Chemical composition, fumigant toxicity and oviposition deterrence of *Cinnamomum zeylanicum* essential oil to three stored-product insects

Habib Abbasipour (Corresponding author)

Department of Plant Protection, Faculty of Agricultural Sciences, Shahed University, Tehran, Iran,

Email: habbasipour@yahoo.com

Mohammad Mahmoudvand

Department of Plant Protection, Khorramabad Brach, Islamic Azad University, Khorramabad, Iran,

Email: msco_1381@yahoo.com

Fahimeh Rastegar

Department of Plant Protection, Faculty of Agricultural Sciences, Shahed University, Tehran, Iran,

Email: rastegar.fa@gmail.com

Mohammad Hossein Hosseinpour

Department of Plant Protection, Faculty of Agricultural Sciences, Shahed University, Tehran, Iran,

Email: hoseinpur181@yahoo.com

This work was supported by a grant from the Shahed University of Iran and carried out in Faculty of Agricultural Sciences

Abstract

Using insecticides has disruptive effects on environments. Replacement of chemical insecticides with new plant materials can be a safe method with low risk. The fumigant activity of essential oil vapors distilled from the cinnamon, *Cinnamomum zeylanicum* was tested against one to seven day old adults of three stored-product insects including *Callosobruchus maculatus* (Fab.), *Tribolium castaneum* (Herbst) and *Ephestia kuehniella* Zeller. The potency of fumigant toxicity of *C. zeylanicum* on *E. kuehniella* was higher (LC_{50}: 2.87 µL L^{-1} air) than *C. maculatus* (LC_{50}: 443.17 µL L^{-1} air) and *T. castaneum* (LC_{50}: 755.9 µL L^{-1} air). The relationships between the exposure time and oil concentration on mortality show that the mortality increased with oil concentration and exposure time, and highest mortality was observed during 12 to 24 hours after experiment. In oviposition deterrence experiment on *C. maculatus* (highest concentration=385.56 mg/ml), essential oils of the cinnamon had the highest detergency rate (93.82%). The constituents of the essential oils were analyzed by GC/MS. The major constituent of the Cinnamon was cinnamaldehyde (97.38%). Results of this study indicated that cinnamon essential oil was useful as insect control fumigant for stored products adults.

Keywords: Essential oil, *Tribolium*, *Ephestia*, *Cinnamomum zeylanicum*, oviposition deterrence, chemical composition

1. Introduction

In the search for alternatives to conventional fumigants, essential oils extracted from aromatic plants have been widely investigated. Their toxicity to stored-product insects has been of special interest during the last decade. Most of these studies assessed fumigant activity of these compounds on adults and to lesser extent larvae(Mahmoudvand et al., 2011a; Mahmoudvand et al., 2011b). As the essential oils are intended to be used like fumigants to disinfest commodities, they should have the ability to kill all stages of insects. Therefore, in order to better knowing the response of the adult stage to essential oils – and especially their vapors - or their constituents, there is a need for systematic investigations of the effect of different essential oil concentrations and exposure periods on stored-product insects. Lauraceae is an economically important family consisting mostly of trees. The genus *Cinnamomum* comprises about 250 species distributed in Asia and Australia (Jayaprakasha et al., 2003). *Cinnamomum zeylanicum* Blume is a tropical evergreen tree and grows wild in Sri Lanka, Madagascar, India and Indochina. The inner bark of the tree has been used in ethno-medicine and flavoring for foods (Bakkali et al., 2008; Baytop, 1999). Modern studies showed that extracts and its constituents from *C. zeylanicum* also posses antimicrobial (Carmo et al., 2008; Chao et al., 2000; Dusan et al., 2006; Ranasinghe et al., 2002) insecticidal (Yang et al., 2005), acaricidal (Fichi et al., 2007) antityrosinase (Marongiu et al., 2007), antioxidant and antimutagenic (Jayaprakasha et al., 2007) activities. The essential oil of another plant of the same genus, *C. osmoploeum* Kaneh, also showed a good insecticidal activity on mosquito larvae and termites (Chang and Cheng, 2002; Cheng et al., 2004).

One of the major storage pests of cowpea is *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae) (Epidi et al., 2008), which is an important pest of many grains such as *Vigna sinensis* L. (cowpea), *Cicer arietinum* L. (chickpea) and *Lens culinaris* Medik (lentil) (Mahfuz and Khalequzzaman, 2007). In addition, *Tribolium castaneum* Herbst (Coleoptera: Tenebrionidae) is also a major storage pest which prefers grain products such as flour(Campbell and Runnion, 2003). Another major pest of flour industrial is the mediterranean flour moth, *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) (Jacob and Cox, 1977).

The objective of this research was investigation the adulticidal of essential oil of *C. zeylanicum* on *C. maculatus*, *T. castaneum* and *E. kuehniella* and lethal time of these tests. In addition study in chemical composition of this essential oil and effect of this plant material on ovposition deterrence of females of *C. maculatus*. The present study is the first study in investigation the fumigant toxicity of essential oil of *C. zeylanicum* on adult stage of mentioned pests and the first in effect of this essential oil on LT_{50} and ovipossition deterrence of insects.

2. Materials and methods

2.1 Essential oil extraction

The cortex of stem and branches of *Cinnamomum zeylanicum* was collected for extraction of the essential oil. All the collected parts were shade dried under indoor condition and were subjected to hydrodistillation using Clevenger type distiller (Cavalcanti et al., 2004). For extraction of essential oils, 50 g of air-dried plant material was put in water (1:12 w:v) for distillation during 4h. Extracted essential oils were dried via anhydrous sodium sulphate and stored at 4°C in darkness. For fumigant bioassay tests, pure essential oil was used.

2.2 GC-MS analysis

The oil was analyzed using a HP-5973 chromatograph equipped with a QP-5000 (Quadruple) mass spectrometer. The sample was diluted 25 times with acetone, and 1 µL was injected. A fused silica column SPB-1 (30 m\250 mn, film thickness 0.25 µm) coated with polydimethyl siloxane was used. Helium was the carrier gas at a flow rate of 1 mL/min. The injector port temperature was 225 ^{o}C, the detector temperature was 250 ^{o}C and the oven temperature was maintained at 60 ^{o}C for 2 min and then increased to 225 ^{o}C at the rate of 2 ^{o}C /min at which temperature the column was maintained for 5 min. The split ratio was 1:25 and the ionization voltage, 70 eV. Unknown essential oil was identified by comparing its GC retention time to that of known compounds and by comparison of its mass spectra, either with known compounds or published spectra.

2.3 Insect rearing

The insects' colonies were obtained from laboratory cultures, maintained in the dark in incubators at 27 ± 1 ºC and 60 ± 5 % RH. The insects were cultured in plastic cages (20×30×30 cm). For rearing *T. castaneum*, *E. kuehniella* and *C. maculatus*, flour, flour and mung bean grains were used, respectively.

2.4 Fumigant toxicity of Coleopteran species

For investigation the fumigant toxicity of essential oil on coleopteran pests, glass vials (70 ml) was applied. In each vial, 10 adults of *T. castaneum* and *C. maculatus* (1-7 days old) were released. Filter paper disks (Whatman No. 1) were cut into 2 cm in diameter and were attached to undersurface of screw caps of glass vials. A series of pure concentration of essential oil of *C. zeylanicum* were dropped on filter papers and they were put on the vials. The numbers of dead and alive insects after 3, 6, 9, 12, 24 and 48 h from the beginning of exposure were counted, albeit after 24 h, the treated insects were transferred to untreated vials. For each concentration and control 4 replicates were run. The numbers of dead and alive insects for various insects and times were depicted for all doses in Figs. 1 and 2. There was no mortality in control.

2.5 Fumigant toxicity on moths of E. kuehniella

These experiments were confirmed similar to those for coleopteran pests though in these tests, moths were 1day old. In these experiments mortality was also recorded after 3, 6, 9, 12 and 24 h from the beginning of exposure and mortality graph for all doses were depicted.

2.6 Lethal time (LT_{50}) of mortality

The high doses (upper than LC_{70}) were selected for investigation on the lethal time (LT_{50}) of essential oil of *C. zeylanicum* on the three pests. These doses were obtained from fumigant toxicity experiments. The methods of LT_{50} test were similar to those for fumigant tests and for each concentration four was used. The mortality of insects was counted after 3, 6, 9, 12 and 24 h and after that, in 3 h intervals, mortality recording was continued until death of all subjects.

2.7 Effect of essential oil on oviposition deterrence of C. maculatus

To investigation the effect of essential oil on the oviposition reduction, two pair (2 males and 2 females) of adults of *C. maculatus* for each concentration and control were selected and were released in a glass vials (70 mL). For each vial, 5 g mung bean grains those were treated with 1 ml of aceton solution of (sublethal concentrations) of essential oil (199.92, 271.32, 382.44 and 385.56 mg/ml). For control, only aceton was used. After evaporation of the aceton, new emerged adults of *C. maculatus* were transferred to vials. For each concentration, 4 replications were performed. The number of laid eggs was recorded after 48 h in all treatments.

2.8 Statistical analysis

The lethal concentrations (LC_{50} and LC_{90}) and lethal time (LT_{50}) values of mortality were assessed by Probit analysis using SAS software (SAS-Institute, 1997). The data from oviposition deterrence were subjected to one-way ANOVA ($P<0.05$) after checking for normality. Means were compared by Tukey's Studentized Range Test, admitting significant differences at $P<0.05$. The SAS software was used for all analyses (SAS-Institute, 1997).

3. Results

3.1 Effect of essential oil vapor

Tables 1 and 2 show the fumigant toxicity of essential oil of *C. zeylanicum* on the adults of *C. maculatus* and *T. castaneum* after 24 and 48 h. Also in Table 1, values of LC_{50} and LC_{90} of this essential oil on *E. kuehniella* after 24 h was shown. Figs. 1-3 separately report the mortality trend of *C. zeylanicum* on these pests in various times. After 24 h, values of LC_{50} were 443.17, 755.09 and 2.87 $\mu L\ L^{-1}$ air for *C. maculatus*, *T. castaneum* and *E. kuehniella*, respectively. The values of LC_{50} were 190.79 and 516.91 $\mu L\ L^{-1}$ air after 48 h for *C. maculatus* and *T. castaneum*. Obtained results of LC_{50} in 48 h showed that the effect of essential oil was stable and the LC_{50} values in 48 h were lower than those in 24 h. Although the highest rate of mortality was seen in the period of 12-24 h in *T. castaneum* and *E. kuehniella* (Figs 2 and 3), but the highest mortality of *T. castaneum* was observed in 9-12 h period (fig. 1). Clearly, gradient of mortality in the higher doses was more than the lower doses.

3.2 Lethal time (LT_{50}) of mortality

In Table 3, the LT_{50} values of various concentrations of essential oil of *C. zeylanicum* on different adult insects were reported. LT_{50} values of 585.48 and 913.92 µL L^{-1} air doses of this essential oil on *C. maculatus* were 10.35 and 7.36 hours, respectively. The LT_{50} values of *C. zeylanicum* on *T. castaneum* in the dose of 1500 µL L^{-1} air was 18.79 and in 2000 dose was 9.34 hours. For *E. kuehniella*, the lethal time of mortality (LT_{50}) was 18.71 and 8.18 hours for 8.3 and 16.6 µL L^{-1} air concentrations, respectively.

3.3 Oviposition deterrence

The number of eggs laid by *C. maculatus* upon mung bean seeds those treated by essential oil of *C. zeylanicum* was shown in Table 4. Results indicated that number of eggs laid by females in 48 h in all concentrations significantly decreased compared to control (df= 4, 15, F= 44.90, $P<0.0001$(Table 4).

3.4 Chemical constituents of C. zeylanicum

The results of the chemical analysis are presented in Table 5. Eleven compounds in the oil were positively identified. The main constituents of the oils were Cinnamaldehde (97.38%), Camphene (1.04%), Perila alcohol (0.51%), Trans caryophyllene (0.34%), Benzenethanamine (0.27%), Cisocimene (0.27%), Benzenepropanal (0.22%). Therefore, in this study Cinnamaldehde, Camphene, and Perila alcohol were found to be the major constituents and accounted for 99% of the total oil.

4. Discussion

Cinnamomum genus comprises about 250 species distributed in Asia and Australia. *Cinnamomum zeylanicum* Blume is a tropical evergreen tree and grows wild in many parts of Asia. The essential oil of *C. zeylanicum* demonstrated fumigant toxicity against *C. maculatus, T. castaneum* and *E. kuehniella.* The insecticidal activity varied with insect species, concentrations of the oil and exposure time. The results showed high mortality rates in *E. kuehniella* compared to *C. maculatus* and *T. castaneum.* This is the first study in researching the adulticidal effect of *C. zeylanicum*. Also mortality time and ovicidal deterrence of *C. zeylanicum* essential oil didn't report so far and in these cases these are the novelty of this study. Yang et al. (2005) indicated that *C. zeylanicum* bark oil have fumigant and contact toxicity on the eggs and adults of human head louse, *pediculus humanus capitis*. Also, Ashouri et al. (2010) have reported the mixture of bark powder of *C. zeylanicum* with wheat grains (in ratio of 5%) caused significant mortality on the adults of *Rhyzopertha dominica* F. and *Sitophilus granarius* L. The results of Ashouri et al. confirmed our results using different insects. Similar to results of this study, Aslam et al. (2002) have also reported that 2.5% mixture of the Cinnamon bark powder with Mungbean grains caused 100% mortality in *Callosobruchus chinensis* L. within 8.5 days. As Salvadores et al (2007) showed that 4% mixture of the Cinnamon bark powder with wheat grains caused 80% mortality in *Sitophilus zeamais* Motschulsky adults.

Moreover, our results indicated that the higher concentrations of the oil for a relatively short period are much more effective than lower concentrations for a long period. The *C. zeylanicum* oil showed potent toxicity giving 90-100% mortality within 24 h exposure at 16.6 µL per L of air for *E. kuehniella*, 913.92 µL per L of air for *C. maculatus* and 2000 µL per L of air for *T. castaneum.*

Plant materials have oviposition deterrence on insects. In addition, essential oil of *C. zeylanicum* showed good effect on decreasing the egg laid by females on surfaces those were treated. Abbasipour et al. (2010) stated that *Peganum harmala* seed extract decreased oviposition of *Plutella xylostella* (L.) on leaves of cauliflower. Also neem extract and essential oils are known to possess ovicidal, repellent and insecticidal activities against various stored-product insects (Desmarchelier, 1994; Hill and Schoonhoven, 1981; Shaaya et al., 1997). The insecticidal constituents of many plant extracts and essential oils against stored-product insects are mainly monoterpenoids such as limonene, linalool, terpineol, carvacrol and myrcene

(Ahn et al., 1998; Coats et al., 1991; Regnault-Roger and Hamraoui, 1995). Additionally, some plant-derived materials are highly effective against insecticide-resistant insect pests (Arnason et al., 1989). In our study with *C. zeylanicum* bark essential oil, the cinnamaldehyde revealed good adulticidal activity against *C. maculatus*, *T. castaneum* and *E. kuehniella* and this confirms its usefulness as candidate for the control of insect pests in stored products. Lawrence (1994) and Rahman et al. (1999) have also confirmed that the Cinnamon bark oil contain 60-82% of cinnamaldehyde as its main constituent.

Cinnamaldehyde (LD_{50} orally, 2220 mg/kg rat) has low acute toxicity to mammals (1989). For the practical use of *Cinnamomum* bark essential oil and test compounds as novel fumigants to proceed, further research is required on the safety issues of these materials for human health. Other areas requiring attention are insecticide mode of action and formulations to improve potency and stability and to reduce cost.

In conclusion, results of this study investigated that essential oil of *C. zeylanicum* had a good toxicity on adults of *C. maculatus*, *T. castaneum* and *E. kuehniella*. Also the highest mortality of these pests were occurred in the first 24 h. Moreover, effect of this essential oil on oviposition deterrence of *C. maculatus* was clear and notable.

References

Abbasipour, H., Mahmoudvand, M., Rastegar, F., & Basij, M. (2010). Insecticidal activity of Peganum harmala seed extract against the diamondback moth, *Plutella xylostella*. *Bulletin of Insectology* 63, 259-263.

Ahn, Y. J., Lee, S. B., Lee, H. S., & Kim, G. H. (1998). Insecticidal and acaricidal activity of carvacrol and b-thujaplicine derived from *Thujopsis dolabrata* var. *hondai* sawdust. *Journal of Chemical Ecology* 24, 81-90.

Arnason, J. T., Philogene, B. J. R., Morand, P., Imrie, K., Iyengar, S., Duval, F., Soucy-Breau, C., Scaiano, J. C., Werstiuk, N. H., Hasspieler, B., & Downe, A. E. R. (1989). Naturally occuring and synthetic thiophenes as photoactivated insecticides. *In* "Insecticides of Plant Origin, ACS Symposium Series " (J. T. Arnason, B. J. R. Philogene & P. Morand, eds.), Vol. No. 387, pp. 164–172. American Chemical Society, Washington, DC.

Ashouri, S., Shayesteh, N., Maroufpoor, M., Ebadollahi, A., & Ghasemzadeh, S. (2010). Toxicity and Progeny Reduction Potency of Two Powdered Spices, Turmeric and Cinnamon on Adults of *Rhyzopertha dominica* (F.) and *Sitophilus granaries* (L.). *Munis Entomology and Zoology* 5, 1095-1103.

Aslam, M., Ali Khan, K., & Bajwa, M. Z. H. (2002). Potency of some spices against *Callosobruchus chinensis* L. *Online Journal of Biological Sciences* 2, 449-452.

Bakkali, F., Averbeck, S., & Averbeck, D. (2008). Biological effects of essential oils-a review. *Food Chemistry Toxicology* 46, 446-475.

Baytop, T. (1999). "Türkiye'de Bitkiler ile Tedavi (Treatment with Plants in Turkey)," Istanbul University Publications, No: 3255/40, Istanbul, Turkey.

Budavari, S. B., O'Neil, M. J., Smith, A., & Heckelman, P. E. (1989). "The Merck Index," Merck and Co, Rahway, NJ.

Campbell, J. F., & Runnion, C. (2003). Patch exploitation by female red flour beetles, *Tribolium castaneum*. 8 p. *Journal of Insect Science* 3, n20.

Carmo, E. S., Lima, E. D., de Souza, E. L., & de Sousa, F. B. (2008). Effect of *Cinnamomum zeylanicum* blume essential oil on the growth and morphogenesis of some potentially pathogenic Aspergillus species. *Brazil Journal of Microbiology* 39, 91-97.

Cavalcanti, E. S. B., Morais, S. M., Lima, M. A. A., & Santana, E. W. P. (2004). Larvicidal activity of essential oils from Brazilian plants against *Aedes aegypti* L. *Memories Institute of Oswaldo Cruz* 99, 541-544.

Chang, S. T., & Cheng, S. S. (2002). Antitermitic activity of leaf essential oil and components from *Cinnamomum osmophleum*. *Journal of Agriculture Food Chemistry* 50, 1389-1392.

Chao, S. C., Young, D. G., & Oberg, C. J. (2000). Screening for inhibitory activity of essential oils on selected bacteria, fungi and viruses. *Journal of Essential Oil Research* 12, 639-649.

Cheng, S. S., Liu, J. T., Tsai, K. H., Chen, W. J., & Chang, S. T. (2004). Chemical composition and mosquito larvicidal activity of essential oils from leaves of different *Cinnamomum osmophloeum* provenances. *Journal of Agriculture Food Chemistry* 52, 4395-4400.

Coats, J. R., Karr, L. L., & Drewes, C. D. (1991). Toxicity and neurotoxic effects of monoterpenoids in insects and earthworms *In* "Naturally Occurring Pest Bioregulators, ACS Symposium Series No. 449 " (P. A. Hedin, ed.), pp. 305–316. American Chemical Society, Washington, DC.

Desmarchelier, J. H. (1994). Grain protectants: trends and developments. *In* "Stored Product Protection" (E. Highley, E. J. Wright, H. J. Banks & B. R. Champ, eds.), pp. 722–728. CAB International, Wallingford, UK.

Dusan, F., Marian, S., Katarina, D., & Dobroslava, B. (2006). Essential oils-their antimicrobial activity against Escherichia coli and effect on intestinal cell viability. *Toxicology In Vitro* 20, 1435-1445.

Epidi, T. T., Nwani, C. D., & Udoh, S. (2008). Efficacy of some plant species for the control of cowpea weevil (*Callosobruchus maculatus*) and maize weevil (*Sitophilus zeamais*). *International Journal of Agricultural Biology* 10, 588-590.

Fichi, G., Flamini, G., Zaralli, L. J., & Perrucci, S. (2007). Efficacy of an essential oil of *Cinnamomum zeylanicum* against Psoroptes cuniculi. *Phytomedicine* 14, 227-231.

Hill, J. M., & Schoonhoven, A. V. (1981). The use of vegetable oils in controlling insect infestations in stored grains and pulses. *Recent Advances in Food Science and Technology* 1, 473-481.

Jacob, T. A., & Cox, P. D. (1977). The influence of temperature and humidity on the life-cycle of *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae). *Journal of Stored Products Research* 13, 107-118.

Jayaprakasha, G. K., Jagan Mohan Rao, L., & Sakariah, K. K. (2003). Volatile constituents from *Cinnamomum zeylanicum* fruit stalks and their antioxidant activities. *Journal Agriculture Food Chemistry* 51, 4344-4348.

Jayaprakasha, G. K., Negi, P. S., Jena, B. S., & Jagan Mohan Rao, L. (2007). Antioxidant and antimutajenic activities of *Cinnamomum zeylanicum* fruit extracts. *Journal of Food Composition Analytical* 20, 330-336.

Lawrence, B. M. (1994). Progress in Essential Oils. *Parfume and Flavor Journal* 19, 59.

Mahfuz, I., & Khalequzzaman, M. (2007). Contact and fumigant toxicity of essential oils against *Callosobruchus maculatus*. *University Journal of Zoology, Rajshahi University* 26, 63-66.

Mahmoudvand, M., Abbasipour, H., Basij, M., Hosseinpour, M. H., Rastegar, F., & Nasiri, M. B. (2011a). Fumigant toxicity of some essential oils on dults of some stored-product pests. *Chilean Journal of Agricultural Research* 71, 83-89.

Mahmoudvand, M., Abbasipour, H., Hosseinpour, M. H., Rastegar, F., & Basij, M. (2011b). Using some Plant Essential Oils as natural fumigants against adults of Callosobruchus maculatus (F.) (Coleoptera: Bruchidae). *Munis Entomology & Zoology* 6, 151-154.

Marongiu, B., Piras, A., Porcedda, S., Tuveri, E., Sanjust, E., Meli, M., Sollai, F., Zucca, P., & Rescigno, A. (2007). Supercritical CO2 extract of *Cinnamomum zeylanicum*: Chemical characterization and antityrosinase activity. *Journal of Agricultre of Food Chemistry* 55, 10022–10027.

Rahman, A., Choudhary, M. I., Farooq, A., Ahmed, A., Iqbal, M. Z., Demirci, B., Demirci, F., & Can Baser, K. H. (1999). Antifungal activities and essential oil constituents of some spices from Pakistan. *In* "Proceedings of Third International Electronic Conference on Synthetic Organic Chemistry".

Ranasinghe, L., Jayawardena, B., & Abeywickrama, K. (2002). Fungicidal activity of essential oils of *Cinnamomum zeylanicum* (L.) and *Syzygium aromaticum* (L.) Merr et L. M. Perry against crown rot and anthracnose pathogens isolated from banana. *Letter of Applied Microbiology* 35, 208-221.

Regnault-Roger, C., & Hamraoui, A. (1995). Fumigant toxic activity and reproductive inhibition induced by monoterpenes on *Acanthoscelides obtectus* (Say) (Coleoptera), a bruchid of kidney bean (Phaseolus vulgaris L.). *Journal of Stored Products Research* 31, 291-299.

SAS-Institute (1997). SAS/STAT. guide for personal computers. Ver. 6.12. SAS Institute, Cary, NC.

Shaaya, E., Kostjukovski, M., Eilberg, J., & Sukprakarn, C. (1997). Plant oils as fumigant and contact insecticides for the control of stored-product insects. *Journal of Stored Products Research* 33, 7-15.

Yang, Y. C., Lee, H. S., Lee, S. H., Clark, J. M., & Ahn, Y. J. (2005). Ovicidal and adulticidal activities of *Cinnamomum zeylanicum* bark essential oil compounds and related compounds against Pediculus humanus capitis (Anoplura: Pediculidae). *International Journal of Parasitology* 23.

Table 1. Fumigant toxicity of essential oil of *Cinnamomum zeylanicum* against three stored products pests after 24 h

Insect	n[a]	Df	LC_{50} (μL L^{-1} air)	LC_{90} (μL L^{-1} air)	Slope ± SE	χ^2
C. maculatus	200	3	443.17 (388.52 - 493.45)	937.49 (765.83 – 1413)	3.93 ± 0.73	0. 92
T. castaneum	240	4	755.09 (670.63 - 844.22)	1687 (1413-2211)	3.67 ± 0.45	1.44
E. kuehniella	200	3	2.87 (2.43 - 3.53)	8.79 (6.18 - 17.20)	2.63 ± 0.44	0.91

[a] number of subjects

Table 2. Fumigant toxicity of essential oil of *Cinnamomum zeylanicum* against two stored products pests after 48 h

Insect	n[a]	Df	LC_{50} (μl L^{-1} air)	LC_{90} (μL L^{-1} air)	Slope ± SE	χ^2
C. maculatus	200	3	190.79 (32.62 - 278.49)	685.41 (539.44 – 1740)	2.30 ± 0.78	5.10
T. castaneum	240	4	516.91 (444.94 - 580.74)	1083 (940.86 - 1331)	3.98 ± 0.50	2.89

[a] number of subjects

Table 3. Lethal time (LT_{50}) of various concentrations of essential oil of *Cinnamomum zeylanicum* against three stored products pests

Insect	Concentration (μL L^{-1} air)	Df	LT_{50} (h)	LT_{90} (h)	Slope ± SE	χ^2
C. maculatus	585.48	4	10.35 (3.48 - 15.82)	24.91 (18.48 - 47.66)	0.08 ± 0.01	14.10
	913.92	4	7.364 (2.10 - 10.90)	18.53 (14.14 - 31.51)	0.11 ± 0.02	10.48
T. castaneum	1500	5	18.79 (17.51 - 20.09)	26.89 (25.26 - 28.92)	0.15 ± 0.01	9.37
	2000	3	5.40 (4.62- 6.07)	9.34 (8.45 - 10.66)	0.32 ± 0.04	3.34
E. kuehniella	8.3	5	18.71 (17.39 - 20.04)	27.46 (25.73 -29.63)	0.14 ± 0.01	9.28
	16.6	3	8.18 (7.43 - 8.97)	12.93 (11.72 - 14.80)	0.26 ± 0.03	0.77

Table 4. Mean (±SE) of oviposition deterrence of *Cinnamomum zeylanicum* essential oil on adult of *Callosobruchus maculatus*

	Control	Concentrations of essential oil (mg/mL)			
		199.92	271.32	328.44	385.56
Mean of laid eggs	158.25 ± 11.69 a	88.81 ± 10.74 b	53.47 ± 4.88 bc	31.15 ± 9.96 cd	9.76 ± 1.17 d

Means marked with the different letters within the same row are significantly different ($P<0.05$; Tukey).

(df= 4, 15, F= 44.90, $P<0.0001$)

Table 5. Volatile compounds in steam-distilled oil of the bark from *C. zeylanicum* identified by gas chromatography–mass spectrometry

Peak No.	Compound	Apex RT	Start RT	End RT	Area	%Area	Height	%Height
1	Cisocimene	6.15	5.93	6.29	25876512	0.27	2943145	6.25
2	Camphene	6.72	6.33	6.89	1E+08	1.04	5357397	11.38
3	Ocimene	6.95	6.92	7.11	4970884	0.05	817331.3	1.74
4	Tricyclene	7.18	7.14	7.42	5836249	0.06	587308.1	1.25
5	Perila alcohol	8.46	8.3	9.16	48821201	0.51	2586949	5.49
6	Benzenepropanal	14.07	12.92	14.29	21366029	0.22	303477.8	0.64
7	Cinnamaldehyde	19.3	16.78	23.45	9.36E+09	97.38	33030988	70.15
8	Benzenethanamine	26.14	25.68	26.7	26404641	0.27	708608.5	1.5
9	Humulene	27.26	27.14	27.73	18664543	0.19	748730	1.59
10	Phenethylamine	23.24	22.91	23.46	31116418	0.5	1992152	5.54
11	Trans caryophyllene	23.85	23.74	24.18	21329730	0.34	1819213	5.06

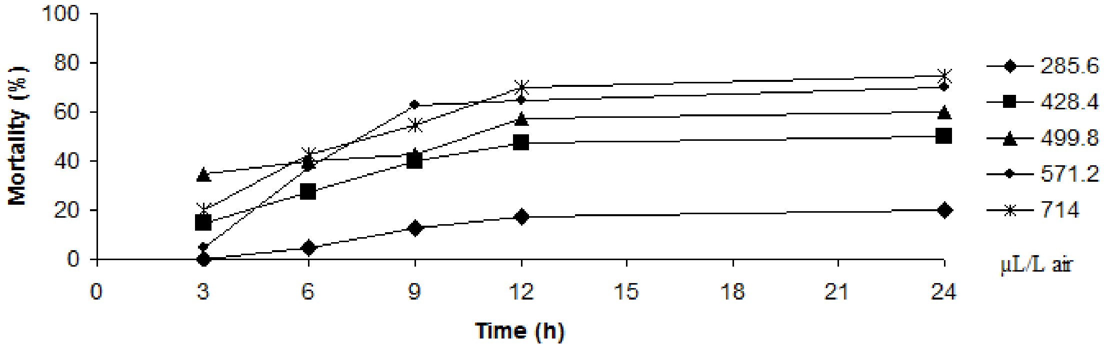

Figure 1. Adults mortality of *C. maculatus* exposed to *C. zeylanicum* essential oil in different concentrations and times.

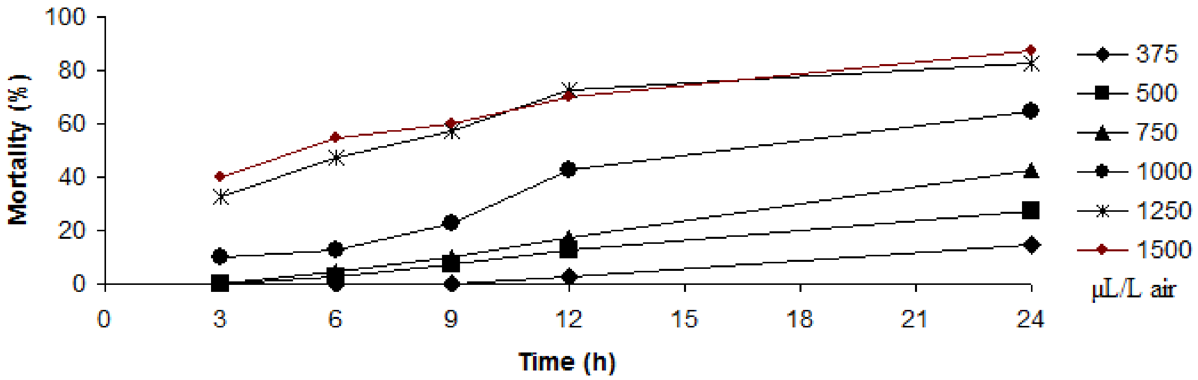

Figure 2. Adult mortality of *T. castaneum* exposed to *C. zeylanicum* essential oil in different concentrations and times.

ISSN 1661-464X

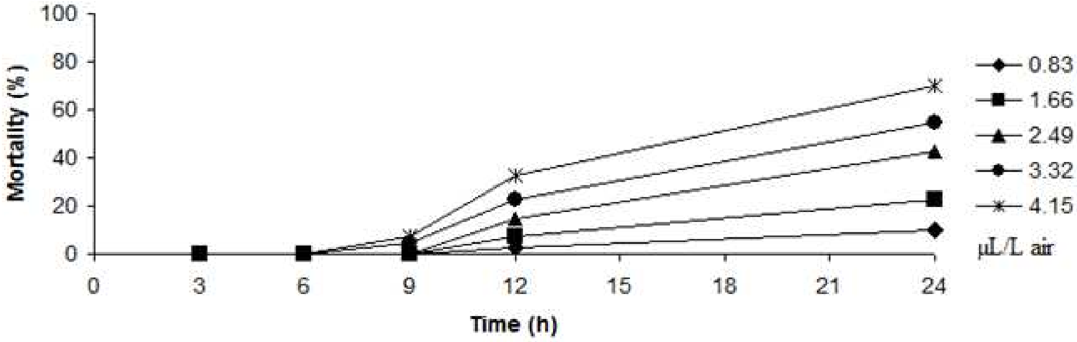

Figure 3. Adult mortality of *E. kuehniella* exposed to *C. zeylanicum* essential oil in different concentrations and times.