Bioactivities of patchoulol and phloroacetophenone from Pogostemon cablin essential oil against three insects

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\textbf{ABSTRACT}

The essential oil was obtained from the aerial parts of \textit{Pogostemon cablin} by hydrodistillation. The chemical compounds of \textit{P. cablin} essential oil were analyzed by gas chromatography-flame ionization detection and gas chromatography-mass spectrometry. Eight compounds were totally identified and accounted for 92.4\% of the oil. Patchoulol was the major component (51.1\%), followed by phloroacetophenone (23.5\%) and \textit{β}-patchoulene (7.3\%). The essential oil and its two major compounds patchoulol and phloroacetophenone were evaluated for their contact and repellent activities against \textit{Tribolium castaneum}, \textit{Lasioderma serricorne}, and \textit{Liposcelis bostrychophila}. Results of bioassays indicated that the essential oil and patchoulol had great contact toxicity against three species of insects. Meanwhile, the essential oil and patchoulol showed great repellent activities against \textit{T. castaneum} and \textit{L. bostrychophila} but were mildly repellent to \textit{L. serricorne}. Phloroacetophenone exhibited neither contact nor repellent activity against any of these target insects. This work emphasized the promising potential of \textit{P. cablin} to control insect pests during storage.

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\textbf{Introduction}

The booklice \textit{Liposcelis bostrychophila} Badonnel (Psocoptera: Liposcelididae), the red flour beetles \textit{Tribolium castaneum} Herbst (Coleoptera: Tenebrionidae), and the cigarette beetles \textit{Lasioderma serricorne} Fabricius (Coleoptera: Anobiidae) are three important insect pest species commonly occurring in stored products.\textsuperscript{[1]} As secondary pests, these three species of insects are unable to attack the whole healthy normal grains but do damage those already infected or processed into products such as flour.\textsuperscript{[1–3]} Under the warm and humid storage conditions, these three insect species could rapidly reproduce and cause serious postharvest losses.

Efforts have been taken to control storage pests along with the development of agriculture. Actually, botanical insecticides have been used for centuries such as nicotine and azadirachtin.\textsuperscript{[4]} But they are overtaken by the discovery of dichloro-diphenyl-tricloroethane (DDT), which is the first synthetic insecticide in the world.\textsuperscript{[5]} Though some synthetic insecticides have been abandoned now, the others are still in practical use widely, including triflumizopyrim, dicloromezotiaz and flupyradifurone.\textsuperscript{[6]} With the extensive use of synthetic insecticides, however, problems ensued: ecosystem disruption,\textsuperscript{[7]} water contamination, biodiversity decrease,\textsuperscript{[8]} and insect resistance.\textsuperscript{[9,10]} Along with consumers’ growing demands for synthetic chemical-free products and severely restrictive government regulatory on synthetic insecticides,\textsuperscript{[11]} researchers turn back to botanical methods for pests management. These methods include sealing,\textsuperscript{[12]} controlled atmospheres storage by purging nitrogen,\textsuperscript{[13]} temperature management,\textsuperscript{[3]} and biopesticide.\textsuperscript{[14]}
Among these rising insects-controlling agents, biopesticide has been considered as a promising alternative to synthetic pesticides\textsuperscript{[11,15]} for its generally more-selective and less-polluting properties. Plants have evolved a capacity to produce secondary metabolites to protect themselves from natural enemies.\textsuperscript{[16]} These metabolic substances could be classified as nitrogen-containing compounds (such as alkaloids), phenolics (flavonoid), polyacetates, and terpenoids (monoterpenoids and sesquiterpenoids).\textsuperscript{[4]} Widely distributed in the plant kingdom, terpenoids can be easily extracted by hydrodistillation, usually known as essential oils.\textsuperscript{[17]}

Generally, essential oils are combined with several dozen active substances at different concentrations, and exhibit multiple bioactivities against insect pests, including insecticidal, ovicidal, antifeedant and repellent effects.\textsuperscript{[4]} Essential oils are a complex natural mixture, and the underlying mechanisms of each compound in them are different from each other.\textsuperscript{[16]} Consequently, this characteristic provides essential oils with efficiency to prevent developing insect resistance.\textsuperscript{[16]} And it makes essential oils more promising alternative to synthetic insecticides.

Currently, Apiaceae, Myrtaceae, Lauraceae, Asteraceae, and Lamiaceae families have been well investigated, for their aromatic properties.\textsuperscript{[16]} Among them, Lamiaceae is widely known and exploited for its aromatic oils. Belonging to Lamiaceae family, *Pogostemon cablin* (Blanco) Benth, is a brushy herb native to tropical Asia. It has been commonly used as Herba Pogostemonis with the effects of resolving dampness in Chinese traditional medicine.\textsuperscript{[18]} Smelling a unique woody odor, the essential oil of *P. cablin*, usually known as patchouli oil, is of great industrial importance\textsuperscript{[19]} and has been reported showing bioactivities against insect pests. There are some reports recording the insecticidal activities of *P. cablin* against mosquito vectors,\textsuperscript{[20]} cockroach,\textsuperscript{[21]} termites,\textsuperscript{[22,23]} armyworm,\textsuperscript{[24]} and ants,\textsuperscript{[25,26]} as well as repellent effects on termites,\textsuperscript{[22,23]} sweetpotato whitefly,\textsuperscript{[27]} urban ants\textsuperscript{[25]} and the cockroach.\textsuperscript{[21]} And a recent paper\textsuperscript{[26]} reported that *P. cablin* essential oil showed behavioral impairment on leaf-cutting ants.

In the present work, the chemical compositions of the essential oil extracted from the aerial part of *P. cablin* were analyzed by gas chromatography with flame ionization detector (GC-FID) and gas chromatography-mass spectrometry (GC-MS). Then, the contact and repellent effects of *P. cablin* essential oil and its two major compounds were evaluated on three storage insect pests, to provide some information for further development of *P. cablin* as bioinsecticide and green repellent for controlling storage insects.

**Materials and methods**

**Insects**

The booklice and the cigarette beetles were introduced from China Agriculture University; and the red flour beetles were from He'nan University of Technology. All of three insect species were identified by Dr. ZL Liu (College of Plant Protection, China Agriculture University, Beijing, China). Booklice were reared on a mixture of milk powder, yeast and flour (1:1:10, w/w/w), cigarette beetles and red flour beetles were cultured on wheat flour blended with yeast (10:1, w/w). Three species of insects were maintained in dark incubator at 30 ± 1 °C and 70–80% relative humidity.

**Plant material**

The dried aerial parts of *P. cablin* were purchased from Anguo Chinese medicine market. The voucher specimens (BNU-CMH-Dushushan-2016-06-01-001) were deposited in the Herbarium (BNU) of the College of Resources Science and Technology, Faculty of Geographical Science, Beijing Normal University.
**Essential oils**

The dried aerial parts of *P. cablin* (143 g) were crushed into powder and performed on hydro-distillation for 6 h. The distilled oil was dehydrated by anhydrous sodium sulfate. The final volume of the essential oil was measured for yield calculating. The prepared essential oil was stored in a hermetic glass bottle in a refrigerator at 4°C for further bioassays.

**Chemicals**

Patchoulol (97%) and phloroacetophenone (98%) were purchased from Ark Pharm, Inc. (Illinois, USA). *n*-Hexane and acetone were purchased from Beijing Chemical Works (Beijing, China). Fluon was purchased from Beijing Sino-Rich Material Science (Beijing, China).

**GC-MS and GC-FID analysis**

Gas chromatography-flame ionization detection (GC-FID) and gas chromatography-mass spectrometry (GC-MS) were performed on an Agilent 6890N gas chromatograph coupled to an Agilent 5973N mass selective detector (70 eV). An HP-5MS (30 m × 0.25 mm × 0.25 μm) capillary column was used. Helium was served as the carrier gas with a flow rate of 1000 μL/min. The column temperature program was set as follows: 50°C for 2 min, then increased to 150°C at 2°C/min and held for 2 min, finally increased to 250°C at 10°C/min and held for 5 min. The injected sample was 1 μL (1% solution). The scan range was set from 50 to 550 m/z. A homologous series of *n*-alkanes (*C* *n*−*C* *40*) was served for retention index (RI) calculations. The components of our sample were identified by comparing their mass spectra and calculating RIs with those recorded in NIST 05 (Standard Reference Data, Gaithersburg, MD, USA) and Wiley 275 libraries (Wiley, New York, NY, USA), and pure standards. Relative percentages of each component were determined according to the GC-FID peak area%.

**Contact toxicity**

Pre-experiments (three concentrations set at 50%, 10%, and 2%) were performed to find appropriate concentration ranges in the following formal experiments. Totally, 5–7 concentrations of the samples preparing in *n*-hexane (the essential oils and patchoulol) or acetone (phloroacetophenone) were used to determine LD<sub>50</sub> values. Generally, the solvents were served as negative controls.

Regarding red flour beetles and cigarette beetles, the contact toxicities of the essential oils and its two major compounds were evaluated by the method described by Liu and Ho.<sup>28</sup> 0.5 μL of dilutions or solvents were applied topically to the dorsal thorax of insects. After the treatment, 10 insects were introduced into a glass bottle and kept under the same condition as that of insects rearing.

As for booklice, the bioassay was adapted from Zhao et al.<sup>29</sup> Filter paper (diameter 5.5 cm) was used to load dilutions. Filter paper was treated with 300 μL of dilutions or solvents, and solvents were allowed to evaporate completely. After that, the filter paper was stuck to the bottom of a fluon-treated Petri dish (diameter 5.5 cm). Ten booklice were released in the center of Petri dish and a cover with two holes was applied to prevent booklice from escaping. After treatment, the Petri dish containing 10 booklice was kept under the same condition as that of insects rearing.

Each of the concentrations and negative controls was repeated five times. Pyrethrins was served as the positive control, and its LD<sub>50</sub> values to three insect species were quoted from previous papers. Mortalities were observed after 24 h to calculate the LD<sub>50</sub> values.

**Repellent activity**

The repellent activities against red flour beetles and cigarette beetles were adapted from Liu and Ho.<sup>28</sup> Four concentrations (15.83, 3.15, 0.63, and 0.13 nL/cm<sup>2</sup>) of the samples were prepared in
-hexane (the essential oil and patchoulol) or acetone (phloroacetophenone). Half of the filter paper (diameter 9 cm) was treated with 500 μL dilutions and the other half with 500 μL solvents as the negative control. After evaporation, these two halves of filter paper were stuck lengthwise in the bottom of a Petri dish. Twenty testing insects were released in the middle of the dish. The insects that settled in the control half were countered after 2 and 4 h.

As for booklice, the filter paper diameter was 5.5 cm and so is the Petri dish. Four concentrations were 12.63, 2.53, 0.51, and 0.10 nL/cm$^2$, and the dilution or the solvent volume was 150 μL per half. Identically, two halves of filter paper were stuck lengthwise at the bottom of a dish, 20 booklice was released in the center of the dish. The insects settling in the control half were countered after 2 and 4 h.

The bioassays mentioned above were repeated five times for each concentration and kept under the same condition as the insects rearing after treatments. Diethytoluamide (DEET) was served as the positive control.

**Statistical analysis**

In contact bioassays, the Probit analysis was adopted for LD$_{50}$ value's calculations.$^{[30]}$ Ninety-five percent Confidence intervals, related parameters, and chi-square values were estimated as well. In repellent bioassays, the percent repellency (PR) was determined using the equation as follows:

$$\text{PR} \% = \frac{(N_c - N_t)/(N_c + N_t)}{N_c} \times 100$$

where the $N_c$ is the number of insects on the control half, and the $N_t$ is that on the treated half. Analysis of variance (ANOVA) and Tukey’s HSD test were performed with the repellency values, which transformed into arcsine values, respectively. Differences between means were considered significant when $p < .05$.

**Results and discussions**

**Chemical composition of the essential oil**

The yield of *P. cablin* essential oil was 2.1% (v/w). A previous review has summarized that the yield of *P. cablin* ranged from 0.54% to 5.2%, and averaged 2.6%. Also, this review stated some factors that could influence the essential oil yield, which included growth, drying, and storage conditions, as well as distillation methods.$^{[19]}$ The essential oil of our sample was dark orange and has a woody smell. The basic compounds responsible for its smell are still in discussion,$^{[39]}$ but some researchers believe that patchoulol, patchoulen, guaiene, and seychellene characterize the aroma odor of *P. cablin* essential oil.$^{[31]}$

The chemical profile of *P. cablin* essential oil is shown in Table 1. Totally, eight components were identified and accounted for 92.4%, of which sesquiterpenoids (67.5%) constituted more than a half. Such a character was in accordance with that of the previous paper.$^{[31]}$ There are some researchers investigated the underlying reasons at genetic aspect. He et al.$^{[32]}$ surveyed the genome of *P. cablin*. Their analysis showed that *P. cablin* contains key genes involved in more sesquiterpenoid types and has more copies of genes for each sesquiterpenoid types than several other related plant species. Among the eight identified compounds, patchoulol was found to be the most abundant component (51.1%), followed by phloroacetophenone (23.5%) and β-patchoulen (7.3%). Moreover, γ-patchoulen (3.2%), 2,3,3-trimethyl-2-(3-methyl-buta-1,3-dienyl)-cyclohexanone (3.0%), epiglobulol (2.7%), γ-Gurjunene (1.5%), and anethol (1.4%) were detected in relative small quantities. Other components were detected in trace amount (<1%). Similar compounds have been detected in previous papers of various relative content.$^{[31,33,34]}$ But pogostone and pogostol were not detected in our sample. As secondary metabolites, chemical compounds and its content of a plant would vary with environment. There are some published papers recording the factors which could influence the chemical constituents and contents, including harvest time,$^{[35]}$ storage times,$^{[36]}$ habitats and
parts, ever mulching and fertilizer method. Variations would bring some challenges to industrial production of the essential oil and their insecticidal usage. Therefore, understanding the constituents that were responsible for the insecticidal activity of \( P. \) cablin essential oil could shed a light on its practical application.

**Contact toxicity**

The contact toxicity of \( P. \) cablin essential oil and its two major compounds are shown in Table 2. The essential oil and patchoulol exhibited contact toxicity against three stored-product insects, but phloroacetophenone exhibited no contact toxicity at the highest concentration (50% for red flour beetles and cigarette beetles, 5% for booklice) used. It is noteworthy that the essential oil exhibited an outstanding contact toxicity against red flour beetles (LD\(_{50}\) = 0.20 \( \mu \)g/adult). Based on the LD\(_{50}\) value, the contact toxicity of \( P. \) cablin was comparable to that of the positive control pyrethrins (LD\(_{50}\) = 0.26 \( \mu \)g/adult). Besides, the essential oil showed strong contact toxicity against cigarette beetles and booklice (LD\(_{50}\) = 2.48 \( \mu \)g/adult and 37.88 \( \mu \)g/cm\(^2\), respectively). Comparing with previous reports, \( P. \) cablin was more toxic than some already investigated plants. For instance, the LD\(_{50}\) value of Mentha haplocalyx Briq. against cigarette beetles was 16.5 \( \mu \)g/adult. It is nearly 7 times larger than that of \( P. \) cablin. Besides, the LD\(_{50}\) values of Clinopodium chinense (Benth.) Kuntze and Teucrium quadrifarium Buch.-Ham. against booklice were 215.25 \( \mu \)g/cm\(^2\) and 95.1 \( \mu \)g/cm\(^2\), respectively. They are nearly 6 and 3 times larger than that of \( P. \) cablin. Above-mentioned three species of plants (\( M. \) haplocalyx, \( C. \) chinense, and \( T. \) quadrifarium) were nearly 6 and 3 times larger than that of \( P. \) cablin. Above-mentioned three species of plants (\( M. \) haplocalyx, \( C. \) chinense, and \( T. \) quadrifarium) were nearly 6 and 3 times larger than that of \( P. \) cablin.

### Table 1. Chemical components identified in the essential oil extracted from aerial parts of \( P. \) cablin.

| No. | RI a | RI b | Compounds           | Molecular Formula | Relative Content(%) | Identified method |
|-----|------|------|---------------------|-------------------|---------------------|------------------|
| 1   | -    | -    | Phloroacetophenone  | \( C_8H_4O_4 \)   | 23.5                | MS; Co           |
| 2   | 1285 | 1283 | Anethol             | \( C_{10}H_{12}O \) | 1.4                 | MS; RI           |
| 3   | 1389 | 1388 | \( \beta \)-Patchoulen | \( C_{15}H_{24} \) | 7.3                 | MS; RI           |
| 4   | 1439 | 1441 | \( \gamma \)-Patchoulen | \( C_{15}H_{24} \) | 3.2                 | MS; RI           |
| 5   | 1472 | 1471 | \( \gamma \)-Gurjunene | \( C_{15}H_{24} \) | 1.5                 | MS; RI           |
| 6   | 1497 | 1503 | \( \delta \)-Gurjunene | \( C_{15}H_{24} \) | 0.8                 | MS; RI           |
| 7   | 1563 | 1564 | Epiglobulol         | \( C_{15}H_{26}O \) | 2.7                 | MS; RI           |
| 8   | 1657 | 1657 | Patchoulol          | \( C_{15}H_{26}O \) | 51.1                | MS; RI; Co       |

\( a \)RI cal.: retention index relative to \( n \)-alkanes (\( C_8 \)–\( C_{40} \)) on HP-5MS column; \( b \)RI lit.: retention index taken from the NIST 05 library; \( c \)MS: based on comparison of mass spectra with those listed in the NIST 05 and Wiley 275 libraries or with those reported in the literatures, Co: co-injection with standard compound.

### Table 2. Contact toxicity of \( P. \) cablin essential oil and its two major compounds against \( T. \) castaneum, \( L. \) serricorne, and \( L. \) bostrychophila.

| Insects | Samples | LD\(_{50}\) (\( \mu \)g/adult; \( \mu \)g/cm\(^2\)) | 95% Confidence Intervals | Slope ± SE c | \( \chi^2 \) | \( P \)-value |
|---------|---------|----------------------------------------------|--------------------------|-------------|------|--------|
| TC      | \( P. \) cablin | 0.20                                        | 0.11–0.30               | 1.55 ± 0.26 | 7.32 | 0.695 |
|         | Patchoulol      | 96.60                                       | 71.19–135.94            | 1.97 ± 0.40 | 10.61| 0.388 |
|         | Phloroacetophenone | -                                           | -                        | -           | -    | -      |
|         | Pyrethrins\(^a\) | 0.26                                        | 0.22–0.30               | 3.34 ± 0.32 | 13.11| 0.950 |
| LS      | \( P. \) cablin | 2.48                                        | 2.13–2.95               | 4.90 ± 0.83 | 5.45 | 0.859 |
|         | Patchoulol      | 13.08                                       | 10.76–16.02             | 2.48 ± 0.36 | 3.45 | 1.000 |
|         | Phloroacetophenone | -                                           | -                        | -           | -    | -      |
|         | Pyrethrins\(^b\) | 0.24                                        | 0.16–0.35               | 1.31 ± 0.20 | 17.36| 0.791 |
| LB      | \( P. \) cablin | 37.88                                       | 35.75–40.24             | 17.49 ± 2.32 | 4.32 | 0.987 |
|         | Patchoulol      | 30.72                                       | 27.94–33.76             | 8.17 ± 1.26 | 5.31 | 0.870 |
|         | Phloroacetophenone | -                                           | -                        | -           | -    | -      |
|         | Pyrethrins\(^b\) | 18.72                                       | 17.60–19.92             | 2.98 ± 0.40 | 10.56| 0.987 |

\(^a\)Data from You et al.\(^{39}\)  \(^b\)data from Yang et al.\(^{40}\)  \(^c\)SE: Standard error.
belong to the same family as our sample does, but their LD_{50} values are larger than that of \textit{P. cablin}. It indicates that \textit{P. cablin} is more toxic than \textit{M. haplocalyx}, \textit{C. chinense}, and \textit{T. quadrifarium}. Moreover, it highlights the potential of \textit{P. cablin} to be a promising alternative to synthetic insecticides.

The bioassays showed that the major compound patchoulol was contact toxic to these three species of insect pests. The contact toxicity of patchoulol against booklice has been reported by Liu et al.\cite{44} And previous researches have confirmed the contact toxicity of patchoulol against \textit{Blattella germanica} and \textit{Coptotermes formosanus} Shiraki.\cite{23} The second rich compound phloroacetophenone, however, was not toxic to any of three insects, as no mortalities were observed at the highest concentration of 50\% for red flour beetles and cigarette beetles, and of 5\% for booklice. Besides, there are some papers\cite{21,45,46} reporting the insecticidal activity of pogostone, one of \textit{P. cablin} essential oil’s constituents. Thus, we can only draw a conclusion that patchoulol is partly responsible for the insecticidal activity of \textit{P. cablin}.

Regarding red flour beetles and cigarette beetles, the essential oil significantly showed stronger toxicity than patchoulol. In contrary, booklice were more sensitive to patchoulol than the essential oil. \textit{C. formosanus}\cite{23} showed the same trend as booklice did. Such a difference of insecticidal activity against various insect species is common.\cite{47} Chen et al.\cite{48} found that the essential oil of \textit{Amomum volosum} Lour. showed fungitoxic toxicity to red flour beetles but was inactive to cigarette beetles. Eljazi et al.\cite{49} also found that coriander essential oil performed better against cigarette beetles than red flour beetles or rice weevils \textit{Sitophilus oryzae}. It could result from the different susceptibilities of various insect species.\cite{2} Bioassays data indicated that \textit{P. cablin} essential oil was much more suitable to control red flour beetles than cigarette beetles.

**Repellent activity**

The repellent effects of \textit{P. cablin} essential oil and its two major constituents are presented in Table 3. Repellent effects of the essential oil and patchoulol showed a dose-dependent tendency. And at the highest concentrations (15.83 and 15.63 nL/cm\textsuperscript{2}, respectively), these two samples exhibited strong repellent effects on red flour beetles and booklice after 2 and 4 h exposure. These results indicated a promising prospect for \textit{P. cablin} to control red flour beetles and booklice. However, the essential oil and patchoulol exhibited moderate repellent effects on cigarette beetles at 15.83 nL/cm\textsuperscript{2} and transferred into attractive effects at 3.15, 0.63, and 0.13 nL/cm\textsuperscript{2}.

Similar to the contact toxicity, the second rich compound phloroacetophenone showed no repellent effects on any of three insects species at all testing concentrations. The repellency of phloroacetophenone was random and the corresponding standard error was large. With high relative content (23.5\%), phloroacetophenone showed no contact or repellent effects on these three storage insects. It makes us wonder, what are the benefits for \textit{P. cablin} from producing phloroacetophenone? As secondary metabolites, they do not directly take part in plants’ growth, development, and reproduction. With developing investigation on the interaction between plants and herbivore (including insects and mammals), researchers proposed that secondary metabolites could function as the defense against herbivore.\cite{50} Based on the current bioassay results, phloroacetophenone would not play the insecticidal role against storage insect pests or at least against above-mentioned three species of insect pests. Without further data, however, we cannot conclude that phloroacetophenone has no bioactivity at all. Moreover, these papers demonstrated that phloroacetophenone showed antioxidant,\cite{51} hypolipidemic\cite{52} and anti-obesity\cite{53} effects. Maybe it would exhibit other bioactivities that require further investigation.

Another assumption is that phloroacetophenone could act as a synergistic compound. Pavela\cite{54} has found that some substances (such as borneol and camphor) might exhibit no or only low acute toxicity but would provide a high synergistic potential. Regarding the contact and repellent toxicities, there is a great possibility that phloroacetophenone synergizes with patchoulol. Thus, it needs further research to confirm whether there is a synergistic effect between patchoulol and phloroacetophenone in \textit{P. cablin}.
Table 3. Repellency of *P. cablin* essential oil and its two major compounds against *T. castaneum*, *L. senicorne*, and *L. bostrychophila*.

| Treatment          | 2 h (% ± SE)          | 4 h (% ± SE)          |
|--------------------|-----------------------|-----------------------|
|                    | 2 h (% ± SE)          | 4 h (% ± SE)          |
|                    | 2 h (% ± SE)          | 4 h (% ± SE)          |
| TC                 | 15.83 ± 3.15 ± 0.63 ± 0.13 | 15.83 ± 3.15 ± 0.63 ± 0.13 |
| *P. cablin*        | 76 ± 5b ± 10 ± 6b ± 18 ± 6ab | 68 ± 7ab ± 68 ± 4b ± 4 ± 2b |
| Patchouliol        | 90 ± 3b ± 18 ± 6a ± 36 ± 4a ± 54 ± 7a | 80 ± 6b ± 32 ± 10a ± 44 ± 5a ± 52 ± 6a |
| Phloroacetophenone | −8 ± 11a ± 18 ± 30a ± 24 ± 17ab ± 52 ± 27a | 28 ± 21a ± 48 ± 11b ± 44 ± 16a ± 30 ± 15ab |
| DEET               | 98 ± 3b ± 78 ± 14a ± 66 ± 10c ± 8 ± 5b | 82 ± 8b ± 68 ± 5b ± 54 ± 8c ± 22 ± 8c |
| LS                 | 15.83 ± 3.15 ± 0.63 ± 0.13 | 15.83 ± 3.15 ± 0.63 ± 0.13 |
| *P. cablin*        | 56 ± 2b ± 0 ± 3ab ± 0 ± 4bc ± 8 ± 4a | 30 ± 8bc ± −2 ± 6a ± 2 ± 9b ± −20 ± 6a |
| Patchouliol        | 30 ± 4b ± −32 ± 4a ± −26 ± 5ab ± −2 ± 8a | −12 ± 8ab ± −26 ± 7a ± −16 ± 5ab ± −24 ± 7a |
| Phloroacetophenone | −34 ± 19a ± −6 ± 18ab ± −48 ± 14a ± −4 ± 27a | −40 ± 23a ± −28 ± 17a ± −32 ± 11a ± 0 ± 36ab |
| DEET               | 76 ± 14b ± 28 ± 7b ± 20 ± 14c ± 16 ± 7a | 78 ± 9c ± 58 ± 15b ± 56 ± 14c ± 46 ± 7b |
| LB                 | 12.63 ± 2.53 ± 0.51 ± 0.10 | 12.63 ± 2.53 ± 0.51 ± 0.10 |
| *P. cablin*        | 76 ± 8b ± 40 ± 8ab ± 10 ± 7b ± −10 ± 8a | 90 ± 3b ± 52 ± 7b ± 62 ± 5b ± −10 ± 4a |
| Patchouliol        | 76 ± 7b ± 28 ± 11ab ± −28 ± 10a ± −2 ± 10a | 78 ± 4b ± 0 ± 9a ± −20 ± 6a ± −4 ± 9ab |
| Phloroacetophenone | −10 ± 19a ± 20 ± 21a ± −8 ± 11ab ± 2 ± 11a | 10 ± 14a ± −42 ± 17a ± 26 ± 13b ± −14 ± 14a |
| DEET               | 82 ± 5b ± 86 ± 8c ± 70 ± 12c ± 56 ± 3b | 84 ± 3b ± 82 ± 8b ± 54 ± 17b ± 28 ± 14b |

*Concentration (nL/cm2); †The values are expressed as the means ± error of five independent experiments; means followed by the same lower-case are not significantly different according to Tukey's HSD test.*
**Conclusion**

The yield of *P. cablin* essential oil was 2.1% (v/w). Here, eight compounds were identified, and the major component was patchoulol (51.1%), followed by phloroacetophenone (23.5%) and β-patchoulene (7.3%). Sesquiterpenoids accounted for 67.5% of the essential oil. In this work, the contact and repellent activities of *P. cablin* essential oil and its two major compounds were evaluated against three storage insects. The essential oil and patchoulol exhibited strong contact toxicity to three species of insects. At 15.83 and 15.63 nL/cm$^2$, respectively, the essential oil and patchoulol exhibited a great repellent effect on red flour beetles and booklice and turned to attractant at lower concentrations. However, phloroacetophenone showed neither contact nor repellent effects on any of three testing insects species. Current works outlined the promising potential of *P. cablin* to control storage insects, but the underlying mechanisms still require further research as well as the synergistic interactions between patchoulol and phloroacetophenone.

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**Disclosure statement**

The authors declare no conflict of interest.

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