Feeding Deterrents from *Zanthoxylum schinifolium* against Two Stored-Product Insects

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Screening for insecticidal principles from several Chinese medicinal herbs showed that the fruit pericarp of *Zanthoxylum schinifolium* possessed significant feeding deterrence against two stored-product insects (*Tribolium castaneum* and *Sitophilus zeamais*). From the methanol extract, two feeding deterrents were isolated by bioassay-guided fractionation. The compounds were identified as schinifoline and skimmianine from their spectroscopic data. Schinifoline has feeding deterrent activity against *T. castaneum* and *S. zeamais* adults with EC_{50} values of 47.8 and 85.6 ppm respectively. Skimmianine possess feeding deterrent activity against *T. castaneum* and *S. zeamais* adults with EC_{50} values of 75.7 and 129.7 ppm respectively.

INTRODUCTION

Botanical pesticides have the advantage of providing novel modes of action against insects that can reduce the risk of cross-resistance as well as offering new leads for design of target-specific molecules. During the screening program for new agrochemicals from Chinese medicinal herbs, green prickly ash, *Zanthoxylum schinifolium* Sieb. et Zucc (Family: Rutaceae), was found to possess significant feeding deterrence activity against two stored-product insects (*Tribolium castaneum* Herbst and *Sitophilus zeamais* Motsch.). *Z. schinifolium*, found in China, Japan and Korea, is an aromatic shrub with protective thorns and surprising culinary and pharmacological properties and has been cultivated in the southern provinces of China. In China, the ripe pericarp of the fruits is one of the sources of pericarpium zanthoxyli and widely consumed in Asia as a spice (*1*). The fruit of this plant has been used in Chinese medicine for epigastric pain accompanied by cold sensation, vomiting, diarrhea and abdominal pain due to intestinal parasitosis and ascariasis and used externally for eczema (*2*). The seeds of this species are very flavorful with strong anise, citrus, and pepper notes. Both the pericarp (seed coating) and the black seeds are used in cooking. Aqueous extracts of *Z. schinifolium* fruits have been used to control aphids on vegetables (*3*), and the ethanol extracts of *Z. schinifolium* fruits were found to possess high feeding deterrent activity against two aphids [*Myzus persicae* (Sulzer) and *Lipaphis erysimi* (Kaltenbach)] (*4*). Moreover, the petroleum ether extracts of *Z. schinifolium* fruits possess strong contact toxicity and repellent activity against *M. persicae* aphids and diamond back moth (*Plutella xylostella* L.) (*5, 6*). Bowers et al. (*7*) also demonstrated that a CH_2Cl_2 extract of Chinese prickly ash (*Z. bungeanum*) is highly repellent to insects, and 3 monoterpenes (piperitone,

4-terpineol, and linalool) were isolated and identified. Piperitone is more repellent than the common insect repellent *N,N*-diethyl-*m*-toluamide (*7*). Xanthoxylin isolated and identified from Chinese prickly ash possesses significant deterrent effects on ovipositional behavior of angoumois grain moth, *Sitotroga cerebella* (Olivier) (*8*). This compound also has strong feeding deterrent properties on larvae of *S. cerebella* in a nonchoice bioassay (*8*).

Due to it being a common Chinese herb used in medical as well as culinary practices, the chemical constituents and bioactivities of *Z. schinifolium* have been extensively studied, and the known chemical constituents of this medicinal herb include monoterpenoids, coumarins, amides, alkaloids, flavonoids, lignans, diterpenoids, sesquiterpenoid, triterpenoids, and steroids (*9–22*). Seven active compounds (with strong inhibitory activity on platelet aggregation in vitro) were isolated and identified from root bark of *Z. schinifolium* by bioassay-guided fractionation (*11*). Moreover, Tsai et al. (*19*) had isolated and identified twenty-two coumarins and nine alkaloids from chloroform-solvated portion of the root bark of *Z. schinifolium*. Among the isolates, terpenyl-coumarins and furoquinolines were the active constituents with antiplatelet aggregation in vitro and collinin showed significant anti-HBV (hepatitis B virus) DNA replication activity. Oxynitidine and collinin isolated from the bark of *Z. schinifolium* possess significant activity of anti-HBV DNA replication (*10*). From the leaves of this species, twenty-one coumarins, eleven alkaloids, one furan, four benzenoids, three chlorophys, four triterpenoids, one diterpenoid, one sesquiterpenoid, four steroids and a new amide were isolated and identified (*11*). However, the bioactive compounds against insects have not been isolated and identified from this Chinese medicinal herb. In this paper, we report the isolation and identification of two feeding deterrents contained in *Z. schinifolium* fruits against two stored-product insects, *T. castaneum* and *S. zeamais*.

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MATERIALS AND METHODS

Extraction of Plant Material. *Z. schinifolium* (15 kg, dried fruit), purchased from a local Chinese Herbs shop, were ground to a powder and extracted with 95% ethanol (50 L) at room temperature over a period of three weeks. A voucher specimen was deposited in the museum of the Department of Entomology, China Agricultural University. The extracts were concentrated using a vacuum rotary evaporator to afford a syrupy gum (323 g). This syrup was partitioned between methanol−water and *n*-hexane (3 × 5,000 mL). The *n*-hexane extracts were evaporated off to given a residue (58 g). The aqueous layer was repartitioned with chloroform (3 × 5,000 mL) to provide a residue (61 g) after evaporation of chloroform. Further partitioning with ethyl acetate (3×5,000 mL) gave a residue (45 g) after evaporation of the solvent.

Apparatus. Melting points were measured on a Buchi 535. ^{1}H and ^{13}C NMR spectra were recorded on Bruker Avance 500 instruments using CDCl$_3$ as solvent with TMS as internal standard. EIMS were determined on an AVI MS-50 mass spectrometer at 70 eV (probe). Infrared spectra were recorded in a Perkim-Elmer 577 spectrophotometer (KBr pressed disk method).

Chromatography. From the feeding deterrence bioassays with the two species of stored-product insects, the chloroform soluble fraction was found to be active. Chromatography of this fraction through a silica gel (Qingdao Marine Chemical Plant, 200−300 mesh, 1,000 g) column using a chloroform−methanol gradient provided 42 fractions. Fractions 8 and 19 were determined to be the most active. Fraction 8 was further chromatographed on silica gel TLC (precoated GF254 plates, Qingdao Marine Chemical Plant) to provide the bioactive compound, which was recrystallized and determined to be skimminine (1.5 g). Fraction 19 was further chromatographed on silica gel TLC to obtain the bioactive compound, which was recrystallized and determined to be schinifoline (0.08 g).

Feeding Deterrence Bioassay. *T. castaneum* and *S. zeamais* were obtained from laboratory cultures maintained for the last 10 years in the dark in incubators at 30 ± 1 °C and 70−80% relative humidity. *T. castaneum* was reared on wheat flour mixed with yeast (10:1, w:w) while *S. zeamais* was reared on whole wheat at 12−13% moisture content. Adults of the two species used in all the experiments were about 2 weeks old. A flour disk bioassay was used to direct the isolation of active compounds from *D. dasycarpus* according to the method of Xie et al. (*24*) with some modifications. Wheat flour (1.0 g) was ultrasonically stirred in 5 mL of distilled water, and 50 μL of ethanol containing a fraction was added. Pure compounds were first dissolved in 500 μL of ethanol, and two drops of Tween-20 (approximately 50 μg) were added to the wheat flour suspension. Aliquots of 200 μL of this stirred suspension were placed on the bottom of a polystyrene Petri dish to form disks. The pipet was fitted with a disposable tip that had an opening enlarged to about 2 mm internal diameter by cutting about 1 cm from the bottom of the tip with a razor blade. The same amounts of ethanol and Tween-20 were applied to produce the control flour disks. The disks were left in the fume hood overnight to air-dry. The disks were then transferred to an incubator to equilibrate at 30 ± 1 °C and 70−80% R.H. for 48 h. Each flour disk weighed between 36 and 39 mg. The moisture content of the disk was determined to be 13.5 ± 0.1% using the Kett's grain moisture tester (model PB-1D2, Japan). The disks were placed in glass vials (diameter 2.5 cm, height 5.5 cm) for weighing. Ten group-weighed, unsexed insects were then added to each vial prior to further weighing. All the insects were starved for 24 h before use. The experimental setup was left in the incubator for 3 days. Glass vials containing treated flour disks but without insects were prepared to determine any decrease in weights that might have occurred due to evaporation of solvents. The following calculations were made for the study of nutritional indices and feeding deterrent index (*25, 26*):

$$\text{relative growth rate (RGR)} = (A - B)/(B \times 3)$$

$$\text{relative consumption rate (RCR)} = D/(B \times 3)$$

$$\text{efficiency of conversion of ingested food (ECI) (\%)} = (\text{RGR/RCR}) \times 100$$

$$\text{feeding deterrence index (FDI) (\%)} = (C - T) \times 100/C$$

where A = weight of live insects on the third day/number of live insects on the third day, B = initial weight of insects/10, D = biomass ingested/number of the insects on the third day, C = the consumption of control disks and

T = the consumption of treated disks. The EC$_{50}$ (the concentration needed to inhibit insect feeding by 50% relative to controls) was determined by linear regression (*27*).

Data for Isolated Bioactive Compounds. Schinifoline: white needle crystal, mp 82−83 °C [mp 81−82 °C (*18*)]. EI-MS *m/z* (%): 257 (17); C$_{17}$H$_{23}$NO, 242 (0.7), 228 (1.2), 214 (0.7), 200 (2.3), 186 (30), 173 (100), 172 (2.4), 160 (4.3), 159 (2.0), 149 (0.7), 144 (13), 130 (4.8). UV $\lambda_{\max}^{\text{EtOH}}$ nm: 214.5, 239.5, 322, 334.5. IR ($\nu_{\max}$ cm^{-1}): 2950 cm^{-1}, 2918 cm^{-1}, 2850 cm^{-1}, 1640 cm^{-1}, 1595 cm^{-1}, 1550 cm^{-1}, 1490 cm^{-1}, 1365 cm^{-1}, 1310 cm^{-1}, 1180 cm^{-1}, 820 cm^{-1}, 760 cm^{-1}. ^{1}H NMR (CDCl$_3$): 8.45 (1H, dd, J = 8, 8-H), 7.41 (1H, t, J = 8, 6-H), 6.37 (1H, s, 3-H), 3.79 (3H, s, N-CH$_3$), 2.75 (2H, t, J = 8, 1'-H), 1.70 (2H, m, 2'-H), 1.2−1.5 (8H, m, 3'-H-6'-H), 0.89 (3H, t, J = 6, 7'-CH3). ^{13}C NMR: 155.3 (C-2), 110.8 (C-3), 177.7 (C-4), 126.6 (C-5), 123.6 (C-6), 132.2 (C-7), 115.4 (C-8), 141.7 (C-9) 126.1 (C-10), 34.3 (C-11), 34.8 (C-1'), 28.6 (C-2'), 29.7 (C-3'), 28.9 (C-4'), 31.6 (C-5'), 22.5 (C-6'), 14.7 (C-7'). The ^{1}H and ^{13}C NMR data were in agreement with the reported data (*19, 20*).

Skimmianine, light yellow needles, m.p. 176−177 °C [m.p. 176.5−178.5 °C (*28*)]. EI/MS *m/z* (%): 259 (M$^+$, 90.5), 244 (100), 230 (57), 216 (49), 201 (30), 173 (19), 130 (20), 101 (11), 75 (18): C$_{14}$H$_{13}$NO$_4$, UV $\lambda_{\max}$ nm (log ε): 243 (3.63), 328 (3.62), 322 (4.61), 308 (3.86). IR ($\nu_{\max}$ cm^{-1}): 1618 cm^{-1}, 1578 cm^{-1}, 1508 cm^{-1}, 1273 cm^{-1}, 1095 cm^{-1}, 986 cm^{-1}. ^{1}H NMR: δ 4.07 (3H, s, 7-OCH$_3$), 4.16 (3H, s, 8-OCH$_3$), 4.46 (3H, s, 4-OCH$_3$), 7.05 (1H, d, J = 2.5, 3-H), 7.23 (1H, d, J = 9.0, 6-H), 7.58 (1H, d, J = 2.5, 2-H), 8.03 (1H, d, J = 9.0, 5-H). ^{13}C NMR: 56.9 (7-OCH$_3$), 59.0 (4-OCH$_3$), 64.7 (8-OCH$_3$), 102.1 (10-C), 104.6 (3-C), 111.2 (6-C), 115.9 (11-C), 118.2 (5-C), 141.0 (8-C), 141.6 (7-C), 143.0 (2-C), 152.2 (9-C), 157.2 (4-C), 164.6 (12-C). The ^{1}H and ^{13}C NMR data were in agreement with the reported data (*29−32*).
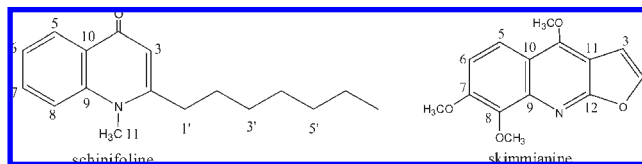
RESULTS AND DISCUSSION

The nutritional and feeding deterrence indices of the two stored-product insects exposed to schinifoline and skimmianine are shown in **Tables 1** and **2**. Schinifoline significantly (P < 0.05) reduced both the growth rate (RGR) and food consumption (RCR) of *T. castaneum* adults at concentrations of 30 ppm and above in a concentration-dependent manner. The feeding deterrence index (FDI) at 10−1000 ppm ranged from 18.64% to 98.34% for the adults. EC$_{50}$ values of *T. castaneum* adults were calculated to be 47.81 ppm. The food utilization (ECI values) of *T. castaneum* adults was also significantly (P > 0.05) lower from that of the controls at concentrations of 30 ppm and above. Schinifoline also significantly (P < 0.05) reduced the growth rate and food consumption of *S. zeamais* at concentrations of 30 ppm and above. The feeding deterrence index at 10−1000 ppm ranged from 10.28% to 92.15% for the *S. zeamais* adults and EC$_{50}$ value of *S. zeamais* was calculated to be 85.63 ppm. Food utilization values (ECI) of *S. zeamais* adults were significantly different from the controls at 100 ppm (P > 0.05), although not at 30 ppm as was observed for *T. castaneum* (**Table 1**).

Skimmianine significantly (P < 0.05) reduced the RGR and RCR of *T. castaneum* and *S. zeamais* adults at a concentration of 30 ppm and above in a concentration-dependent manner. The feeding deterrence index at 30−1000 ppm ranged from 26.12% to 82.43% for the *S. zeamais* adults, and from 30.12% to 89.56% for *T. castaneum* adults. EC$_{50}$ values of *T. castaneum* and *S. zeamais* adults were calculated to be 75.71 and 129.72 ppm respectively. Food utilization of *T. castaneum* and *S. zeamais* adults was also significantly (P > 0.05) different between the controls and the treated insects at concentrations of 30 ppm and above.

Table 1. Nutritional and Feeding Deterrence Indices of *S. zeamais* and *T. castaneum* Adults to Schinifoline[a]

| insect | concn (ppm) | mean ± SD (μg/mg/day) | | ECI (%) (mean ± SD) | mort (%) | FDI (%) | EC$_{50}$ (ppm) |
		RGR	RCR				
S. zeamais	0	13.61 ± 1.13 a	122.72 ± 4.32 a	11.09 ± 1.12 a	0		
	3	13.72 ± 0.79 a	122.39 ± 7.83 a	11.21 ± 1.62 a	0	1.47	85.63
	10	12.25 ± 1.21 a	114.13 ± 8.30 a	10.73 ± 1.82 a	0	10.28	
	30	9.06 ± 0.69 b	89.93 ± 6.57 b	10.07 ± 1.71 a	2	26.69	
	100	3.79 ± 0.29 c	50.29 ± 3.60 c	7.54 ± 0.58 b	0	59.19	
	300	2.04 ± 0.18 d	34.51 ± 1.12 d	5.92 ± 0.38 c	6	72.35	
	1000	0.40 ± 0.03 e	10.51 ± 0.73 e	3.84 ± 0.22 d	16	92.15	
T. castaneum	0	29.49 ± 1.35 a	143.22 ± 4.32 a	20.59 ± 1.47 a	0		
	3	28.85 ± 2.16 a	139.51 ± 5.67 a	20.68 ± 1.85 a	0	4.46	47.81
	10	24.24 ± 1.65 a	119.29 ± 6.31 b	20.32 ± 1.63 a	0	18.64	
	30	13.13 ± 1.14 b	79.64 ± 7.13 c	16.50 ± 1.25 b	0	45.07	
	100	6.17 ± 0.36 c	53.37 ± 5.70 d	11.57 ± 1.25 c	2	66.28	
	300	1.60 ± 0.13 d	21.29 ± 3.26 e	7.53 ± 0.65 d	8	85.85	
	1000	0.07 ± 0.01 e	2.13 ± 6.26 f	3.29 ± 0.02 e	20	98.34	

[a] Within each stage of species, means in the same column followed by the same letters do not differ significantly ($P > 0.05$) in ANOVA test.

Table 2. Nutritional and feeding deterrence indices of *S. zeamais* (S.Z.) and *T. castaneum* adults to skimmianine[a]

| insect | concn (ppm) | mean ± SD (μg/mg/day) | | ECI (%) (mean ± SD) | mort (%) | FDI (%) | EC$_{50}$ (ppm) |
		RGR	RCR				
S. zeamais	0	13.61 ± 1.13 a	122.72 ± 4.32 a	11.09 ± 1.12 a	0		
	3	13.27 ± 1.26 a	120.90 ± 5.34 a	10.98 ± 1.04 a	0	3.53	129.72
	10	12.03 ± 1.09 a	112.77 ± 7.65 a	10.67 ± 1.13 a	0	10.21	
	30	9.60 ± 0.78 b	92.84 ± 5.60 a	10.34 ± 1.47 a	0	26.12	
	100	4.99 ± 0.56 c	59.65 ± 4.71 c	8.37 ± 1.90 b	0	47.32	
	300	3.07 ± 0.23 c	45.13 ± 3.12 d	6.81 ± 1.04 c	4	60.24	
	1000	0.77 ± 0.04 c	18.31 ± 6.12 d	4.21 ± 0.32 d	10	82.43	
T. castaneum	0	29.49 ± 1.35 a	143.22 ± 4.32 a	20.59 ± 1.47 a	0		
	3	27.92 ± 2.03 a	137.89 ± 7.45 a	20.25 ± 1.12 a	0	4.31	75.71
	10	24.21 ± 2.17 a	124.71 ± 4.93 b	19.41 ± 1.05 a	0	13.21	
	30	15.31 ± 1.44 b	101.27 ± 7.39 b	15.12 ± 0.94 b	0	30.12	
	100	8.49 ± 0.65 c	61.88 ± 3.43 c	13.72 ± 0.83 b	2	57.45	
	300	3.17 ± 0.12 d	31.56 ± 1.73 d	10.03 ± 0.66 c	6	68.62	
	1000	1.23 ± 0.04 e	15.72 ± 0.62 e	7.81 ± 0.11 d	14	89.56	

[a] Within each stage of species, means in the same column followed by the same letters do not differ significantly ($P > 0.05$) in ANOVA.

Comparing the feeding deterrent activity of the two compounds, schinifoline was more active than skimmianine to the two species of insects. It is possible that the reduction in growth rate of *T. castaneum* and *S. zeamais* adults was due to both a behavioral (starvation, feeding deterrent) action and postingestive toxicity (*33, 34*) because their food utilization was decreased at concentrations of 30 ppm and above (**Table 1** and **2**). Dietary skimmianine also reduces the growth of *Spodoptera litura* (F.) and *Trichoplusia ni* (Hubner), and this reduction in growth is likely due to a combination of deterrent and toxic properties (*23*). Dietary skimmianine also showed some toxicity against the parsnip webworms (*Depressaria pastinacella*) (*37*). Schinifoline was suggested to possess feeding deterrent activities against insects by using the method of Knowledge Discovery in Database (KDD) and searching in Dictionary of Natural Products (DNP) and MDDR3D with KDD (*38*). Skimmianine is furanocoumarin that is a class of compounds with potent photogenotoxicity (*23, 36*). Skimmianine was shown to be phototoxic to yeasts and bacteria (*39*). Furoquinolines have been found to form monoadducts with DNA bases upon exposure to UV light, reacting through the double bond of the furan ring (*40*). However, no phototoxicity of skimmianine to *T. ni* (*23*) was found in topical application and oral administration tests.

When compared with the commercial feeding deterrent, azadirachtin, schinifoline and skimmianine were less active against *T. castaneum* and *S. zeamais* (for azadirachtin, EC$_{50}$ values of *T. castaneum* and *S. zeamais* adults were 3 and 57 ppm respectively) (*32*). However, they possess similar feeding deterrent activity against the two species of insects to another commercial feeding deterrent, toosendanin (EC$_{50}$ values of *T. castaneum* and *S. zeamais* adults were 66 and 100 ppm respectively) (*35*).

In traditional Chinese medicine, prickly ash is used in many chronic problems such a rheumatism and skin diseases; chilblains, cramp in the leg, varicose veins and varicose ulcers. It is also used for low blood pressure, fever, and inflammation. Externally it may be used as a stimulation liniment for rheumatism and fibrositis (*2*). It seems that this medicinal herb is quite safe to human consumption because it has been used as a spice for hundreds of years. However, no experimental data about the safety of this herb is available so far. The isolated constituent skimmianine is reported to have an LD$_{50}$ of 160 mg/kg by intravenous injection, more than 600 mg/kg by subcutaneous injection and more than 1,000 mg/kg by oral administration in mice (*36*). Thus, this compound is relatively safe for human consumption and possesses the potential to be developed as a new insect feeding deterrent. However, no toxicity data on the human consumption of schinifoline is available to date.

LITERATURE CITED

(1) *Pharmacopoeia of the People's Republic of China*; Edited by the Pharmacopoeia Commission of PRC; Guangdong Science and Technology Press: Guangzhou, China, 1995; Vol. *1*, p 135.

(2) *Jiangsu New Medical College Encyclopedia of Chinese Medicinal Substances*; Shanghai People's Publisher: 1986; pp 737−739.

(3) Yang, R. Z.; Tang, C. S. Plants used for pest control in China: a literature review. *Econ. Bot.* **1988**, *42*, 376−406.

(4) Zhou, Q.; Liang, G. W.; Zeng, L. Study on antifeedant effect of plant extracts on *Myzus persicae* (Sulzer) and *Lipaphis erysimi* (Kaltenbach). *Nat. Prod. Res. Dev.* **2004**, *16*, 521−524 (in Chinese with English abstract).

(5) Liu, S.; Pan, M. H.; Zhang, L. H.; He, Y. Z.; Zhang, L.; Zhao, Y. Studies on the bioactivity of *Zanthoxylum schinifolium* Sieb. et Zucc extraction to *Myzus persicae* (Sulzer). *J. Agric. Univ. Heibei* **2007**, *30*, 84−88 (in Chinese with English abstract).

(6) Liu, S.; He, Y. Z.; Zhao, Y.; Qin, Q. J.; Zheng, Y. Y. Bioactivity of extracts from *Zanthoxylum schinifolium* against *Plutella xylostella*. *Chin. Agric. J. Sci. Bull.* **2007**, *23*, 427−430 (in Chinese with English abstract).

(7) Bowers, W. S.; Ortego, F.; You, X. Q.; Evans, P. H. Insect repellents from the Chinese prickly ash *Zanthoxylum bungeanum*. *J. Nat. Prod.* **1993**, *566*, 935–938.

(8) Ge, X. S.; Weston, P. A. Ovipositional and feeding deterrent from Chinese prickly ash against Angoumois grain moth (Lepidoptera: Gelechiidae). *J. Econ. Entomol.* **1995**, *88*, 1771–1175.

(9) Brader, G.; Wurz, G.; Greger, H.; Hofer, O. Novel prenylated 2-quinolinones from east asian Zanthoxylum species. *Liebigs Ann. Chem.* **1993**, *4*, 355–358.

(10) Chang, C. T.; Doong, S. L.; Tsai, I. L.; Chen, I. S. Coumarins and anti-HBV constituents from *Zanthoxylum schinifolium*. *Phytochemistry* **1997**, *45*, 1419–1422.

(11) Chen, I. S.; Lin, Y. C.; Tsai, I. L.; Teng, C. M.; Ko, F. N.; Ishikawa, T.; Ishii, H. Coumarins and anti-platelet aggregation constituents from *Zanthoxylum schinifolium*. *Phytochemistry* **1995**, *39*, 1091–1097.

(12) Cheng, M. J.; Yang, C. H.; Lin, W. Y.; Lin, W. Y.; Tsai, I. L.; Chen, I. S. Chemical constituents from the leaves of *Zanthoxylum schinifolium*. *J. Chin. Chem. Soc.* (*Taipei, Taiwan*) **2002**, *49*, 125–128.

(13) Jiang, T. Y.; Hong, M. F.; Pan, J. X.; Yang, X. B. NMR study of two new compounds from the roots of *Zanthoxylum schinifolium* Sieb. et Zucc. *Chin. J. Magn. Reson.* **1992**, *9*, 413−417 (in Chinese with English abstract).

(14) Jo, Y. S.; Huong, D. T. L.; Bae, K. H.; Lee, M. K.; Kim, Y. H. Monoamine oxidase inhibitory coumarin from *Zanthoxylum schinifolium*. *Planta Med.* **2002**, *68*, 84–85.

(15) Liu, S. L.; Wei, L. X.; Wang, D.; Gao, C. Y. Studies on the chemical constituents from the peel of *Zanthoxylum schinifolium* Sieb et Zucc. *Acta Pharm. Sin.* **1991**, *26*, 836−840 (in Chinese with English abstract).

(16) Liu, S. L.; Wei, L. X. Determination of chemical constituents in peppertree pricklyask (*Zanthoxylum schinifolium*) and bunge pricklyash (*Z. bungeanium*). *Chin. Tradit. Herb. Drugs* **1991**, *22*, 16−18 (in Chinese with English abstract).

(17) Paik, S. Y.; Koh, K. H.; Beak, S. M.; Paek, S. H.; Kim, J. A. The essential oils from *Zanthoxylum schinifolium* pericarp induce apoptosis of HepG2 human hepatoma cells through increased production of reactive oxygen species. *Biol. Pharm. Bull.* **2005**, *28*, 802–807.

(18) Tsai, I. L.; Lin, W. Y.; Chang, C. T.; Chen, I. S. Peroxycoumarins from the root bark of *Zanthoxylum schinifolium*. *J. Chin. Chem. Soc.* (*Taipei, Taiwan*) **1998**, *45*, 99–101.

(19) Tsai, I. L.; Lin, W. Y.; Teng, C. M.; Ishikawa, T.; Doong, S. L.; Huang, M. W.; Chen, Y. C.; Chen, I. S. Coumarins and antiplatelet constituents from the root bark of *Zanthoxylum schinifolium*. *Planta Med.* **2000**, *66*, 618–23.

(20) Wang, D.; Gao, C. Y.; Liu, S. L.; Wei, L. X. Structure investigation of a new alkaloid from *Zanthoxylum schinifolium* Sieb et Zucc. *Chem. Res. Chin. Univ.* **1991**, *7*, 124–128.

(21) Yang, X. G. Aroma constituents and alkylamides of red and green Huajiao (*Zanthoxylum bungeanum* and *Zanthoxylum schinifolium*). *J. Agric. Food Chem.* **2008**, *56*, 1689–1696.

(22) Iseli, V.; Potterat, O.; Hagmann, L.; Egli, J.; Hamburger, M. Characterization of the pungent principles and the essential oil of *Zanthoxylum schinifolium* pericarp. *Pharmazie* **2007**, *62*, 396–400.

(23) Sackett, T. E.; Towers, G. H. N.; Isman, M. B. Effects of furoquinoline alkaloids on the growth and feeding of two polyphagous lepidopterans. *Chemoecology* **2007**, *17*, 97–101.

(24) Xie, Y. S.; Bodnaryk, R. P.; Fields, P. G. A rapid and simple flour-disk bioassay for testing substances active against stored-product insects. *Can. Entomol.* **1996**, *128*, 865–875.

(25) Manuwoto, S.; Scriber, J. M. Consumption and utilization of three maize genotypes by the southern armyworm. *J. Econ. Entom.* **1982**, *75*, 163–167.

(26) Farrar, R. R. Jr.; Babour, J. D.; Kennedy, G. G. Quantifying food consumption and growth in insects. *Ann. Entom. Soc. Am.* **1989**, *82*, 593–598.

(27) Chen, C. C.; Chang, S. J.; Cheng, L. L.; Hou, R. F. Effects of chinaberry fruit extract on feeding, growth and fecundity of the diamondback moth, *Plutella xylostella* L. (Lep., Yponomeutidae). *J. Appl. Entomol.* **1996**, *120*, 341–345.

(28) Vaquett, J.; Pousset, J. L.; Paris, R. R.; Cave, A. Alkaloids of *Zanthoxylum decaryi*. II. Decarine, a new alkaloid derived from benzophenanthridine. *Phytochemistry* **1974**, *13*, 1257–1259.

(29) Jackson, G. E.; Campbell, W. E.; Davidowitz, B. Two dimensional NMR study of 8-methoxyflindersine, skimmianine and monocrotaline. *Spectrosc. Lett.* **1990**, *23*, 971–982.

(30) Moura, N. F.; Ribeiro, H. B.; Machado, E. C. S.; Ethur, E. M.; Zanatta, N.; Morel, A. F. Benzophenanthridine alkaloids from *Zanthoxylum rhoifolium*. *Phytochemistry* **1997**, *46*, 1443–1446.

(31) Brown, N. M. D.; Grundon, M. F.; Harrison, D. M.; Surgenor, S. A. Quinoline alkaloids. XXI. the carbon-13 NMR spectra of hemiterpenoid quinoline alkaloids and related prenylquinolines. *Tetrahedron* **1980**, *36*, 3579–3584.

(32) Ahond, A.; Poupat, C.; Pusset, J. New caledonian plants. Part 54. geibalansine and o-acetylgeibalansine, new alkaloids from *Geijera balansae*. *Phytochemistry* **1979**, *18*, 1415–1416.

(33) Blaise, A. T.; Winternitz, F. Isofraxinellone, a limonoid lactone from the bark of *Fagaropsis glabra*. *Phytochemistry* **1985**, *24*, 2379–23381.

(34) Blau, P. A.; Feeny, P.; Contardo, L. Allylglucosinolate and herbivores caterpillars: a contrast in toxicity and tolerance. *Science* (*Washington, D.C.*) **1978**, *200*, 1296–1298.

(35) Liu, Z. L.; Xu, Y. J.; Wu, J.; Goh, S. H.; Ho, S. H. Feeding deterrents from *Dictamnus dasycarpus* Turcz against two stored-product insects. *J. Agric. Food Chem.* **2002**, *50*, 1447–1450.

(36) Kanamori, H.; Sakamoto, I.; Mizuta, M. Further study on mutagenic furoquinoline alkaloids of Dictamni radicis cortex: isolation of skimmianine and high-performance liquid chromatographic analysis. *Chem. Pharm. Bull.* **1986**, *34*, 1826–1829.

(37) Berenbaum, M. R.; Lee, K. Toxicity of nonhost phototoxins to parsnip webworms (Lepidoptera: Oecophoridae). *Chemoecology* **1990**, *1*, 81–85.

(38) Zhou, Y. X.; Du, S. S.; Qiao, Y. J.; Wei, L. X. Molecular modeling and activities prediction on schinifoline. *J. Beijing Univ. Tradit. Chin. Med.* **2000**, *23*, 21−22 (in Chinese with English abstract).

(39) Towers, G. H. N.; Abramowski, Z. UV-mediated genotoxicity of furanoquinoline and of certain tryptophan-derived alkaloids. *J. Nat. Prod.* **1983**, *46*, 576–581.

(40) Pfyffer, G. E.; Towers, G. H. N. Photochemical interaction of dictamnine, a furoquinoline alkaloid, with fungal DNA in vitro and in vivo. *Can. J. Microbiol.* **1982**, *28*, 468–473.