of food packaging, cardboard spacer, and pallet with bergamot oil had critical repellent activity against *Sitophilus granarius* and *Tribolium confusum* Jacquelin du Val, 1863.

The storage experiment summarized in Table 6 showed that all tested bags had lasting toxic efficiency against adult *T. granarium* along the storage period that extended for three months. Where after one month of storage mortality percentage ranged from 90 to 70 % with the superiorly of paper bags over clothes and plastic bags for both tested essential oils respectively. On the other side, garlic oil was significantly more effective than parsley with all bag types after 3 months of storage, where the mortality rate was 20, 40, and 33.3 % for paper, plastic, and clothes bags respectively compared to 16.6, 30, and 26.66 in parsley.

In the long-term experiment, results indicate that LC_{90} concentration of garlic and parsley essential oils applied to tested bag types could produce protection to stored grains against *T. granarium* infection for a while lasting for three months. This technique offers the possibility of developing a new approach with many advantages. Amalraj et al. (2020) reported that black pepper and ginger essential oils consolidated in chitosan- (CS), gum arabic– (GA), and polyethylene glycol (PEG) showed high antimicrobial activity against a wide range of bacteria such as *Bacillus cereus* Frankland & Frankland 1887, *Staphylococcus aureus* Rosenbach 1884, *Escherichia coli* Migula 1895, *and Salmonella typhimurium* Lignières 1900, as a promising option in food packaging and wound dressing materials. Also, Mapossa et al. (2021) reported that studies searched for controlled-release formulations could be effective against mosquito vectors of malaria parasites. Moreover, plant powder from *Xylopia aethiopica* (Dunal) A. Rich. can serve as a carrier when mixed with its essential oil giving longer-term protection for grain against *Callosobruchus maculatus* insect due to lipids or other components present in the fruit powder may adsorb the terpenes, slowing down their release in the flask as reported by Habiba et al. (2010).

4 CONCLUSION

Controlling *T. granarium* adults could be attainable by impregnating both garlic and parsley essential oil in three types of storage bags polypropylene (BOPP), kraft paper (KP), and clothes. Garlic oil had a greater mortality effect on *T. granarium* than parsley oil. The BOPP and clothes bags showed higher mortality than (KP) bags with both garlic and parsley oil after 7 days of exposure. It was revealed that the treatment of clothes bags is the most effective approach for protecting grain against storage pests, which might have significant ramifications for the utilization under industrial conditions. For long-term storage results indicated that all tested bags had lasting toxicity effectiveness extended for 3 months varying from one type to another, whereas paper bags (KP) was the most lasting one over the other two types. Finally, the impregnation of essential oils as toxicants in different storage bag types mentioned above can offer protection against stored insects indicating that this approach could be considered as an additional tool to the concept of stored product management.

4.1 DECLARATION OF CONFLICTING INTERESTS

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

4.2 FUNDING

The author(s) received no financial support for the research, authorship, and/or publication of this article.

5 REFERENCES

Abbott, W.S. (1925**)**. A method for computing the effectiveness of an insecticide. *Journal of Economic Entomology*, *18*, 265-267. https://doi.org/10.1093/jee/18.2.265a

Adams, R. P. (1995). *Identification of essential oil components by gas chromatography/mass spectroscopy*. Allured Publishing Co., Carol Stream, IL javascript:void.

Amalraj, A., Raj, K. J., Haponiuk, J. T., Thomas, S., & Gopi, S. (2020)**.** Preparation, characterization, and antimicrobial activity of chitosan/gum arabic/polyethylene glycol composite films incorporated with black pepper essential oil and ginger essential oil as potential packaging and wound dressing materials. *Advanced Composites and Hybrid Materials*, *3*(4), 485-497. https://doi.org/10.1007/s42114-020-00178-w

Athanassiou, C.G., Kavallieratos, N.G., (2014)**.** Evaluation of spinetoram and spinosad for control of *Prostephanus truncatus, Rhyzopertha dominica, Sitophilus oryzae*, and *Tribolium confusum* on stored grains under laboratory conditions. *Journal of Pest Science*, *87*, 469-483. https://doi.org/10.1007/s10340-014-0563-9

Athanassiou, C.G., Kavallieratos, N.G., Boukouvala, M.C., (2016). Population growth of the khapra beetle, *Trogoderma granarium* Everts (Coleoptera: Dermestidae) on different commodities. *Journal of Stored Products Research, 69*, 72, 72–77. https://doi.org/10.1016/j.jspr.2016.05.001

Athanassiou, C.G., Kavallieratos, N.G., Boukouvala, M.C., Mavroforos, M.E., Kontodimas, D.C., (2015). Efcacy of alpha-cypermethrin and thiamathoxam against *Trogoderma granarium* Everts (Coleoptera: Dermestidae) and *Tenebrio molitor* L. (Coleoptera: Tenebrionidae) on concrete. *Journal of Stored Products Research*, *62*, 101–107. https://doi.org/10.1016/j.jspr.2015.04.003

Athanassiou, C.G., Phillips, T.W., Wakil, W., (2019). Biology and control of the khapra beetle, Trogoderma granarium, a major quarantine threat to global food security. *Annual Review of Entomology*, *64*, 131e148.

Bazargani-Gilani, B., Aliakbarlu, J., & Tajik, H. (2015). Effect of pomegranate juice dipping and chitosan coating enriched with *Zataria multiflora* Boiss essential oil on the shelf-life of chicken meat during refrigerated storage. *Innovative Food Science & Emerging Technologies*, *29*, 280–287. https://doi.org/10.1016/j.ifset.2015.04.007

Bohinc, T., Horvat, A., Ocvirk, M., Košir, I. J., Rutnik, K., & Trdan, S. (2020). The first evidence of the insecticidal potential of plant powders from invasive alien plants against rice weevil under laboratory conditions. *Applied Sciences*, *10*(21), 7828. https://doi.org/10.3390/app10217828

Camilotti, J., Ferarrese, L., de Campos Bortolucci, W., Takemura, O. S., Junior, R. P., Alberton, O., Linde, G. A., Gazim, Z. C. (2015). Essential oil of parsley and fractions to in vitro control of cattle ticks and dengue mosquitoes. *Journal of Medicinal Plants Research*, *9*(40),1021–1030. https://doi.org/10.5897/JMPR2015.5941

Campbell, J.F., Arthur, F.H., Mullen, M.A., (2004). Insect management in food processing facilities. In: Taylor, S.L. (Ed.), *Advances in Food and Nutrition Research*, *48*(2), 239-295. https://doi.org/10.1016/S1043-4526(04)48005-X

Costa, S. J. (2014). Reducing Food Losses in Sub-Saharan Africa: an "*'Action Research'Evaluation Trial from Uganda and Burkina*

Degri, M.M., Zainab, J.A., (2013). A study of insect pest infestations on stored fruits and vegetables in the north eastern Nigeria. *International Journal of Science and Nature*, *4*(4), 646-650.

Desneux, N., Decourtye, A., Delpuech, J.M., (2007). The sublethal effects of pesticides on beneficial arthropods. *Annual Review of Entomology*, *52*, 81-106. https://doi.org/10.1146/annurev.ento.52.110405.091440

Ebadollahi, A., Jalali Sendi, J., (2015). A review on recent research results on bio-effects of plant essential oils against major Coleopteran insect pests. *Toxin Reviews*, *34*(2), 76-91. https://doi.org/10.3109/15569543.2015.1023956

Edde, P. A., Eaton, M., Kells, S. A., Phillips, T. W., & Hagstrum,

D. W. (2012). Biology, behavior, and ecology of pests in other durable commodities. *Stored Product Protection*, 45-61.

Elegir, G., Kindl, A., Sadocco, P., Orlandi, M. (2008**).** Development of antimicrobial cellulose packaging through laccase-mediated grafting of phenolic compounds. *Enzyme and Microbial Technology*, *43*(2), 84-92. https://doi.org/10.1016/j.enzmictec.2007.10.003

EPPO (European and Mediterranean Plant Protection Organization), (2013). Diagnostics. PM 7/13 (2) Trogoderma granarium. *EPPO Bulletin*, *43*, 431-448. https://doi.org/10.1111/epp.12080

Finney, D. J. (1971). *Probit Analysis*, Cambridge: Cambridge University Press**.**

George, D.R., Sparagano, O.A.E., Port, G., Okello, E., Shiel, R.S., Guy, J.H., (2010). Toxicity of plant essential oils to different life stages of the poultry red mite, *Dermanyssus gallinae*, and non-target invertebrates. *Medical and Veterinary Entomology*, *24*(1), 9-15. https://doi.org/10.1111/j.1365-2915.2009.00856.x

Habiba, K., Thierry, H., Jules, D., Félicité, N., Georges, L., Franccedil, M., & Eric, H. (2010). Persistent effect of a preparation of essential oil from *Xylopia aethiopica* against *Callosobruchus maculatus* (Coleoptera, Bruchidae). *African Journal of Agricultural Research*, *5*(14), 1881-1888.

Herrera, J. M., Zygadlo, J. A., Strumia, M. C., & Peralta, E. (2021). Biopesticidal silo bag prepared by co-extrusion process. *Food Packaging and Shelf Life*, *28*, 100645. https://doi.org/10.1016/j.fpsl.2021.100645

Hillocks, R.J., 2012. Farming with fewer pesticides: EU pesticide review and resulting challenges for UK agriculture. *Crop Protection*, *31*(1), 85-93. https://doi.org/10.1016/j.cropro.2011.08.008

Honey, S.F., Bajwa, B., Mazhar, M.S., Wakil, W., (2017**).** *Trogoderma granarium* (Everts) (Coleoptera: Dermestidae), an alarming threat to rice supply chain of Pakistan. *International Journal of Entomological Research*, *5*(1), 23-31.

Hu, Fei, Tu, X.-F., Thakur, K., Hu, Fan, Li, X.-L., Zhang, Y.-S., Zhang, J.-G., Wei, Z.-J., (2019). Comparison of antifungal activity of essential oils from different plants against three fungi. *Food and Chemical Toxicology*, *134*, 110821. https://doi.org/10.1016/j.fct.2019.110821

Janaki, S., Zandi Sohani, N., Ramezani, L., Szumny, A., (2018). Chemical composition and insecticidal efcacy of *Cyperus rotundus* essential oil against three stored product pests. *International Biodeterioration & Biodegradation*, *133*, 93-98. https://doi.org/10.1016/j.ibiod.2018.06.008

Kavallieratos, N. G., & Boukouvala, M. C. (2018). Efficacy of four insecticides on different types of storage bags for the management of *Trogoderma granarium* Everts (Coleoptera: Dermestidae) adults and larvae. *Journal of Stored Products Research*, *78*, 50-58. https://doi.org/10.1016/j.jspr.2018.05.011

Kavallieratos, N. G., Boukouvala, M. C., Ntalli, N., Skourti, A., Karagianni, E. S., Nika, E. P., Benelli, G. (2020). Effectiveness of eight essential oils against two key stored-product beetles, *Prostephanus truncatus* (Horn) and *Trogoderma granarium* Everts. *Food and Chemical Toxicology*, *139*, 111255. https://doi.org/10.1016/j.fct.2020.111255

Kavallieratos, N.G., Athanassiou, C.G., Arthur, F.H., (2017a). Effectiveness of insecticide-incorporated bags to control stored-product beetles. *Journal of Stored Products Research*, *70*, 18-24. https://doi.org/10.1016/j.jspr.2016.11.001

Kavallieratos, N.G., Athanassiou, C.G., Nika, E.P., Boukouvala, M.C., (2017b). Efficacy of alpha-cypermethrin, chlorfenapyr and pirimiphos-methyl for the control of *Prostephanus truncatus* (Horn), *Rhyzopertha dominica* (F.) and *Sitophilus oryzae* (L.). *Journal of Stored Products Research*, *73*, 54-61. https://doi.org/10.1016/j.jspr.2017.06.005

Kavallieratos, N.G., Boukouvala, M.C., (2019). Efficacy of d-tetramethrin and acetamiprid for control of *Trogoderma granarium* Everts (Coleoptera: Dermestidae) adults and larvae on concrete. *Journal of Stored Products Research*, *80*, 79-84. https://doi.org/10.1016/j.jspr.2018.11.010

Khalique, U., Farooq, M.U., Ahmed, M.F., Niaz, U., (2018). Khapra beetle: a review of recent control methods. *Current Investigations in Agriculture and Current Research*, *5*(5), 666-671.

Lowe, S., Brone, M., Boudjelas, S., De Poorter, M., (2000). 100 of the world's worst invasive alien species: a selection from the global invasive species database (Vol. 12). *Auckland: Invasive Species Specialist Group.*

Lucchi, A., Benelli, G., (2018). Towards pesticide-free farming? Sharing needs and knowledge promotes Integrated Pest Management. *Environmental Science and Pollution Research*, *25*(14), 13439-13445.

Mansour, S.A., El-Sharkawy, A.Z., Abdel-Hamid, N.A. (2015). Toxicity of essential plant oils, in comparison with conventional insecticides, against the desert locust, *Schistocerca gregaria* (Forska˚l). *Industrial Crops and Products*, *63*, 92-99. https://doi.org/10.1016/j.indcrop.2014.10.038

Mapossa, A. B., Focke, W. W., Tewo, R. K., Androsch, R., & Kruger, T. (2021). Mosquito-repellent controlled-release formulations for fighting infectious diseases. *Malaria Journal*, *20*(1), 1-33. https://doi.org/10.1186/s12936-021-03681-7

Mossa, A. T. H., Afia, S. I., Mohafrash, S. M., & Abou-Awad, B. A. (2018). Formulation and characterization of garlic (Allium sativum L.) essential oil nanoemulsion and its acaricidal activity on eriophyid olive mites (Acari: Eriophyidae). *Environmental Science and Pollution Research*, *25*(11), 10526-10537. https://doi.org/10.1007/s11356-017-0752-1

Mullen, M. A., Vardeman, J. M., & Bagwell, J. (2012). 12 Insect-Resistant Packaging. *Stored Product Protection*, *135*.

Myers, S.W., Hagstrum, D.W., (2012). Quarantine. In: Hagstrum, D.H., Phillips, T.W., Cuperus, G. (Eds.), *Stored Product Protection*. Kansas State University, Manhattan, KS, pp. 297–304.

Paudyal, S., Opit, G.P., Arthur, F.H., Bingham, G.V., Payton, M.E., Gautam, S.G., Noden, B., (2017a). Effectiveness of the ZeroFly® storage bag fabric against stored product insects. *Journal of Stored Products Research*, *73*, 87-97. https://doi.org/10.1016/j.jspr.2017.07.001

Paudyal, S., Opit, G.P., Osekre, E.A., Arthur, F.H., Bingham, G.V., Payton, M.E., Danso, J.K., Manu, N., Nsiah, E.P., (2017b). Field evaluation of the long-lasting treated storage bag, deltamethrin incorporated, (ZeroFly® storage bag) as a barrier to insect pest. *Journal of Stored Products Research*, *70*, 44-52.

Pavela, R., Maggi, F., Iannarelli, R., Benelli, G., (2019). Plant extracts for developing mosquito larvicides: from laboratory to the feld, with insights on the modes of action. *Acta tropica*, *193*, 236-271. https://doi.org/10.1016/j.actatropica.2019.01.019

Rajendra, S. and V. Sriranjini. (2008). Plant products as fumigants for stored product insect control. *Journal of Stored Products Research, 44(2), 126-135*.

Satyal, P., Craft, J. D., Dosoky, N. S., & Setzer, W. N. (2017**).** The chemical compositions of the volatile oils of garlic (*Allium sativum*) and wild garlic (*Allium vineale*). *Foods*, *6*(8), 63. https://doi.org/10.3390/foods6080063

Scheff, D.S., Arthur, F.H., (2018). Fecundity of *Tribolium castaneum* and *Triboliumconfusum* adults after exposure to deltamethrin packaging. *Journal of Pest Science*, *91*, 717-725.

Scheff, D.S., Subramanyam, Bh, Arthur, F.H., (2016). Effect of methoprene treatedpolymer packaging on fecundity, egg, hatchability, and egg-to-adult emergence of *Tribolium castaneum* and *Trogoderma variabile*. *Journal of Stored Products Research*, *69*, 227-234.

Scheff, D.S., Subramanyam, Bh, Arthur, F.H., (2017). Susceptibility of *Tribolium castaneum* and *Trogoderma variabile* larvae and adults exposed to methoprenetreated woven packaging material. *Journal of Stored Products Research*, *73*, 142-150. https://doi.org/10.1016/j.jspr.2017.08.002

Soher, E.A., El–Shaffey, A.A., Selim, M.E., El-massry, K.F. and Sabry, B.A. (2014). Chemical profile, antioxidant, antifungal and antiaflatoxigenic activity of Parsley and Ginger volatile and non-volatile extracts. *Journal of Biologically Active Products from Nature*, *1*(1), 81-96. https://doi.org/10.1080/22311866.2011.10719074

Stejskal, V., Bostlova, M., Nesvorna, M., Volek, V., Dolezal, V., Hubert, J. (2017). Comparison of the resistance of mono- and multiplayer packaging films to stored-product insects in a laboratory test. *Food Control*, *73*, 566-573. https://doi.org/10.1016/j.foodcont.2016.09.001

Stevenson, P.C., Isman, M.B., Belmain, S.R., (2017). Pesticidal plants in Africa: a globalvision of new biological control products from local uses. *Industrial Crops and Products*, *110*, 2-9.

Swigar A. A. and R. M. Silverstein (1981). *Monoterpenes*. Aldrich Chemical Company Publ., Milwaukee, WI javascript:void.

Tripathi, A.K., S. Upadhyay, M. Bhuiyan and P.R. Bhattacharya. (2009). A Review on Prospects of Essential Oils as Biopesticides in Insect-Pest Management. *Journal of Pharmacognosy and Phytotherapy*, *15*, 052-053.

Tu, X. F., Hu, F., Thakur, K., Li, X.-L., Zhang, Y.-S., Wei, Z.-J., (2018). Comparison of antibacterial effects and fumigant toxicity of essential oils extracted from different plants. *Industrial Crops and Products*, *124*, 192-200. https://doi.org/10.1016/j.indcrop.2018.07.065

Vendl, T., Stejskal, V., Kadlec, J., & Aulicky, R. (2021). New approach for evaluating the repellent activity of essential oils against storage pests using a miniaturized model of stored-commodity packaging and a wooden transport pallet. *Industrial Crops and Products*, *172*, 114024. https://doi.org/10.1016/j.indcrop.2021.114024

Wong, K. K., Signal, F. A., Campion, S. H., Motion, R. L. (2005). Citronella as an insect repellent in food packaging. *Journal of Agricultural and Food Chemistry*, *53*(11), 4633-4636. https://doi.org/10.1021/jf050096m

Yang, F.L., Li, X.G., Zhu, F., Lei, C.H.L., (2009). Structural characterization of nanoparticles loaded with garlic essential oil and their insecticidal activity against *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). *Journal of Agricultural and Food Chemistry 57*, 10156e10162. https://doi.org/10.1021/jf9023118

Zhang, H., Chen, F., Wang, X. and Hui-Yuan, Y. (2006). Evaluation of Antioxidant activity of parsley (*Petroselinum crispum*) essential oil and identification of its antioxidant constituents. *Food research international*, *39*(8), 833-839. https://doi.org/10.1016/j.foodres.2006.03.007