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Evaluation of insecticidal activity of *Nardostachys jatamansi* essential oil against some grain storage insects

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Abstract
Water-distilled essential oil from *Nardostachys jatamansi* (Caprifoliaceae) roots was analyzed by gas chromatography-mass spectrometry (GC-MS). Twenty-nine compounds, accounting for 98.1% of the total oil, were identified. The main components of the essential oil of *N. jatamansi* were calerene (25.9%), patchouol (10.6%), α-gurjunene (7.5%), aristolone (7.1%) and β-maaliene (6.5%) followed by spathulenol (4.3%). The essential oil had higher sesquiternoids content (85.4%) than monoterpenoids (8.5%). It exhibited contact toxicity with LC_{50} value of 277.05 μg/cm^2 and fumigant toxicity with LC_{50} value of 0.74 mg/l against *Liposcelis bostrychophila*. The oil exhibited contact toxicity against *Sitophilus zeamais* and *Tribolium castaneum* adults with LC_{50} values of 70.83 and 45.38 μg/adult, respectively. This oil possessed fumigant toxicity against *S. zeamais* and *T. castaneum* adults with LC_{50} values of 82.13 and 53.29 mg/l. The results indicate that the essential oil of *N. jatamansi* has potential for development into natural insecticides or fumigants for control of insects in stored grains.

Keywords: *Nardostachys jatamansi*; *Liposcelis bostrychophila*; *Sitophilus zeamais*; *Tribolium castaneum*; Fumigant; Contact Toxicity

1. Introduction
Maize weevils (*Sitophilus zeamais* Motsch.) and red flour beetles (*Tribolium castaneum* Herbst) are two of the major pests of stored grains and grain products in the tropics and subtropics [1]. Infestation not only causes significant loss due to the consumption of grains; It also results in elevated temperature and moisture conditions that lead to an accelerated growth of molds, including toxigenic species [2]. Booklice (*Liposcelis bostrychophila* Badonnel) were regarded as secondary pests, often overlooked due to their small size and the existence of other more damaging post-harvest primary pests e.g. *S. zeamais*, rice weevils (*S. oryzae*) and lesser grain borer (*Rhyzopertha dominica*) in cereal grains [3, 4]. However, new evidence indicates that psocids are perhaps the most important emerging pests in stored grains and related commodities due to their small size, and resistance to chemicals [4, 5]. Currently, control of these insects relies heavily on the use of synthetic insecticides and fumigants, which has led to problems such as environmental disturbances, increasing costs of application, pest resurgence, pest resistance and lethal effects on non-target organisms in addition to direct toxicity to users [6-8]. Thus, there is an urgent need to develop safer, environmentally friendlier and efficient alternative with potential to replace synthetic insecticides and fumigants. Evaluation of local plants especially medicinal plants (cultivated, low toxicity to human and well-studied chemical composition) as sources of protectants is very desirable to help farmers use locally available and environmental friendly products to limit post-harvest losses of their produce [9]. Many plant essential oils and their constituent compounds have been evaluated for repellency and insecticidal activity against stored products insects and some of them are quite promising in the development of natural repellents/insecticides [10-19].
Nardostachys jatamansi (D. Don) DC. (syn. *N. chinensis* Batalin, Family: Caprifoliaceae) is a perennial herb that grows in West and Northwest China (Gansu, Qinghai, Sichuan, Yunnan and Tibet) as well as Bhutan, India, Nepal [20]. In traditional Chinese medicine, the roots and rhizomes of *N. jatamansi* are used for their stomachic and sedative effects [20]. It is also used as

a stimulant, antiseptic, insect repellent and for the treatment of epilepsy, hysteria, convulsive affections, stomachache, constipation and cholera in Ayurvedic and Unani systems of Medicine [21]. Previous phytochemical investigations of *N. jatamansi* revealed the presence of phenolic compounds, caffeoylquinic acid derivatives, lignans, neolignans, monoterpenoids, sesquiterpenoids, diterpenoids, and iridoids [22-31]. Chemical composition of essential oils derived from the three species has been analyzed previously [25, 32-37]. The methanol extract of *N. jatamansi* possessed strong repellency against female blood-starved *Aedes aegypti* [38] while the essential oil of *N. jatamansi* also exhibited repellency against *L. bostrychophila* and *T. castaneum* [18]. Moreover, the methanol extract of *N. jatamansi* showed weak acute toxicity against *Lasioderma serricorne* adults using the filter paper diffusion method and only 22% mortality was observed after 4-day exposed to 3.5 mg/cm^2 [39]. However, insecticidal activities of the essential oil against three grain storage insects, *L. bostrychophila*, *S. zeamais* and *T. castaneum* have not been determined so far. In this paper, the essential oil of *N. jatamansi* roots was evaluated for contact and fumigant toxicity against these three grain storage insects.

2. Materials and Methods

2.1. Insects

The booklice (*L. bostrychophila*) were obtained from laboratory cultures in the dark in incubators at 28-30 ^{0}C and 70-80% relative humidity (RH) and was reared on a 1: 1: 1 mixture, by mass, of milk powder, active yeast, and flour. All the containers housing insects and the Petri dishes used in experiments were made escape proof with a coating of polytetrafluoroethylene (Fluon®, Blades Biological, Edenbridge, UK). Laboratory bioassays (August-October, 2013) were done within one week after adult collections.

The maize weevils (*S. zeamais*) and red flour beetles (*T. castaneum*) were obtained from laboratory cultures maintained in the dark in incubators at 29-30 ^{0}C and 70-80% RH. The red flour beetles were reared on wheat flour mixed with yeast (10:1, w/w) while maize weevils were reared on whole wheat at 12-13% moisture content. Unsexed adult weevils/beetles used in all the experiments were about 2 weeks old.

2.2. Chinese medicinal herb and essential oil extraction

Dried roots (5 Kg) of *N. jatamansi* were purchased from Anguo Chinese Medicinal Herbs Market (Anguo 071200, Hebei Province, China). A voucher specimen was deposited at the Department of Entomology, China Agricultural University (CMH-GanSong-Hebei-2011-10). The sample was ground to powder using a grinding mill (Retsch Muhle, Haan, Germany). It was subjected to hydrodistillation using a modified Clevenger-type apparatus for 6 h and extracted with *n*-hexane. Anhydrous sodium sulphate was used to remove water after extraction. The essential oil was stored in airtight containers in a refrigerator at 4 °C for subsequent experiments. Pyrethrum extract (25% pyrethrin I and pyrethrin II) was purchased from Fluka Chemie (Buchs, Switzerland). Dichlorvos (99.9%) was purchased from Aladdin-reagent Company (Shanghai, China).

2.3. GC-MS analysis

Analyses of volatile constituents were determined using an Agilent 5973 GC-MS system operating in the EI mode at 70 eV [equipped with a 30m HP-5MS column (0.25mm ×30m × 0.25 μm) and coated with 5% phenyl-methylpolysiloxane using a HP-5MS (df = 0.25 μm) (Agilent J&W Scientific, USA)]. The temperature program used for the analysis was as follows: initial temperature at 60 ^{0}C, held for 1 min, ramped at 4 °C /min to 290 °C and held for 0.5 min. Helium was the carrier gas at 1.0 ml/min; the sample (1 μl, diluted to 1/100, v/v, in hexane) was injected in the split mode (1:5). The injector and detector temperatures were preformed at 230 °C and 300 °C, respectively. The Kovats retention indices were calculated for all volatile constituents using a homologous series of *n*-alkanes C_8-C_{24}. Quantification was performed using percentage peak area calculations and the identification of individual compartments was done using the Wiley/ NBS Registry of Mass Spectral Database and NIST MS Search, literature [40] and several authentic compounds. The relative concentration of each compound in essential oil was quantified based on the peak area integrated by the analysis program.

2.4. Contact toxicity with treated filter paper against the booklice

Contact toxicity of the essential oil of *N. jatamansi* against the booklice was measured as described by Zhao *et al.* [41]. Range-finding studies were run to determine the appropriate testing concentrations of the essential oil. The essential oils were diluted in acetone. The filter paper with 3.5 cm in diameter (Whatman) was treated with 150 μl of the solution. The treated filter paper after treated with solid glue (Glue Stick, Jong Ie Nara Co., Ltd. Hong Kong) was placed in a petri dish (3.5 cm in diameter) and 10 booklice were put on the filter paper. The plastic cover with holes was put and all the peteri dishes were kept in incubators at 27-29 ^{0}C, 70-80% RH for 24 h and mortality of insects was observed. Acetone was used as control and pyrethrum extract was used as a positive control. Six concentrations (2.0%, 2.4%, 2.9%, 3.5%, 4.2%, and 5.0%) and five replicates of each concentration were used in all treatments and controls.

2.5. Fumigant toxicity against the booklice

Fumigant toxicity of the essential oil of *N. jatamansi* against the booklice was determined as described by Zhao *et al.* [41]. Range-finding studies were run to determine the appropriate testing concentrations of the essential oil. A filter paper strip (3.5 cm×1.5 cm) was treated with 10 μl of the respective concentration of test essential oils in acetone. The impregnated filter paper was then placed in the bottom cover of glass bottle of 250 ml. The insects, 10 adults with undefined sex in a small glass bottle (8 ml), were exposed for 24 h and each concentration with five replicates. Six concentrations (3.1%, 3.3%, 3.5%, 3.6%, 3.8%, 4.0%) were used in all treatments and controls. All the treatments were replicated five times. Acetone was used as controls and dichlorvos was used as a positive control. Mortality of insects was observed.

2.6. Contact toxicity using topical application

The contact toxicity of the essential oil of *N. jatamansi* against *S. zeamais* and *T. castaneum* adults was measured as described by Liu and Ho [1]. Range-finding studies were run to determine the appropriate testing concentrations of the essential oil. A serial dilution of the essential oil was prepared in *n*-hexane. Aliquots of 0.5 μl of the dilutions (six concentrations: 15.0%, 11.5%, 8.9%, 6.8%, 5.3%, and 4.0% for *S. zeamais*; 2.0%, 3.0%, 4.5%, 6.8%, 10.0%, and 15.0% for *T. castaneum*) were applied topically to the dorsal thorax of the insects, using an Arnold Automatic Micro-applicator (Burkard, Ricksmanworth, England). Controls were determined using *n*-hexane. Both treated and control insects were then transferred to glass vials

(10 insects/vial) with culture media and kept in incubators. Mortality of insects was observed at 24 h after treatment.

2.7. Fumigant toxicity against *S. zeamais* and *T. castaneum*

Range-finding studies were run to determine the appropriate testing concentrations of the essential oil. A Whatman filter paper (diameter 2.0 cm, CAT No. 1001020) was placed on the underside of the screw cap of a glass vial (diameter 2.5 cm, height 5.5 cm, volume 24 ml). Ten microliters of the dilutions of essential oils (6 concentrations: 2.0%, 3.0%, 4.4%, 6.7%, 10.0%, and 15.0% for *S. zeamais*; 14.8%, 19.3%, 25.0%, 32.5%, 42.0%, and 55.0% for *T. castaneum*) was added to the filter paper. The solvent was allowed to evaporate for 15 s before the cap was placed tightly on the glass vial (with 10 unsexed insects) to form a sealed chamber. Fluon (ICI America Inc, Parkersburg, West Virginia) was used inside glass vial to prevent insects from the treated filter paper. *n*-Hexane was used as a control. Six replicates were used in all treatments and control and they were incubated at 29-30 ^{0}C and 70-80% RH for 24 h. Mortality of insects was observed.

2.8. Statistical analysis

The observed mortality data were corrected for control mortality using Abbott's formula. The results from all replicates in fumigant and contact toxicity were subjected to Probit analysis using PriProbit Program V1.6.3 to determine LC_{50} values with their fiducial limits [42].

3. Results and Discussion

3.1. Chemical composition of the essential oil

The water distillation for 6 h of *N. jatamansi* roots afforded essential oil (yellow) with a yield of 1.07% (v/w, based on dry weight) and the density of the concentrated oil was 0.83 g/ml. A total of 29 components of the essential oil of *N. jatamansi* were identified, accounting for 98.1% of the total oil (Table1). Monoterpenoids only represented 8 of the 29 compounds, corresponding to 8.5% of the whole oil, while 18 of the 27 constituents were sesquiterpenoids (85.4% of the crude essential oil) (Table 1). The principal compounds in the essential oil of *N. jatamansi* were calerene (25.9%), patchouol (10.6%), α-gurjunene (7.5%), aristolone (7.1%) and β-maaliene (6.5%) followed by spathulenol (4.3%). The chemical profiles of the essential oil of *N. jatamansi* in this study were similar to those (collected from China) of the previous reports [32-35]. For example, major compounds have been identified in the essential oil of *N. jatamansi* as calarene (29.44%), δ-1(10)-aristolenone-2 (16.57%) and jatamansinol (8.80%) [32] while Deng et al. **[33]** determined that the essential oil of *N. jatamansi* contained calerene (35.39%), β-maaliene (10.20%), α-gurjunene (9.12%), and aristolenone (6.28%). In some other reports, calarene (37.7%), β-maaliene (7.9%), valerena-4,7(11)-diene (6.6%), 9-aristolene (4.7%) and patchouol (4.5%) were identified as the major volatile constituents of *N. jatamansi* **[34]** while calarene (25.31%), aristolone (13.35%), α-selinene (7.32%) and β-maaliene (6.70%) were the major compounds of the 23 identified components which accounted for 92.76% of the total oil of *N. jatamansi* [35]. However, the chemical profiles of the essential oil of *N. jatamansi* in this study were quite different from those (not from China) of the previous reports **[21, 36, 37]**. For example, the essential oil of *N. jatamansi* harvested from Pakistan mainly contained ledene oxide [II] (13.02%) and patchouli alcohol (9.58%) [21]. Moreover, the predominant constituents in the essential oil of *N. jatamansi* harvested from Indian Himalayas were nardol (10.1%), and α-selinene (9.2%) **[36]**. In another report, jatamansone or valeranone (36.71%), and α-cadinol (22.67%) were found to be the major constituents in the essential oil of *N. jatamansi* rhizomes collected from India [37].

Table 1: Chemical constituents of the essential oil of *Nardostachys jatamansi*

No.	Compounds	RI[a]	Composition (%)
1	Isovaleric acid[b]	875	1.5
2	3-Methylvaleric acid[b]	902	2.3
3	Valeric acid[b]	912	0.4
4	α-Pinene[b]	931	0.6
5	Camphene	945	0.5
6	β-Pinene[b]	981	0.9
7	1,8-Cineole[b]	1032	3.6
8	γ-Terpinene	1057	0.8
9	Linalool[b]	1094	0.5
10	4-Terpinenol[b]	1179	1.1
11	α-Terpineol[b]	1191	0.5
12	β-Patchoulene	1382	0.6
13	β-Elemene	1393	0.1
14	α-Gurjunene	1406	7.5
15	β-Maaliene	1418	6.5
16	Aristolene	1427	3.1
17	Calarene	1432	25.9
18	Aromadendrene	1440	3.8
19	β-Ionone	1487	1.0
20	α-Selinene	1492	3.7
21	α-Bulnesene	1503	1.4
22	Alloaromadendrene	1508	2.3
23	δ-Cadinene	1520	0.5
24	α-Panasinsen	1526	0.5
25	Spatulenol	1578	4.3
26	Viridiflorol	1592	2.8
27	Patchoulol[b]	1660	10.6
28	Valeranone	1679	3.7
29	Aristolone	1762	7.1
	Total identified		98.1
	Monoterpenoids		8.5
	Sesquiterpenoids		85.4
	Others		4.2

[a] RI, retention index as determined on a HP-5MS column using the homologous series of *n*-hydrocarbons; [b]Identification based on comparison of LRI and spectra with authentic standards.

3.2. Insecticidal activities against *S. zeamais* and *T. castaneum*

The essential oil of *N. jatamansi* roots exhibited contact toxicity against *S. zeamais* and *T. castaneum* adults with LC_{50} values of 70.83 µg/adult and 45.38 µg/adult, respectively (Table 2). Pyrethrum extract showed contact toxicity against *S. zeamais* and *T. castaneum* adults with LC_{50} values of 5.15 µg/adult and 1.24 µg/adult, respectively. Thus the essential oil of *N. jatamansi* roots possessed only 14 and 36 times less toxicity to *S. zeamais* and *T. castaneum* adults, respectively. When compared with the other essential oils in the previous studies, the essential oil of *N. jatamansi* exhibited stronger acute toxicity against the maize weevils, e.g. essential oils of *A. sieversiana* (LD_{50} = 112.7 µg/adult) [10], *A. capillaris* (LD_{50} = 105.95 µg/adult) and *A. mongolica* (LD_{50} = 87.92 µg/adult) [43], *Illicium simonsii* (LD_{50} = 112.74 µg/adult) [44], and *Caryopteris incana* (122.65) [45].

T. castaneum (LC_{50} = 53.29 mg/l) proved to be more susceptible (on overlap in 95% fiducial limits) to the essential

oil of *N. jatamansi* in fumigant toxicity bioassay than *S. zeamais* (LC_{50} = 82.13 mg/l) (Table 2). The commercial grain fumigant, methyl bromide (MeBr) was reported to have fumigant activity against *S. zeamais* and *T. castaneum* adults with LC_{50} values of 0.67 mg/l and 1.75 mg/l, respectively [1], thus the essential oil of *N. jatamansi* was 122 and 30 times less toxic to *S. zeamais* and *T. castaneum*, respectively. However, fumigant activity of the essential oil of *N. jatamansi* against *S. zeamais* and *T. castaneum* adults is quite promising because the most effective fumigants (e.g. phosphine and MeBr) are highly toxic to humans and other non-target organisms.

3.3. Insecticidal activities against *L. bostrychophila*

The essential oil of *N. jatamansi* exhibited strong contact toxicity against *L. bostrychophila* with an LC_{50} value of 277.05 μg/cm^2 (Table 2). However, compared with the positive control, pyrethrum extract (LC_{50} = 18.99 μg/cm^2), the essential oil of *N. jatamansi* showed 15 times less toxic to *L. bostrychophila*. The essential oil of *N. jatamansi* roots possessed strong fumigant toxicity with an LC_{50} value of 0.74 mg/l against the booklice (Table 2). The positive control, dichlorvos had LC_{50} value of 1.35 μg/l. Thus the essential oil of *N. jatamansi* showed only 500 times less toxic against *L. bostrychophila* when compared with the positive control. However, the essential oil of *N. jatamansi* possessed stronger fumigant toxicity against the booklice than essential oils of *Artemisia rupestris* (LC_{50} = 6.67 mg/l) and *A. frigida* (LC_{50} =1.25 mg/l) [46, 47], *Curcuma wenyujin* (LC_{50} = 2.76 mg/l) [48], *Valeriana jatamansi* (LC_{50} = 5.98 mg/l) [49] and *Ageratum houstonianum* (LC_{50} > 50 mg/l) [50]. But less toxic than the essential oils of *Acorus calamus* (LC_{50} = 0.39 mg/l) [51] and *Foeniculum vulgare* (LC_{50} = 0.03 mg/l) [41]. However, considering the commercial fumigants are synthetic insecticides and the most effective fumigants (e.g. phosphine and MeBr) are also highly toxic to humans and other non-target organisms, fumigant activity of the essential oil of *N. jatamansi* is quite promising. The essential oils of *N. jatamansi* roots showed potential to be developed as possible natural fumigants/insecticides for the control of grain storage insects.

There is no report on insecticidal activity of the major constituents, calarene, α-gurjunene, aristolone and β-maaliene. The other constituent, patchoulol exhibited strong acute toxicity to the booklice *L. bostrychophila* with a LC_{50} value of 61.35 μg/cm^2, but no fumigant toxicity was observed [49]. Patchoulol was also demonstrated to exhibit toxic and repellency against Formosan subterranean termites (*Coptotermes formosanus*) [52] and exhibited pupicidal and repellent activities against three important vector mosquitoes (*Aedes aegypti*, *Anopheles stephensi*, and *Culex quinquefasciatus* [53]. Weak larvical activity of patchoulol against *Culex pipiens pallens* was also observed [54]. The roots of *N. jatamansi* have been commonly used in traditional Chinese medicines for their stomachic and sedative effects [20] and seem to be safe to human consumption. However, for the practical application of the essential oil of *N. jatamansi* as novel insecticide/fumigant, further studies on the safety of the essential oil to humans and plants are needed. A further study is also necessary to determine the toxicity of the essential oil on other economically important pests and their natural enemies in greenhouse conditions where pest management depends on chemical applications. Further studies on the development of formulations are also necessary to improve the efficacy and stability and to reduce cost.

Table 2: Contact and fumigant toxicity of the essential oil of *Nardostachys jatamansi* against *Liposcelis bostrychophila*, *Sitopilus zeamais* and *Tribolium castaneum*

Insects	Treatment	Extracts	LC_{50}	95% FL	Slope ± SE	Chi square (χ^2)
Liposcelis bostrychophila	Contact (μg/cm^2)	*N. jatamansi*	277.05	249.82-304.16	6.57 ± 0.58	9.24
		Pyrethrum extract	18.99	17.56-20.06	7.64 ± 0.75	-
	Fumigant (mg/l)	*N. jatamansi*	0.74	1.95-3.67	5.25 ± 0.43	11.20
		Dichlorvos	1.35×10^{-3}	$(1.25\text{-}1.47)\times10^{-3}$	6.87 ± 0.77	-
Sitopilus zeamais	Contact (μg/adult)	*N. jatamansi*	70.83	66.01-76.28	5.63 ± 0.55	21.00
		Pyrethrum extract	5.15	4.66-6.18	4.14 ± 0.33	6.78
	Fumigant (mg/l)	*N. jatamansi*	82.13	75.01-89.55	3.46 ± 0.35	14.00
		MeBr*	0.67	-	-	-
Tribolium castaneum	Contact (μg/adult)	*N. jatamansi*	45.38	41.82-49.16	5.43 ± 0.47	7.56
		Pyrethrum extract	1.24	1.05-1.28	4.64 ± 0.35	13.43
	Fumigant (mg/l)	*N. jatamansi*	53.29	49.35-58.49	5.22 ± 0.52	10.36
		MeBr*	1.75	-	-	-

* from Liu and Ho [1]

4. Conclusion

The essential oil of *N. jatamansi* roots demonstrated contact and fumigant toxicity against three grain storage insects. They showed potential to be developed as possible natural insecticide and fumigant for control of the stored product insects but need to be further evaluated for safety to humans.

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6. References

1. Liu ZL, Ho SH. 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). J Stored Prod Res 1999; 35:317-328.
2. Magan, N, Hope R, Cairns V, Aldred D. Postharvest fungal ecology: impact of fungal growth and mycotoxin accumulation in stored grain. Eur J Plant Pathol 2003; 109:723-730.

3. Turner BD. Psocids as pests: the global perspective. Int Pest Control 1999; 41:185-186.
4. Diaz-Montano JJE. Campbell, Phillips TW, Throne JE. Evaluation of potential attractants for *Liposcelis bostrychophila* (Psocoptera: Liposcelididae). J Econ Entomol 2014; 107:867-874.
5. Athanassiou CG, Arthur FH, Throne JE. Efficacy of grain protectants against four psocid species on maize, rice and wheat. Pest Manag Sci 2009; 65:1140-1146.
6. Zettler JL, Arthur FH. Chemical control of stored product insects with fumigants and residual treatments. Crop Prot 2000; 19:577-582.
7. Isman MB. Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world. Annu Rev Entomol 2006; 51:45-66.
8. Regnault-Roger C, Vincent C, Arnason JT. Essential oils in insect control: Low-risk products in a high-stakes world. Annu Rev Entomol 2012; 57:405-424.
9. Liu, ZL, Goh SH, Ho SH. Screening of Chinese medicinal herbs for bioactivity against *Sitophilus zeamais* Mostchulsky and *Tribolium castaneum* (Herbst). J Stored Prod Res 2007; 43:290-296.
10. Liu ZL, Liu QR, Chu SS, Jiang GH. Insecticidal activity and chemical composition of the essential oils of *Artemisia lavandulaefolia* and *Artemisia sieversiana* from China. Chem Biodiv 2010; 7:2040-2045.
11. Zhang JS, Zhao NN, Liu QZ, Liu ZL, Du SS, Zhou L *et al*. Repellent constituents of essential oil of *Cymbopogon distans* aerial parts against two stored-product insects. J Agric Food Chem 2011; 59:9910-9915.
12. Chu SS, Hu JF, Liu ZL. Composition of essential oil of Chinese *Chenopodium ambrosioides* and insecticidal activities to maize weevil, *Sitophilus zeamais*. Pest Manag Sci 2011; 67:714-71.
13. Chu SS, Jiang GH, Liu ZL. Insecticidal compounds from the essential oil of Chinese medicinal herb, *Atractylodes chinensis*. Pest Manag Sci 2011; 67:1253-1257.
14. Liu ZL, Cao J, Zhang HM, Lin LL, Liu HJ, Du SS *at al.* Feeding deterrents from *Aconitum episcopale* roots against the red flour beetle, *Tribolium castaneum*. J Agric Food Chem 2011; 59:3701-3706.
15. Chu SS, Liu ZL, Du SS, Deng ZW. Chemical composition and insecticidal activity against *Sitophilus zeamais* of the essential oils derived from *Artemisia giraldii* and *Artemisia subdigitata.* Molecules 2012; 17:7255-7265.
16. Jiang GH, Liu QR, Chu SS, Liu ZL. Chemical composition and insecticidal activity of the essential oil of *Artemisia eriopoda* against maize weevil, *Sitophilus zeamais*. Nat Prod Commun 2012; 7:267-268.
17. Liang Y, Li JL, Xu S, Zhao NN, Zhou L, Cheng J *at al.* Repellent constituents of the essential oil of *Epimedium pubescens* aerial parts against two grain storage insects. J Econ Entom 2013; 106:513-519.
18. Liu ZL, Liu QZ, Zhou L, Jiang GH. Essential oil composition and insecticidal activity of *Salvia umbratica* flowering aerial parts from China against *Sitophilus zeamais*. J Essent Oil-bearing Plant 2013; 16:672-678.
19. Liu ZL, Yang K, Bai PH, Zhou L, Liu SL, Liu QZ. Gas chromatography-mass spectrometric analysis of essential oil of aerial parts of *Glycosmis parviflora* (Sims) Little (Rutaceae). Trop J Pharm Res 2014; 13:275-280.
20. Editorial Committee of Flora Reipublicae Popularis Sinicae. Flora Reipublicae Popularis Sinicae, Science Press Beijing China, 1986, 73(1):23-27. http://www.efloras.org/florataxon.aspx?flora_id=2&taxon_id=200022534. 09 Sep, 2014.
21. Parveen Z, Siddique S, Shafique M, Khan SJ, Khanum R. Volatile constituents, antibacterial and antioxidant activities of essential oil from *Nardostachys jatamansi* DC. roots. Pharmacology online 2011; 3:329-337.
22. Bagchi A, Oshima Y, Hikino H. Validity of the Oriental medicines. Part 123. Nardostachin, an iridoid of *Nardostachys chinensis*. Planta Med 1988; 54:87-88.
23. Bagchi A, Oshima Y, Hikino H. Neolignans and lignans of *Nardostachys jatamansi* roots. Planta Med 1991; 57:96-97.
24. Chatterjee A, Basak B, Saha M, Dutta U, Mukhopadhyay C, Banerji J *at al.* Structure and stereochemistry of nardostachysin, a new terpenoid ester constituent of the rhizomes of *Nardostachys jatamansi*. J Nat Prod 2000; 63:1531-1533.
25. Chatterjee A, Basak B, Datta U, Banerji J, Neuman A, Prange T. Studies on the chemical constituents of *Nardostachys jatamansi* DC (Valerianaceae). Indian J Chem 2005; 44B:430-433.
26. Rao GV, Annamalai T, Mukhopadhyay T. Nardal, a new sesquiterpene aldehyde from the plant, *Nardostachys jatamansi* DC. Indian J Chem 2008; 47B:163-165.
27. Rekha K, Rao RR, Pandey R, Prasad KR, Babu KS, Vangala JR *at al.* Two new sesquiterpenoids from the rhizomes of *Nardostachys jatamansi*. J Asian Nat Prod Res 2013; 15:111-116.
28. Wang PC, Ran XH, Luo HR, Zheng YM, Liu YQ, Hu JM *at al.* Nardoaristolone A, a new type of sesquiterpenoid-chalcone hybrid from *Nardostachys chinensis*. Tetrahedron Lett 2013; 54:4365-4368.
29. Liu ML, Duan YH, Zhang JB, Yu Y, Dai Y, Yao XS. Novel sesquiterpenes from *Nardostachys chinensis* Batal. Tetrahedron 2013; 69:6574-6578.
30. Liu ML, Duan YH, Hou YL, Li C, Gao H, Dai Y *at al.* Nardoaristolones A and B, two terpenoids with unusual skeletons from *Nardostachys chinensis* Batal. Organic Lett 2013; 15:1000-1003.
31. Zhang JB, Liu ML, Duan YH, Tian HY, Li C, Dai Y *at al.* Novel nardosinane type sesquiterpenoids from *Nardostachys chinensis* Batal. Tetrahedron 2014; 70:4507-4511.
32. Han Y, Xiao D, Xiang Y, Ye L, Cheng C. Study on the volatile oil of *Nardostachys chinensis*. J Chin Med Materials 2000; 23:34-35.
33. Deng WX, Yang ZB, Kang WY. Analysis of chemical constituents of the volatile from *Nardostachys chinensis* Batal by supercritical CO2 extraction. J Henan Univ (Med Sci) 2007; 26:27-29.
34. Tanaka K, Komatsu K. Comparative study on volatile components of *Nardostachys* rhizome. J Nat Med 2008; 62:112-116.
35. Wang JH, Zhao JL, Liu H, Zhou L, Liu ZL, Han JG *at al.* Chemical analysis and biological activity of the essential oils of two valerianaceous species from China: *Nardostachys chinensis* and *Valeriana officinalis*. Molecules 2010; 15:6411-6422.
36. Mahalwal, VS, Ali M. Volatile constituents of the rhizomes of *Nardostachys jatamansi* DC. J Essent Oil-Bearing Plant 2002; 5:83-89.
37. Naquvi KJ, Ansari SH, Ali M. Composition of volatile oil of sambul-ut-teeb (*Nardostachys jatamansi* DC.), an endangered species. Anal Chem An Indian J 2013;

12:347-351.
38. Yang YC, Lee EH, Lee HS, Lee DK, Ahn YJ. Repellency of aromatic medicinal plant extracts and a steam distillate to *Aedes aegypti*. J Am Mosq Control Assoc 2004; 20:146-149.
39. Kim SI, Park C, Ohh MH, Cho HC, Ahn YJ. Contact and fumigant activities of aromatic plant extracts and essential oils against *Lasioderma serricorne* (Coleoptera: Anobiidae). J Stored Prod Res 2003; 39:11-19.
40. Adams RP. Identification of Essential Oil Components by Gas Chromatography/Quadrupole Mass Spectroscopy; Allured: Carol Stream, IL, USA, 2007.
41. Zhao NN, Zhou L, Liu ZL, Du SS, Deng ZW. Evaluation of toxicities of some common spices essential oils from China against *Liposcelis bostrychophila*. Food Control 2012; 26(2):486-490.
42. Sakuma M. Probit analysis of preference data. Appl Entomol Zool 1998; 33:339-347
43. Liu ZL, Chu SS, Liu QR. Chemical composition and insecticidal activity against *Sitophilus zeamais* of the essential oils of *Artemisia capillaries* and *Artemisia mongolica*. Molecules 2010; 15:2600-2608.
44. Chu SS, Liu SL, Jiang GH, Liu ZL. Composition and toxicity of essential oil of *Illicium simonsii* Maxim (Illiciaceae) fruit against the maize weevils. Rec Nat Prod 2010; 4:205-210.
45. Chu SS, Liu QZ, Zhou LG, Du SS, Liu ZL. Chemical composition and toxic activity of essential oil of *Caryopteris incana* against *Sitophilus zeamais*. Afr J Biotechnol 2011; 10:8476-8480
46. Liu XC, Li XP, Li HQ, Deng ZW, Zhou L, Liu ZL *at al.* Identification of repellent and insecticidal constituents of the essential oil of *Artemisia rupestris* L. aerial parts against *Liposcelis bostrychophila* Badonnel. Molecules 2013; 18:10733-10746
47. Liu XC, Li Y, Wang T, Wang Q, Liu ZL. Chemical composition and insecticidal activity of essential oil derived from *Artemisia frigida* Willd. (Compositae) against two grain storage insects. Trop J Pharm Res 2014; 13:587-592.
48. Liu ZL, Zhao NN, Liu CM, Zhou L, Jiang GH. Identification of insecticidal constituents of the essential oil of *Curcuma wenyujin* rhizomes against *Liposcelis bostrychophila* Badonnel. Molecules 2012; 17:12049-12060.
49. Liu XC, Zhou L, Liu ZL. Identification of insecticidal constituents from the essential oil of *Valeriana jatamansi* Jones against *Liposcelis bostrychophila* Badonnel. Journal of Chemistry, 2013.
50. Lu XN, Liu XC, Liu QZ, Liu ZL. Isolation of iInsecticidal constituents from the essential oil of *Ageratum houstonianum* Mill. against *Liposcelis bostrychophila*. Journal of Chemistry, 2014.
51. Liu XC, Zhou L, Liu ZL, Du SS. Identification of insecticidal constituents of essential oil of *Acorus calamus* rhizomes against *Liposcelis bostrychophila* Badonnel. Molecules 2013; 18:5684-5695.
52. Zhu BCR, Henderson G, Yu Y, Laine RA. Toxicity and repellency of patchouli oil and patchouli alcohol against Formosan subterranean termites *Coptotermes formosanus* Shiraki (Isoptera: Rhinotermitidae). J Agric Food Chem 2003; 51:4585-4588.
53. Gokulakrishnan J, Kuppusamy E, Shanmugam D, Appavu A, Kaliyamoorthi K. Pupicidal and repellent activities of *Pogostemon cablin* essential oil chemical compounds against medically important human vector mosquitoes. Asian Pacific J Trop Disease 2013; 3:26-31.
54. Park HM, Park IK. Larvicidal activity of *Amyris balsamifera*, *Daucus carota* and *Pogostemon cablin* essential oils and their components against *Culex pipiens pallens*. J Asia-Pacific Entomol 2012; 15:631-634.