Insecticidal and repellent activity of essential oil from *Amomum villosum* Lour. and its main compounds against two stored-product insects

Zhen-yang Chen*, Shan-shan Guo*, Ju-qin Cao*<sup>e,b</sup>, Xue Pang*, Zhu-feng Geng*<sup>c</sup>, Yang Wang*, Zhe Zhang*, and Shu-shan Du*

*Beijing Key Laboratory of Traditional Chinese Medicine Protection and Utilization, Faculty of Geographical Science Beijing Normal University, Beijing, China; **Medical Chemistry Department, School of Basic Medical Sciences, Ningxia Medical University, Yinchuan, China; Analytical and Testing Center, Beijing Normal University, Beijing, China

**ABSTRACT**

The *Amomum villosum* essential oil was obtained from hydrodistillation and was investigated by GC-MS. The main constituents were bornyl acetate (51.6%), camphor (19.8%), camphene (8.9%) and limonene (6.2%). Insecticidal toxicity of the essential oil was evaluated in this study. It showed that the essential oil possessed contact toxicity against *Tribolium castaneum* and *Lasioderma serricorne* (LD<sub>50</sub> = 32.4 and 20.4 μg/adult). Three monoterpenoids camphor, camphene and limonene showed strong fumigant toxicity against *T. castaneum* (LC<sub>50</sub> < 2.3, LC<sub>50</sub> = 6.2 and 6.2 mg/L air). In addition, repellency of the essential oil was also evaluated. Data showed that the essential oil and all four compounds had repellent activity against *T. castaneum* and *L. serricorne* at high concentration (78.63 nL/cm<sup>2</sup>). But with the decrease of concentration, they showed a different degree of attractant properties.

**ARTICLE HISTORY**

Received 25 March 2018
Accepted 2 August 2018

**KEYWORDS**

*Amomum villosum*; essential oil; stored-product insects; insecticidal toxicity; repellent activity

**CONTACT** Shu-Shan Du dushushan@bnu.edu.cn Beijing Key Laboratory of Traditional Chinese Medicine Protection and Utilization, Beijing Normal University, NO.19 Xinjiekouwai Street, Beijing, 100875, China

© 2018 Zhen-yang Chen, Shan-shan Guo, Ju-qin Cao, Xue Pang, Zhu-feng Geng, Yang Wang, Zhe Zhang and Shu-shan Du. Published with license by Taylor & Francis.

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

**Introduction**

Stored-product insects are serious pests of oilseeds, stored pulses, cereals crops, of many value-added food products and nonfood derivatives of agricultural products.[1,2] These pests are worldwide distributed and cause huge economic losses.[3–7] *Tribolium castaneum* (Herbst) is among the most economically important stored-product pests.[8] It is one of the common pests infesting many indoor food storage facilities.[9] Infestations not only cause economic losses because of the consumption of grains; they also result in elevated temperature and moisture conditions that lead to an accelerated growth of molds, including toxigenic species.[10] *Lasioderma serricorne* is widely distributed in tropical and subtropical regions. The cigarette beetle is a strong flyer and highly mobile, and has been scattered from the food warehouse to other habitats in the field.[11] The females lay eggs masses in the crevice of tobacco bales and its eggs can survive during the cigarette production. Its larvae are quick and feed on tobacco leaves.[12,13] Besides being a primary pest of tobacco, the adults of *L. serricorne* also infests packaged foods and cause problems in food products as dry fruits, crumbs, grains and flours.[11,14]

Chemical control using synthetic insecticides have been well applied because of their rapid action and ease of use.[15] However, the widespread extensive use has many negative consequences (i.e., insecticide resistance, toxicity to mammals and other non-target animals, residue problems, environmental pollution).[11,14] Therefore, it is extremely important to develop a safe, low toxicity to non-target animals and environment friendly natural drug to control pests.
Essential oils have received much attention as pest control agents. They are characterized by low toxicity to human and animals, high volatility and toxicity to insect pests of stored products.\textsuperscript{[16]} Some literatures have shown that essential oil has good control over the red beetle and the tobacco beetle.\textsuperscript{[17,18]} There are also numerous reports on insecticidal activity of the essential oils and other products from \textit{Zingiber} species.\textsuperscript{[19–22]} \textit{Amomum villosum} Lour. belongs to the Zingiberaceae family and is widely distributed in the south of China. The fruit of \textit{A. villosum} can be used for cooking and it also has a variety of medicinal value, for example, \textit{A. villosum} essential oil and its main component bornyl acetate could inhibit intestinal mucositis.\textsuperscript{[23]} And it can improve gastrointestinal function and start the production of digestive juice, as well as analgesic and antidiarrheal effects.\textsuperscript{[24]} However, few studies have investigated bioactivity of the plant extract obtained from \textit{A. villosum} against pests. Therefore, we decided to evaluate the insecticidal toxicity of the essential oil for the first time.

### Materials and methods

#### Plant material and extraction of essential oil

Fruits (1 kg) of \textit{A. villosum} were collected in July 2013 from Yunnan Province, China. The species were identified according to the voucher specimen (BNU-CMH- Dushushan-2013-07-11-011) deposited at the Herbarium of College of Resources Science and Technology, Beijing Normal University. Fruits of \textit{A. villosum} were subjected to hydrodistillation by a modified Clevenger-type apparatus for 6 h. After extraction, the water in the essential oil was removed by anhydrous sodium sulfate. The essential oil was stored in an closed container in 4°C refrigerator.

#### Insects

Cultures of \textit{T. castaneum} and \textit{L. serricorne} were maintained in the laboratory without exposure to any insecticide before use. The two storage insect pests were obtained in incubators about 30°C and 75% r.h in the dark. They were fed on wheat flour mixed with yeast (10:1, w/w) and the moisture content is about 12%. The unsexed insect adults used in the experiments were 1–2 weeks old.

#### GC-FID and GC-MS analysis

GC-MS analysis was performed on a Thermo Finnigan Trace DSQ instrument equipped with a flame ionization detector and an HP-5MS (30 m × 0.25 mm × 0.25 μm) capillary column. The column temperature was programmed at 50°C for 2 min, then increased at 2°C/min to the temperature of 150°C and held for 2 min, and then increased at 10°C/min until the final temperature of 250°C was reached, where it was held for 5 min. The injector temperature was maintained at 250°C and the volume injected was 1 μL of 1% solution (diluted in \textit{n}-hexane). The carrier gas was helium at a flow rate of 1.0 mL/min. Spectra were scanned from 50 to 550 m/z. The retention indices were determined in relation to a homologous series of \textit{n}-alkanes (C\textsubscript{5}–C\textsubscript{36}) under the same operating conditions. GC retention time and their mass spectra that stored in NIST 05 and Wiley 275 libraries or from literature were used for identifying the essential oil compounds.\textsuperscript{[25]} Relative percentages of the individual compounds were obtained by averaging the GC peak area % reports.

#### Contact toxicity

The essential oil and individual components against the two storage insect pests were measured as described by Liu and Ho.\textsuperscript{[9]} The four compounds (L-bornyl acetate, D-camphor, camphene and D-limonene) were obtained from Beijing Inno Chem Science & Technology Co., Ltd., Beijing, China. Range-finding studies were run to determine the appropriate testing concentrations. A series of testing samples (five concentrations) were prepared in \textit{n}-hexane for the essential oil and individual
components. Aliquots of 0.5 µL of the dilutions were applied topically to the dorsal thorax of the insects. Pyrethrins (pyrethrin I and II, 37%) were used as positive controls and n-hexane were used as negative controls. Ten insects were used for each concentration and control, and five parallel experiments were carried out. Both treated and control insects were then transferred to glass vials and preserved in the incubators. Mortality was recorded after 24 h.

**Fumigant toxicity**

The appropriate testing concentrations were determined by range-finding studies. A serial dilution of the essential oil and compounds with five concentrations were prepared in n-hexane. The essential oils and above samples were tested with the method described by Liu and Ho. Ten insects were put into a glass vial (diameter 2.5 cm, height 5.5 cm, volume 25 ml). A filter paper (diameter 2 cm) was placed at the bottom of cap and treated with 10 µL sample solution. The solvent was allowed to evaporate for 20 s before the cap was placed tightly on the glass vial to form a sealed chamber. n-Hexane was used as a control. Five repeated experiments were carried out for all treatments and controls, and they were incubated under the same conditions as rearing. The mortality was measured after 24 h.

**Repellency tests**

The repellent effects of the essential oil and its main compounds against *T. castaneum* and *L. serricorne* were assessed by using assays on Petri dishes. Petri dishes 9 cm in diameter were used to confine insects during the experiment. The essential oil of *A. villosum* and its main compounds were prepared in n-hexane (78.63, 15.73, 3.15, 0.63, and 0.13 nL/cm²). Filter paper 9 cm in diameter was cut in half and 500 µL of each concentration was applied separately to half of the filter paper as uniformly as possible. The other half (control) was treated with 500 µL of absolute n-hexane. 20 insects were released at the center of each filter disk, and a lid was covered on the Petri dish. Five parallel experiments were done, and each experiment was repeated three times. A commercial repellent, DEET (N,N-diethyl-3-methylbenzamide), was brought from the National Center of Pesticide Standards (8 Shenliao West Road, Tiexi District, Shenyang 110021, China) and used as a positive control. Counts of insects presented on each paper were made at 2 and 4 h after exposure. The percent repellency (PR) of the essential oil and individual compounds was then calculated using the formula:

\[
P R(\%) = \left(\frac{N_c - N_t}{N_c + N_t}\right) \times 100
\]

where \(N_c\) is the number of insects present in the negative control half and \(N_t\) is the number of insects present in the treated half. The averages were then assigned to different classes (0 to V) using the following scale (percentage repellency): Class, % repellency: 0, > 0.01 to < 0.1; I, 0.1–20.0; II, 20.1–40.0; III, 40.1–60.0; IV, 60.1–80.0; and V, 80.1–100.

**Data analysis**

The data were corrected for control mortality using Abbott’s formula. The \(LD_{50}\) (Contact toxicity) and \(LC_{50}\) (Fumigant toxicity) values were calculated by using Probit analysis (IBM SPSS V 20.0). In repellency tests, means and standard errors were conducted by Microsoft Excel 2007 for Windows 7.

**Results and discussion**

**Chemical composition of the essential oil**

*A. villosum* essential oil was light blue with a yield of 1.9% (v/w) and density of 1.01 g/mL. The chemical component of the essential oil was summarized in Table 1. A total of 17 components of the
essential oil were identified. The quantity of each constituent was determined by GC-FID. The main constituents of the essential oil were bornyl acetate (51.6%), camphor (19.8%), camphene (8.9%) and limonene (6.2%).

According to the previous paper about the essential oil from different origins of fruits of *A. villosum*, the results showed that their main components were similar but the contents were different. For example, *A. villosum* oil from Guangxi contains more bornyl acetate (69.3%) and camphor (20.9%) than from Guangdong (50.6% and 10.3%) and Vietnam (48.2% and 14.8%).[28] Chemical analysis indicated that bornyl acetate and camphor were the main components of *A. villosum* essential oil. The result was in agreement with ours. But our analysis revealed that there are more limonene (6.2%) than in Guangdong (1.0%), Vietnam (1.2%) and Guangxi (0.3%). In addition, camphene was not detected in the essential oil from other origins. These differences in chemical composition and content among the essential oils could be due to different effects of environmental factors (such as sunlight, water and soil) or may result from different metabolic pathways in the plant. Thus, further studies on plant cultivation and essential oil standardization are necessary.

**Contact toxicity**

The consequence of contact toxicity of *A. villosum* essential oil and its main constituents against the two stored-product insects were shown in **Table 2**. The essential oil of *A. villosum* showed contact toxicity against *T. castaneum* and *L. serricorne* adults with LD$_{50}$ values of 32.4 and 20.4 µg/adult, respectively (**Table 2**). Compared with the positive control pyrethrins, the essential oil demonstrated 125 times less toxicity against the red flour beetle and 102 times less toxicity against the tobacco beetle. In this context, compared with other essential oils mentioned in the literature, the essential oil of *A. villosum* showed stronger contact toxicity against *T. castaneum*, e.g. essential oils of *Ajania fruticulosa* (LD$_{50}$ = 106 µg/adult),[29] *Platycladus orientalis* (LD$_{50}$ = 48.59 µg/adult)[30] and *Acorus calamus* (LD$_{50}$ = 32.55 µg/adult).[31] Moreover, compared with another essential oil from the ginger family in the previous studies, the essential oil of *A. villosum* exhibited stronger contact toxicity than *Zingiber purpureum* (LD$_{50}$ = 39.0 µg/adult).[32] In addition, the toxicity of limonene (LD$_{50}$ = 15.0 µg/adult)[33] and camphene (LD$_{50}$ = 21.6 µg/adult) were stronger than camphor (LD$_{50}$ > 50.0 µg/adult)[34] and bornyl acetate (LD$_{50}$ = 66.0 µg/adult). At the same time, our research showed that *L. serricorne* was more susceptible than *T. castaneum* to the contact toxicity of the essential oil of *A. villosum*. Moreover,
there were many literatures showed that the A. Villosum essential oil exhibited stronger contact toxicity against L. serricorne than other essential oils mentioned in the literature, e.g. essential oils of Artemisia anethoides (LD50 = 24.03 µg/adult), Vitex negundo L. var. cannabifolia (Sieb. et Zucc.) Hand.-Mazz. (LD50 = 25.30 µg/adult), Forsythia suspensa (LD50 = 23.66 µg/adult), Lagerra pterodonta (LD50 = 32.97 µg/adult) and Platycladus orientalis (LD50 = 50.45 µg/adult). In addition, compared with the other essential oils from the ginger family in the previous studies, the essential oil of A. villosum exhibited stronger contact toxicity against L. serricorne, e.g. essential oil of Alpinia kwangsiensis (LD50 = 24.59 µg/adult) and Zingiber zerumbet (L.) Smith (LD50 = 48.3 µg/adult). The four monoterpenoids (bornyl acetate, camphor, camphene and limonene) exhibited fair contact toxicity against T. castaneum and L. serricorne respectively. E.g., limonene showed 50 and 68.5 times less toxicity to T. castaneum and L. serricorne when compared to pyrethrins. Monoterpenoids from plants are considered to have anticholinesterasic properties which cause high levels of mortality of insects when higher concentrations were used. For instance, limonene exhibited contact toxicity with LD50 values of 0.187 mg/adult and 0.283 mg/adult against T. castaneum adults with LC50 values of 28.3 mg/L air (Table 3). Compared with the positive control MeBr (LC50 = 1.8 mg/L air), essential oil was almost 16 times less toxic. In this context, compared with essential oil mentioned in the literature, the essential oil of A. villosum showed stronger fumigant toxicity against T. castaneum than Platycladus orientalis (LC50 = 39.25 mg/L air). And we had done fumigation tests with camphor and limonene under the same conditions. In order to further evaluate the relationship between the essential oil and its main compounds in the toxicity activity, we had direct references to the past data. Analysis of the data showed that the compounds camphor, camphene and limonene had strong contact toxicity against T. castaneum adults (LC50 < 2.3 mg/L air, LC50 = 6.2 and 6.2 mg/L air, respectively). There were many literatures also showed that the three compounds had good fumigant toxicity for other storage pests such as Sitophilus oryzae.

### Fumigant toxicity

The essential oil of A. villosum fruits showed fumigant toxicity against T. castaneum adults with LC50 values of 28.3 mg/L air (Table 3). Compared with the positive control MeBr (LC50 = 1.8 mg/L air), essential oil was almost 16 times less toxic. In this context, compared with essential oil mentioned in the literature, the essential oil of A. villosum showed stronger fumigant toxicity against T. castaneum than Platycladus orientalis (LC50 = 39.25 mg/L air). And we had done fumigation tests with camphor and limonene under the same conditions. In order to further evaluate the relationship between the essential oil and its main compounds in the toxicity activity, we had direct references to the past data. Analysis of the data showed that the compounds camphor, camphene and limonene had strong contact toxicity against T. castaneum adults (LC50 < 2.3 mg/L air, LC50 = 6.2 and 6.2 mg/L air, respectively). There were many literatures also showed that the three compounds had good fumigant toxicity for other storage pests such as Sitophilus oryzae.
Sitophilus zeamais, Rhyzopertha dominica and Cryptolestes pusillus. In addition, the three compounds with significant fumigation effect (camphor, camphene and limonene) all belong to monoterpenoids. We suspected T. castaneum may be very susceptible to the fumigation toxicity of some monoterpenoids. To prove this point, we had consulted many literatures. These results showed that other monoterpenoids, such as 1,8-cineole, menthone, pulegone, l-fenchone and linalool, also had significant fumigation activity to T. castaneum.

So the existence of the three monoterpenoids compounds might be one of the key elements which affected the fumigant toxicity of A. villosum essential oil against T. castaneum. However, in our preliminary experiments, fumigating activity of essential oil on L. serricorne was less effective for 24 h, the differences in mortality between T. castaneum and L. serricorne maybe because the susceptibility of different insects to essential oils constituents can vary depending on endogenous and exogenous factors.

Repellent activity

The repellent activities of the essential oil from A. villosum and its major constituents to T. castaneum adults were tested using the area preference method 2 h and 4 h after treatment (Figure 1). Data showed that at 78.63 nL/cm², the essential oil of A. villosum, camphor and limonene showed strong repellent activity against T. castaneum with the percentage repellency (PR) over 70% after 2 h. Compared with the positive control DEET, camphor and limonene showed the same level (Class V) of repellency after 2 h treatment. Limonene also showed strong repellency at tested concentration of 15.73 nL/cm², 0.63 nL/cm², and 0.13 nL/cm² at 2 h after exposure. However, at the dose of 0.63 nL/cm², camphene showed insect attractant properties (PR = −50%) and at the dose of 0.13 nL/cm², camphor and bornyl acetate showed insect attractant properties (PR = −30% and −84%). Data showed that at 78.63 nL/cm² the essential oil of A. villosum, camphor and camphene showed strong repellent activity against T. castaneum with the PR over 70% after 4 h. And at 15.73 nL/cm² and 0.13 nL/cm², bornyl acetate showed strong attractant properties (PR = −62%).

The repellent activities of the essential oil of A. villosum and isolated constituents to L. serricorne adults were tested using the area preference method 2 h and 4 h after treatment (Figure 2). Data showed that at 78.63 nL/cm³, the essential oil of A. villosum, camphor, bornyl acetate, limonene showed repellent activity against L. serricorne with the PR over 70% after 2h. Compared with the positive control DEET and camphor showed the same level (Class V) of repellency after 2h treatment. And limonene also showed strong repellency at tested concentration of 0.13 nL/cm² at 4 h after exposure. However, at the dose of 0.63 nL/cm², camphor showed insect attractant properties (PR = −6%) and at the dose of 0.13 nL/cm², the essential oil of A. villosum, camphor and bornyl acetate showed insect attractant properties (PR = −26%, PR = −18% and −74%).

Table 3. Fumigant toxicity of Amomum villosum essential oil and its major constituents against Tribolium castaneum adults.

| Samples        | LC₅₀ (mg/L air) | 95% FL (mg/L air) | Slope ± SE | Chi square (χ²) | p-Value |
|----------------|-----------------|-------------------|------------|----------------|---------|
| Essential oil  | 28.3            | 26.8–29.8         | 13.2 ± 1.9 | 5.4            | 0.965   |
| Camphor*       | < 2.3 (mortality 87% ± 5) | – | – | – | – |
| Camphene       | 6.2             | 5.3–7.0           | 3.5 ± 0.5  | 14.0           | 0.730   |
| Limonene**     | 6.2             | 5.4–7.1           | 3.1 ± 0.4  | 13.3           | 0.945   |
| Bornyl acetate | > 126.3         | –                 | –          | –              | –       |
| MeBr***        | 1.8             | –                 | –          | –              | –       |

* data from Guo et al. [34], ** data from Wang et al. [33], *** data from Liu et al. [9]
Consulting the past literature, borneol acetate also showed similar attraction effect to *L. serricorne* \(^{51}\). At almost all tested concentration, the essential oil and the constituents show the weak repellency at 4 h after exposure. And at 3.15 nL/cm\(^2\), camphor and bornyl acetate showed insect attractant properties (PR = −42% and −52%). The results showed that the essential oil had repellent activity against *T. castaneum* and *L. serricorne* at high concentration (78.63 nL/cm\(^2\)). However, with the decreasing of concentration, the repellent effect of the essential oil was also reduced, even attractant properties appeared. On *T. castaneum* larvae, *Tagetes terniflora*, *Cymbopogon citratus* and *Elyonorus muticus* essential oils also showed repellent action at high concentrations while attractive at low concentrations. \(^{52}\) The same substance can behave as repellent or attractant, depending on the conditions used in the bioassay. \(^{53}\) And the attractant effects of isolated constituents maybe had made a negative effect on the essential oil. But change an angle to consider this problem, the strong attraction of borneol acetate at 0.13 nL/cm\(^2\) can provide useful information for developing attractive chemicals for *T. castaneum*.

**Conclusion**

The chemical composition of the essential oil from *A. villosum* fruits was analyzed. And the contact, fumigant and repellent activities of the essential oil against two stored-product insects were reported for the first time. This work investigated the insecticidal bioactivity of the essential oil of *A. villosum* and −46%). Consulting the past literature, borneol acetate also showed similar attraction effect to *L. serricorne*. \(^{51}\) At almost all tested concentration, the essential oil and the constituents show the weak repellency at 4 h after exposure. And at 3.15 nL/cm\(^2\), camphor and bornyl acetate showed insect attractant properties (PR = −42% and −52%). The results showed that the essential oil had repellent activity against *T. castaneum* and *L. serricorne* at high concentration (78.63 nL/cm\(^2\)). However, with the decreasing of concentration, the repellent effect of the essential oil was also reduced, even attractant properties appeared. On *T. castaneum* larvae, *Tagetes terniflora*, *Cymbopogon citratus* and *Elyonorus muticus* essential oils also showed repellent action at high concentrations while attractive at low concentrations. \(^{52}\) The same substance can behave as repellent or attractant, depending on the conditions used in the bioassay. \(^{53}\) And the attractant effects of isolated constituents maybe had made a negative effect on the essential oil. But change an angle to consider this problem, the strong attraction of borneol acetate at 0.13 nL/cm\(^2\) can provide useful information for developing attractive chemicals for *T. castaneum*. 

**Figure 1.** Percentage repellency (PR) of *A. villosum* essential oil and its constituents against *T. castaneum* at 2 h (**a**) and 4 h (**b**) after exposure. Means in the same column followed by the same letters do not differ significantly (P > 0.05) in ANOVA and Tukey’s tests. PR was subjected to an arcsine square-root transformation before ANOVA and Tukey’s tests.
fruits against *T. castaneum* and *L. serricorne*. However, further studies are needed to focus on the safety of the essential oil to humans and to improve the potency and stability of these crop protection products for practical use.

**Acknowledgments**

This project was supported by the National Key Research and Development Program (2016YFC0500805).

**Funding**

This work was supported by the National Key Research and Development Program [2016YFC0500805].

**References**

[1] Phillips, T.W.; Throne, J.E. Biorational Approaches to Managing Stored-Product Insects. Annual Review of Entomology **2010**, *55*, 375–397. DOI: [10.1146/annurev.ento.54.110807.090451](https://doi.org/10.1146/annurev.ento.54.110807.090451).

[2] Wakil, W.; Ashfaq, M.; Ghazanfar, M.U.; Riasat, T. Susceptibility of Stored-Product Insects to Enhanced Diatomaceous Earth. Journal of Stored Products Research **2010**, *46*, 248–249. DOI: [10.1016/j.jspr.2010.05.001](https://doi.org/10.1016/j.jspr.2010.05.001).

[3] Flinn, P.W.; Hagstrom, D.W.; Reed, C.; Phillips, T.W. Insect Population Dynamics in Commercial Grain Elevators. Journal of Stored Products Research **2010**, *46*, 43–47. DOI: [10.1016/j.jspr.2009.09.001](https://doi.org/10.1016/j.jspr.2009.09.001).
[4] Upadhyay, R.K.; Ahmad, S. Management Strategies for Control of Stored Grain Insect Pests in Farmer Stores and Public Ware Houses. World Journal of Agricultural Sciences 2011, 5, 527–549.
[5] Silva, G.N.; Faroni, L.R.A.; Sousa, A.H.; Freitas, R.S. Bioactivity of Jatropha Curcas L. To Insect Pests of Stored Products. Journal of Stored Products Research 2012, 48, 111–113. DOI: 10.1016/j.jspr.2011.10.009.
[6] Shadai, E.; Abd, E.A. Control Strategies of Stored Product Pests. Journal of Entomology 2011, 8, 101–122. DOI: 10.3923/jje.2011.101.122.
[7] Nukenine, E.N.; Stored Product Protection in Africa: Past, Present and Future. 10th International Working Conference on Stored Product Protection 2010, 425, 26–41.
[8] Garcia, M.; Donadel, O.J.; Ardanaz, C.E.; Tonn, C.E.; Sosa, M.E. Toxic and Repellent Effects of Baccharis Salicifolia Essential Oil on Tribolium Castaneum. Pest Management Science 2005, 61, 612–618. DOI: 10.1002/ps.1028.
[9] Liu, Z.-L.; Ho, S.-H. Bioactivity of the Essential Oil Extracted from Evodia Rutaecarpa Hook F. Et Thomas against the Grain Storage Insects, Sitophilus Zeamais Motsch. and Tribolium Castaneum (Herbst). Journal of Stored Products Research 1999, 35, 317–328. DOI: 10.1016/S0022-474X(99)00015-6.
[10] Magan, N.; Hope, R.; Cairns, V.; Aldred, D. Post-harvest fungal ecology and mycotoxin accumulation in stored grain. European Journal of Plant Pathology 2003, 109, 723–730. DOI: 10.1023/A:1026082425177.
[11] Arthur, F.H.; Campbell, J.F.; Toews, M.D. Distribution, Abundance, and Seasonal Patterns of Stored Product Beetles in a Commercial Food Storage Facility. Journal of Stored Products Research 2014, 56, 21–32. DOI: 10.1016/j.jspr.2013.11.003.
[12] Lecato, G.L.; Infestation and Development by the Cigarette Beetle in Spices. Journal of the Georgia Entomological Society 1978, 13, 98–100.
[13] Mahroof, R.M.; Phillips, T.W. Life History Parameters of Lasioderma Serricorne (F.) As Influenced by Food Sources. Journal of Stored Products Research 2008, 44, 219–226. DOI: 10.1016/j.jspr.2007.12.001.
[14] Canevari, G.D.C.; Rezende, F.; Silva, R.B.D.; Faroni, L.R.D.; Zanuncio, J.C.; Papadopoulou, S.; Serrão, J.E. Potential of Tyrophagus Putrescentiae (Schrank) (Astigmata: Acaridae) for the Biological Control of Lasioderma Serricorne (F.). (Coleoptera: Anobiidae). Brazilian Archives of Biology & Technology 2012, 55, 299–303. DOI: 10.1590/S1516-89132012000200017.
[15] Kalu, I.G.; Ofogbue, U.; Eroegbusi, J.; Nwachukwu, C.U.; Ibeh, B. Larvicidal Activities of Ethanol Extract of Allium Sativum (Garlic Bulb) against the Filarial Vector, Culex Quinquefasciatus. Journal of Medicinal Plants Research 2010, 4, 496–498.
[16] Batish, D.R.; Sing, P.H.; Kohli, K.R.; Kaur, S. Eucalyptus Essential Oil as a Natural Pesticide. Forest Ecology and Management 2008, 256, 2166. DOI: 10.1016/j.foreco.2008.08.008.
[17] Eljazi, I.S.; Bachrouch, O.; Salem, N.; Msaada, K.; Aouini, J.; Hammami, M.; Boushih, E.; Abderraba, M.; Limam, F.; Jemaa, J.M.B. Chemical Composition and Insecticidal Activity of Essential Oil from Coriander Fruit against Tribolium Castaneum, Sitophilus Oryzae, and Lasioderma Serricorne. International Journal of Food Properties 2018, 20, 2833–2845. DOI: 10.1080/10942912.2017.1381112.
[18] Salem, N.; Bachrouch, O.; Sriti, J.; Msaada, K.; Khammassi, S.; Hammami, M.; Boushih, E.; Koorani, S.; Abderraba, M.; Marzouk, B.; Limam, F.; Jemaa, J.M.B. Fumigant and Repellent Potentials of Ricinus Communis and Mentha Pulegium Essential Oils against Tribolium Castaneum and Lasioderma Serricorne. International Journal of Food Properties 2018, 20, 2899–2913. DOI: 10.1080/10942912.2017.1382508.
[19] Maedeh, M.; Hamzeh, I.; Hossein, D.; Majid, A.; Reza, R.K. Bioactivity of Essential Oil from Zingiber Officinale (Zingiberaceae) against Three Stored-Product Insect Species. Journal of Essential Oil Bearing Plants 2012, 15, 122–133. DOI: 10.1080/09729700.2012.10644028.
[20] Chaubey, M.K.; Biological Activities of Zingiber Officinale (Zingiberaceae) and Piper Cubeba (Piperaceae) Essential Oils against Pulse Beetle, Callosobruchus Chinensis (Coleoptera: Bruchidae). Pakistan Journal of Biological Sciences 2013, 16, 517–523.
[21] Ukeh, D.A.; Umaotok, S.B.A.; Bowman, A.S.; Mordue, A.J.; Pickett, J.A.; Birkett, M.A. Alligator Pepper, Aframomum Melegueta, and Ginger, Zingiber Officinale, Reduce Stored Maize Infestation by the Maize Weevil, Sitophilus Zeamais in Traditional African Granaries. Crop Protection 2012, 32, 99–103. DOI: 10.1016/j.cropro.2011.10.013.
[22] Ahmad, F.; Iqbal, N.; Zaka, S.M.; Qureshi, M.K.; Saeed, Q.; Khan, K.A.; Ghrahman, H.A.; Ansari, M.J.; Jaleel, W.; Aasim, M.; Awar, M.B. Comparative Insecticidal Activity of Different Plant Materials from Six Common Plant Species against Tribolium Castaneum (Herbst) (Coleoptera: Tenebrionidae). Saudi Journal of Biological Sciences 2018, DOI: 10.1016/j.jsbs.2018.02.018.
[23] Zhang, T.; Yu, J.; Gu, W. The Prevention Mechanism of Volatile Oil of Amomi Fructus on Drug-Induced Intestinal Mucositis. Yunnan University of TCM Press: Yunnan, China, 2017.
[24] Lu, S.-H.; Zhao, R.-H.; Yao, C.; Chen, X.-S.; Han, M.-N.; Yu, J. Progress in Chemical and Pharmacological Research of Fructus Amomi. Pharmacology and Clinics of Chinese Materia Medica 2016, 32, 227–230.
[25] Adams, R.P.; Identification of Essential Oil Components by Gas Chromatography/Quadrupole Mass Spectroscopy. American Society for Mass Spectrometry 2005, 16, 1902–1903.
[46] Suthisut, D.; Fields, P.G.; Chandrapatya, A. Fumigant Toxicity of Essential Oils from Three Thai Plants (Zingiberaceae) and Their Major Compounds against Sitophilus Zeamais, Tribolium Castaneum and Two Parasitoids. Journal of Stored Products Research 2011, 47, 222–230. DOI: 10.1016/j.jspr.2011.03.002.

[47] Yildirim, E.; Emsen, B.; Kordali, S. Insecticidal Effects of Monoterpenes on Sitophilus Zeamais Motschulsky (Coleoptera: Curculionidae). Journal of Applied Botany and Food Quality 2013, 86, 198–204.

[48] Maria, D.; Lopez, M.J.; Jordan, M.J.; Pascual, V. Toxic Compounds in Essential Oils of Coriander, Caraway and Basil Active against Stored Rice Pests. Journal of Stored Products Research 2008, 44, 273–278. DOI: 10.1016/j.jspr.2008.02.005.

[49] Partes, H.T.; Santos, J.P.; Waquil, J.M.; Fabris, J.D.; Oliveira, A.B.; Foster, J.E. Insecticidal Activity of Monoterpenes against Rhyzopertha Dominica (F.) and Tribolium Castaneum (Herbst). Journal of Stored Products Research 1998, 34, 243–249. DOI: 10.1016/S0022-474X(98)00005-8.

[50] Lee, S.; Peterson, C.J.; Coats, J.R. Fumigation Toxicity of Monoterpenoids to Several Stored Product Insects. Journal of Stored Products Research 2003, 39, 77–85. DOI: 10.1016/S0022-474X(02)00020-6.

[51] Wei, X.-M.; Guo, -S.-S.; Yan, H.; Cheng, X.-L.; Wei, F.; Du, -S.-S. Contact Toxicity and Repellency of the Essential Oil from Bupleurum Bicaule Helm against Two Stored Product Insects. Journal of Chemistry 2018, 3, 1–8.

[52] Stefanazzi, N.; Stadler, T.; Ferrero, A. Composition and Toxic, Repellent and Feeding Deterrent Activity of Essential Oils against the Stored-Grain Pests Tribolium Castaneum (Coleoptera: Tenebrionidae) and Sitophilus Oryzae (Coleoptera: Curculionidae). Pest Management Science 2011, 67, 639–646. DOI: 10.1002/ps.2102.

[53] Hasyim, A.; Muryati,; Istianto, M.; Kogel, W.J. Male Fruit Fly, Bactrocera Tau (Diptera; Tephritidae) Attractants from Elsholtzia Pubescens Bth. A. Asian Journal of Plant Sciences 2007, 6, 181–183. DOI: 10.3923/ajps.2007.181.183.