




Review

Insecticidal Triterpenes in Meliaceae: Plant Species, Molecules, and Activities: Part II (*Cipadessa*, *Melia*)

Meihong Lin [†], Xiaoyang Bi [†], Lijuan Zhou ^{*†}  and Jiguang Huang ^{*}

Key Laboratory of Natural Pesticides and Chemical Biology, Ministry of Education, South China Agricultural University, Guangzhou 510642, China; 24628@nopusosion.com (M.L.); xiaoyangbi@stu.scau.edu.cn (X.B.)

^{*} Correspondence: zhoulj@scau.edu.cn (L.Z.); hnnyzx@scau.edu.cn (J.H.)

[†] These authors contributed equally to this work.

Abstract: Plant-originated triterpenes are important insecticidal molecules. Research on the insecticidal activity of molecules from Meliaceae plants has always been a hotspot due to the molecules from this family showing a variety of insecticidal activities with diverse mechanisms of action. In this paper, we discussed 116 triterpenoid molecules with insecticidal activity from 22 plant species of five genera (*Cipadessa*, *Entandrophragma*, *Guarea*, *Khaya*, and *Melia*) in Meliaceae. In these genera, the insecticidal activities of plants from *Entandrophragma* and *Melia* have attracted substantial research attention in recent years. Specifically, the insecticidal activities of plants from *Melia* have been systematically studied for several decades. In total, the 116 insecticidal chemicals consisted of 34 ring-intact limonoids, 31 ring-seco limonoids, 48 rearranged limonoids, and 3 tetracyclic triterpenes. Furthermore, the 34 ring-intact limonoids included 29 trichilin-class chemicals, 3 azadirone-class chemicals, and 1 cedrelone-class and 1 havanensin-class limonoid. The 31 ring-seco limonoids consisted of 16 C-seco group chemicals, 8 B,D-seco group chemicals, 4 A,B-seco group chemicals, and 3 D-seco group chemicals. Furthermore, among the 48 rearranged limonoids, 46 were 2,30-linkage group chemicals and 2 were 10,11-linkage group chemicals. Specifically, the 46 chemicals belonging to the 2,30-linkage group could be subdivided into 24 mexicanolide-class chemicals and 22 phragmalin-class chemicals. Additionally, the three tetracyclic triterpenes were three protolimonoids. To sum up, 80 chemicals isolated from 19 plant species exhibited antifeedant activity toward 14 insect species; 18 chemicals isolated from 17 plant species exhibited poisonous activity toward 10 insect species; 16 chemicals isolated from 11 plant species possessed growth-regulatory activity toward 8 insect species. In particular, toosendanin was the most effective antifeedant and insect growth-regulatory agent. The antifeedant activity of toosendanin was significant. Owing to its high effect, toosendanin has been commercially applied. Three other molecules, 1,3-dicinnamoyl-11-hydroxymeliacarpin, 1-cinnamoyl-3-methacryl-11-hydroxymeliacarpin, and 1-cinnamoyl-3-acetyl-11-hydroxymeliacarpin, isolated from *Melia azedarach*, exhibited a highly poisonous effect on *Spodoptera littoralis*; thus, they deserve further attention.

Keywords: Meliaceae; triterpenoid molecules; insecticidal activities



Citation: Lin, M.; Bi, X.; Zhou, L.; Huang, J. Insecticidal Triterpenes in Meliaceae: Plant Species, Molecules, and Activities: Part II (*Cipadessa*, *Melia*). *Int. J. Mol. Sci.* **2022**, *23*, 5329. <https://doi.org/10.3390/ijms23105329>

Academic Editor:
Massimiliano Tattini

Received: 16 March 2022

Accepted: 7 May 2022

Published: 10 May 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Currently, chemical insecticides are still undoubtedly the most useful method to control insect pests. However, it is also clear that the residue of certain insecticides could lead to some possible negative impacts on human health, food safety, and the ecological environment. Therefore, the agrochemical industry is continuously searching for new insecticides. Natural products are valuable resources due to the vast biodiversity of plants and microbes. Plant-derived insecticidal molecules are secondary metabolites in plants. Generally, these secondary metabolites cause less environment pollution and are safer to natural enemies. Due to their structural diversity and biological characteristics, plant-derived natural products have received significant attention as lead compounds. Therefore,

the application of these natural plant products as alternatives to synthetic insecticides has attracted more attention in recent years [1–4].

Triterpenes, as the main bioactive chemical compounds in Meliaceae plants, have attracted significant attention owing to their exclusive structural characteristics and remarkable biological activity. Due to their multiple bioactivities, the Meliaceae plants have been used as folk herbs in treating leprosy, eczema, asthma, malaria, fever, and pain. To date, diverse insecticidal molecules have been isolated from Meliaceae plants. A great many studies have revealed that, in these plants, triterpenoids were the active molecules [5,6]. Triterpenes are terpenoids derived from squalene, usually composed of 30 carbon atoms. The structural classification of triterpenoids is mainly grouped into six groups, including linear triterpenes, simple cyclic triterpenes (monocyclic triterpenes, bicyclic triterpenes, and tricyclic triterpenes), tetracyclic triterpenes, pentacyclic triterpenes, nortriterpenes, and triterpenoid saponins (Figure 1) [7].

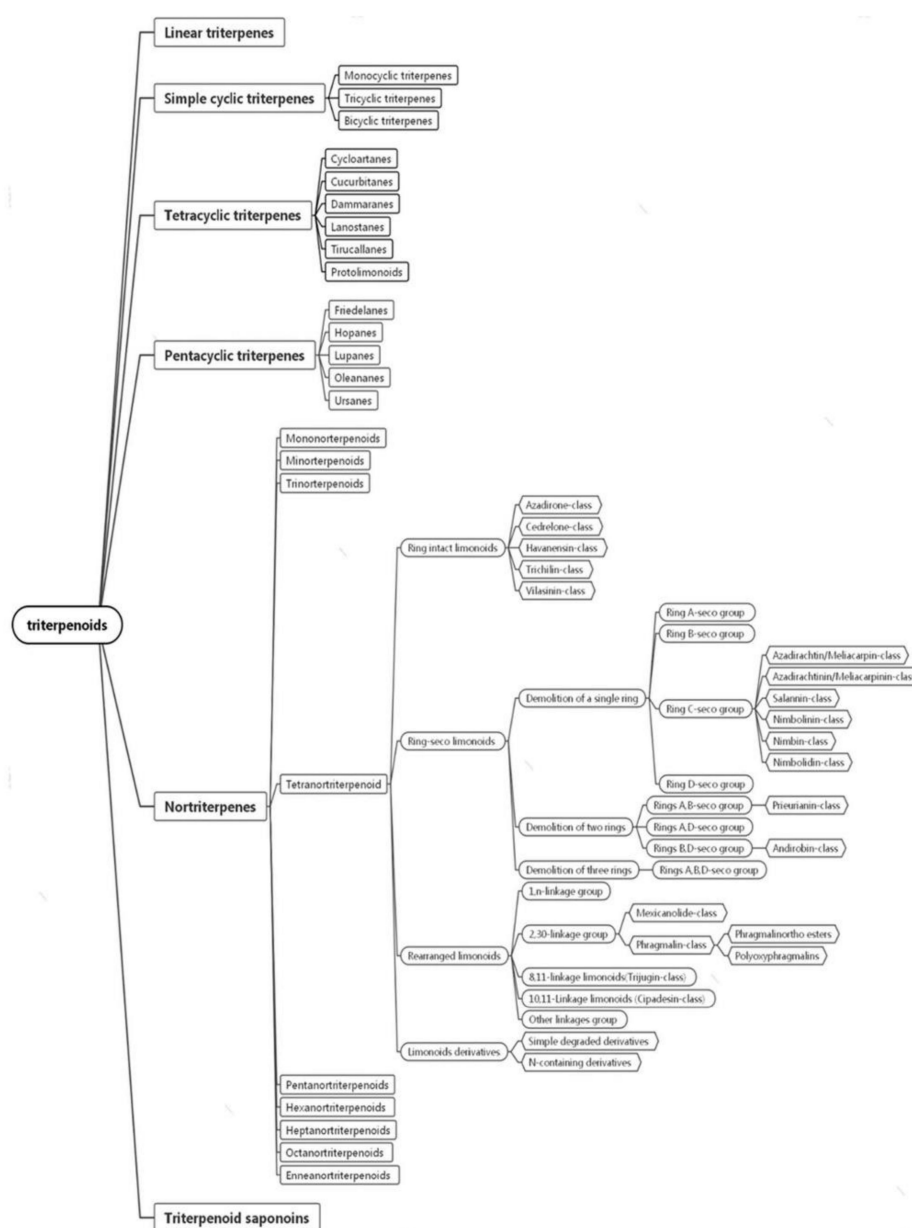


Figure 1. The main structural categories of triterpenes.

This review, as a continuation of our first review (“insecticidal triterpenes in Meliaceae: plant species, molecules, and activities of eight genera (*Aglaia*, *Aphanamixis*, *Azadirachta*, *Cabralea*, *Carapa*, *Cedrela*, *Chisocheton*, and *Chukrasia*) in Meliaceae” [7]), covers naturally occurring insecticidal triterpenoids from five genera (*Cipadessa*, *Entandrophragma*, *Guarea*, *Khaya*, and *Melia*) in Meliaceae. Herein, we summarize the insecticidal plant species, insecticidal phytochemicals and their structures, various insecticidal activities, the structure–activity relationship (SAR), the insecticidal mechanism of action, and the environmental toxicity of the active insecticidal chemicals, hoping to offer some constructive information for the exploration of these chemicals as the lead compounds of novel insecticides. Furthermore, the future research perspectives are discussed.

2. Plant Species and Their Insecticidal Chemicals

In total, 22 insecticidal plant species (*Cipadessa baccifera* (Roth) Miq., *Cipadessa cinerascens* (Pell.) Hand-Mazz, *Entandrophragma angolense* C. DC., *Entandrophragma bussei* Harms ex Engl., *Entandrophragma caudatum* Sprague, *Entandrophragma candolei* (Harms), *Entandrophragma delevoyi* (de Wild), *Entandrophragma cylindricum* (Sprague) Sprague, *Entandrophragma spicatum* (C. DC.) Sprague, *Entandrophragma macrophyllum* A. Chev., *Guarea guidonia* A. Juss, *Guarea grandiflora* ADC, *Guarea thompsonii* Sprague et Hutch., *Guarea kunthiana* A. Juss, *Khaya anthotheca* (Welv.) C. DC., *Khaya senegalensis* (Desr.) A. Juss., *Khaya grandifoliola* C. DC., *Khaya ivorensis* A. Chev., *Melia azedarach* L., *Melia toosendan* Sieb. et Zucc., *Melia dubia* Cav., and *Melia volkensii* Gurke) from five genera (*Cipadessa*, *Entandrophragma*, *Guarea*, *Khaya*, and *Melia*) in Meliaceae were reported to show insecticidal activities (Table 1 and Figure 2). In these genera, the insecticidal activities of plants from *Entandrophragma* and *Melia* have attracted considerable research attention in recent years. Specifically, the insecticidal activities of plants from *Melia* have been systemically studied for several decades [8–30].



Cipadessa baccifera (Roth) Miq.



Cipadessa cinerascens (Pell.)
Hand-Mazz



Entandrophragma angolense C. DC



Entandrophragma bussei Harms
ex Engl.



Entandrophragma caudatum Sprague



Entandrophragma candolei (Harms)



Entandrophragma delevoyi
(de Wild)



Entandrophragma cylindricum (Sprague)
Sprague



Entandrophragma spicatum (C. DC.)
Sprague

Figure 2. Cont.



Entandrophragma macrophyllum
A.Chev.



Guarea guidonia (L.) Sleumer



Guarea grandiflora ADC



Guarea thompsonii Sprague et Hutch.



Guarea kunthiana A. Juss



Khaya anotheca (Welv.) C. DC



Khaya senegalensis (Desr.) A. Juss.



Khaya grandifoliola C. DC



Khaya ivorensis A. Chev.



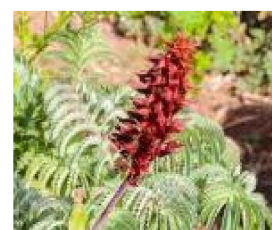
Melia azedarach L.



Melia toosendan Sieb. et Zucc.



Melia dubia Cav.



Melia volkensii Gurke

Figure 2. The 22 insecticidal plant species from genera *Cipadessa*, *Entandrophragma*, *Guarea*, *Khaya*, and *Melia* in Meliaceae.

In all, from the aforementioned 22 plant species, 116 insecticidal chemicals were reported to be active toward 30 insect species (*Aedes aegypti* (L.), *Aphis citricidis* Kirkaldy, *Atta sexdens rubropilosa* Forel, *Brontispa longissima* (Gestro), *Callosobruchus maculatus* (Fabricius), *Cryptolestes ferrugineus* (Stephens), *Culex annulirostris* (Skuse), *Drosophila melanogaster* Meigen, *Epilachna paenulata* Germar, *Helicoverpa armigera* (Hübner), *Leptinotarsa decemlineata* (Say), *Leucania compta* Moore, *Myzus persicae* Sulzer, *Ostrinia furnacalis* Guenee, *Ostrinia nubilalis* (Hübner), *Peridroma saucia* (Hübner), *Pieris brassicae* (L.), *Pieris rapae* L., *Plutella xylostella* (L.), *Reticulitermes speratus* Kollbe, *Rhipicephalus microplus* Canestrini, *Sitophilus oryzae* L., *Spodoptera abyssinia* Guenee, *Spodoptera eridania* Cramer, *Spodoptera exigua* (Hübner), *Spodoptera frugiperda* (J. E. Smith), *Spodoptera littoralis* (Boisduval), *Spodoptera litura* (F.), *Toxoptera aurantia* (Boyer) and *Trichoplusia ni* (Hübner)). Taken together, the antifeedant activity of these plant-derived chemicals was the main studied activity [5,11,24,29,31–46]. However, the poisonous activity [5,20,25,26,41,47–53] and the growth-regulatory activity [18,21,23,26,32,43,50,54–56] have also been studied.

Table 1. The 22 insecticidal plant species of five genera in Meliaceae.

Family	Genus	Species
Meliaceae	<i>Cipadessa</i>	<i>Cipadessa baccifera</i> (Roth) Miq. <i>Cipadessa cinerascens</i> (Pell.) Hand-Mazz
	<i>Entandrophragma</i>	<i>Entandrophragma angolense</i> C. DC <i>Entandrophragma bussei</i> Harms ex Engl. <i>Entandrophragma caudatum</i> Sprague <i>Entandrophragma candolei</i> (Harms) <i>Entandrophragma delevoiyi</i> (de Wild) <i>Entandrophragma cylindricum</i> (Sprague) Sprague <i>Entandrophragma spicatum</i> (C.DC.) Sprague <i>Entandrophragma macrophyllum</i> A. Chev.
	<i>Guarea</i>	<i>Guarea guidonia</i> (L.) Sleumer <i>Guarea grandiflora</i> ADC <i>Guarea thompsonii</i> Sprague et Hutch. <i>Guarea kunthiana</i> A. Juss
	<i>Khaya</i>	<i>Khaya anthotheca</i> (Welv.) C. DC <i>Khaya senegalensis</i> (Desr.) A. Juss. <i>Khaya grandifoliola</i> C. DC <i>Khaya ivorensis</i> A. Chev.
	<i>Melia</i>	<i>Melia azedarach</i> L. <i>Melia toosendan</i> Sieb. Et Zucc. <i>Melia dubia</i> Cav. <i>Melia volkensii</i> Gurke

In summary, 80 chemicals isolated from 19 plant species (*C. baccifera*, *C. cinerascens*, *C. fruticosa*, *E. angolense*, *E. bussei*, *E. caudatum*, *E. cylindricum*, *E. delevoiyi*, *E. macrophyllum*, *E. spicatum*, *G. grandiflora*, *G. thompsonii*, *K. anthotheca*, *K. grandifoliola*, *K. ivorensis*, *K. senegalensis*, *M. azedarach*, *M. toosendan*, and *M. volkensii*) in Meliaceae exhibited antifeedant activity toward 14 insect species (*D. melanogaster*, *E. paenulata*, *H. armigera*, *L. decemlineata*, *O. nubilalis*, *P. saucia*, *P. rapae*, *R. speratus*, *S. Abyssinia*, *S. eridania*, *Spodoptera exigua*, *S. frugiperda*, *S. littoralis*, and *S. litura*) (Table 2) [5,11,24,29,31–46]. Among these chemicals, the antifeedant activity of toosendanin was significant. It was reported that 0.01% toosendanin could have a 100% antifeedant effect on *S. litura*. This molecule was also effective on many other insects such as *P. rapae* and *H. armigera*. Owing to its high effect, toosendanin has been commercially applied [32,37,39,44,57,58].

Overall, 18 chemicals isolated from 17 plant species (*C. guianensis*, *C. baccifera*, *C. cinerascens*, *C. fruticosa*, *E. angolense*, *E. delevoiyi*, *E. macrophyllum*, *G. grandiflora*, *G. guidonia*, *G. kunthiana*, *G. thompsonii*, *K. anthotheca*, *K. grandifoliola*, *K. ivorensis*, *K. senegalensis*, *M. azedarach*, and *M. toosendan*) in Meliaceae exhibited poisonous activity toward 10 insect species (*A. aegypti*, *A. sexdens rubropilosa*, *C. ferrugineus*, *M. persicae*, *O. furnacalis*, *P. xylostella*, *R. speratus*, *S. oryzae*, *S. frugiperda*, and *S. littoralis*) (Table 3) [5,20,25,26,41,47–53]. Among them, 1,3-dicinnamoyl-11-hydroxymeliacarpin, 1-cinnamoyl-3-methacryl-11-hydroxymeliacarpin, and 1-cinnamoyl-3-acetyl-11-hydroxymeliacarpin, isolated from *M. azedarach*, were high effective on the African cotton leafworm, *S. littoralis*, with LC₅₀ values (12 days) of 2.36, 1.19, and 0.48 µg/mL, respectively [52].

Furthermore, 16 chemicals isolated from 11 plant species (*C. guianensis*, *C. baccifera*, *C. cinerascens*, *C. fruticosa*, *E. candolei*, *G. grandiflora*, *G. guidonia*, *G. kunthiana*, *K. senegalensis*, *M. azedarach*, and *M. toosendan*) in Meliaceae possessed insect growth-regulatory activity toward eight insect species (*B. longissima*, *H. armigera*, *O. furnacalis*, *O. nubilalis*, *P. saucia*, *R. microplus*, *S. frugiperda*, and *S. littoralis*) (Table 4) [18,21,23,26,32,43,50,54–56]. Among these chemicals, toosendanin was the most effective insect growth-regulatory agent, showing good activity toward *P. saucia*, *O. furnacalis*, *S. frugiperda*, etc. [20,23,55].

Below, we review the insecticidal plant species, the corresponding insecticidal chemicals, and their activities in detail.

2.1. *Cipadessa*

In the genus *Cipadessa*, two species, *C. baccifera* and *C. cinerascens*, have been reported to show insecticidal activities. Additionally, limonoids isolated from the leaves of *C. baccifera* showed moderate antimalarial activity [8,9].

The acetone extract of *C. baccifera* inhibited the freshly laid eggs of the mosquito *C. quinquefasciatus*. The acetone extract of the leaf of *C. baccifera* showed smoking toxicity toward mosquitoes *A. stephensi*, *A. aegypti*, and *C. quinquefasciatus* [59,60]. The hexane and dichloromethane extracts from the fruits of *C. baccifera* showed toxicity toward the leaf-cutting ant, *A. sexdens rubropilosa* [61]. Likewise, the hexane extract from the leaves of *C. baccifera* showed insecticidal activity toward the cotton bollworm, *H. armigera*. Further studies revealed that the petroleum ether extract reduced the pupation rate and pupal weight and caused a higher percentage of malformed adults. However, the hexane extract reduced the fecundity and egg hatchability in the first-generation adults [62].

A total of 12 mexicanolide limonoids and four tetranortriterpenoids were reported to show insecticidal activities. In detail, the 12 mexicanolide limonoids were cipadesin, cipadesin A, 2'S-cipadesin A, febrifugin, febrifugin A, 3-O-detigloyl-3-O-isobutyrylfebrifugin A, ruageanin A, khayasin, khayasin T, granatumin E, swietemahonolide, and mexicanolide. The four tetranortriterpenoids were two ring B,D-seco limonoids (cipadonoid B and cineracipadesin G) and two 10,11-linkage limonoids (cipadesin B and 3-deacetyl-cipadonoid D) [42,63–67].

2.1.1. Mexicanolide Limonoids

In this group, 12 chemicals were reported to show insecticidal activity: cipadesin, cipadesin A, 2'S-cipadesin A, febrifugin, febrifugin A, 3-O-detigloyl-3-O-isobutyrylfebrifugin A, ruageanin A, khayasin, khayasin T, granatumin E, swietemahonolide, and mexicanolide [47,63,67–70].

Febrifugin A, khayasin T, cipadesin, febrifugin, ruageanin A, and cipadesin A showed poisonous activity toward the fall armyworm, *S. frugiperda*. At 50 mg/kg, the total cycle mortalities of febrifugin A and khayasin T toward the fall armyworm were 73.3% and 50%, respectively. However, the total cycle mortalities of the other four chemicals toward the fall armyworm were less than 40%. Febrifugin, khayasin T, cipadesin, and cipadesin A also showed growth-inhibitory activity toward the fall armyworm. At 50 mg/kg, febrifugin and khayasin T shortened larval phases by 1.8 and 1.2 days, respectively. At 100 mg/kg, cipadesin A and cipadesin shortened the larval phases by 2.1 and 0.8 days, respectively. Meanwhile, febrifugin also showed antifeedant activity toward the fall armyworm at 100 mg/kg [43,47,51,61,63,70,71].

Khayasin T, cipadesin, febrifugin, ruageanin A, and cipadesin A, together with two other chemicals (swietemahonolide and mexicanolide), also showed poisonous activity toward the leaf-cutting ant, *A. sexdens rubropilosa*. The median survival (S_{50}) value varied from 6–9 days [42,51].

Additionally, khayasin exhibited marked insecticidal activity toward the fifth larvae of coconut leaf beetle, *B. longissimi*, with an LC_{50} value of 7.28 $\mu\text{g/mL}$ at 24 h [53].

2.1.2. Rings B,D-Seco Limonoids

In this group, two andirobin-type chemicals, cipadonoid B and cineracipadesin G, were reported to show insecticidal activity.

Cineracipadesin G showed antifeedant activity toward the fruit fly, *D. melanogaster*. The antifeedant index was 32.8% at 1 mM after 17 h [42]. An in vitro assay at the insect nicotinic acetylcholine receptor (nAChR) was performed for cipadonoid B, and the pI_{50} value was found to be 4.2, showing that this chemical was a weak antagonist of the insect nAChR [47,72].

2.1.3. 10,11-Linkage Limonoids

In this group, two chemicals, cipadesin B and 3-deacetyl-cipadonoid D, were reported to show insecticidal activity. In detail, 3-deacetyl-cipadonoid D showed antifeedant activity toward the fruit fly, *D. melanogaster*, at 1 mM, and the antifeedant index was 39.1% after 17 h [42]. Cipadesin B was reported to show poisonous activity toward the leaf-cutting ant, *A. sexdens rubropilosa*, with a median survival (S_{50}) value of 9 days [51].

2.2. Entandrophragma

The genus *Entandrophragma* comprises 10–12 tree species distributed exclusively in tropical Africa. In this genus, eight species, *E. angolense*, *E. bussei*, *E. caudatum*, *E. candolei*, *E. delevoiyi*, *E. cylindricum*, *E. spicatum*, and *E. macrophyllum*, have been reported to show insecticidal activities [10–16].

In total, 16 tetranortriterpenoids were reported to show insecticidal activities. In detail, there were eight ring-seco limonoids, seven rearranged limonoids, and one ring-intact limonoid (azadirone). Furthermore, the eight ring-seco limonoids consisted of four rings A,B-seco group limonoids (prieurianin, epoxy-prieurianin, prieurianin acetate, and epoxy-prieurianin acetate) [32], two rings B,D-seco group limonoids (6-acetoxymethyl angolensate and methyl angolensate), one ring D-seco chemical (secomahoganin), and one ring D-seco chemical (gedunin). The seven rearranged limonoids were all 2,30-linkage group limonoids and could be further divided into two groups consisting of five mexicanolide-type limonoids (angolensin A, angolensin B, angolensin C, 3 β -hydroxy-3-deoxycarapin, and xylocensin K) and two phragmalin-type limonoids (entandrophragmin and bussein) [5,15,31,32,73–75].

2.2.1. Ring-Secco Limonoids

In this group, eight chemicals were reported to show insecticidal activity: epoxy-prieurianin, prieurianin acetate, epoxy-prieurianin acetate, prieurianin, 6-acetoxymethyl angolensate, methyl angolensate, secomahoganin, and gedunin.

Rings A,B-seco group limonoids: prieurianin-type limonoids, prieurianin, epoxy-prieurianin, and their acetyl derivatives, could inhibit the larval growth of the cotton bollworm, *H. armigera*. The EC_{50} values (7 days) of prieurianin and epoxy-prieurianin were 18.8 and 3.2 $\mu\text{g/mL}$, respectively. In addition, the EC_{50} values (7 days) of prieurianin acetate and epoxy-prieurianin acetate were 11.5 and 2.6 $\mu\text{g/mL}$, respectively [32,76].

Rings B,D-seco group limonoids: the two rings B,D-seco group limonoids, 6-acetoxymethyl angolensate and methyl angolensate, could be further classified as andirobin-class limonoids. The minimum antifeedant concentration (MAC) of 6-acetoxymethyl angolensate against the African cotton leafworm, *S. littoralis*, was 500 $\mu\text{g/mL}$ [46]. Methyl angolensate showed antifeedant activity toward the tobacco cutworm, *S. litura*. At 1 $\mu\text{g/cm}^2$, the PFI (percentage feeding index) value of methyl angolensate was 65.3 (24 h) [46].

Ring D-seco chemical: gedunin possessed various activities toward insects. It showed antifeedant activity toward the lower subterranean termite, *R. speratus*, with a PC_{95} value of 218.4 $\mu\text{g/disc}$ after 30 days [77]. Gedunin also showed poisonous activity toward the fall armyworm, *S. frugiperda*, and growth-inhibitory activity toward the cotton bollworm, *H. armigera* [77,78]. In our previous review, we summarized its activity. Therefore, further information can be obtained from the review by Lin (2021) [7]. Additionally, secomahoganin showed antifeedant activity toward the African cotton leafworm, *S. littoralis*, at 1000 $\mu\text{g/mL}$ [31].

2.2.2. Rearranged Limonoids

In this group, seven chemicals were reported to show insecticidal activity; five of them were mexicanolide-type limonoids (angolensin A, angolensin B, angolensin C, 3 β -hydroxy-3-deoxycarapin, and xylocensin K), while two of them were phragmalin-type limonoids (entandrophragmin and bussein).

Mexicanolide-type limonoids: angolensins A–C, 3 β -hydroxy-3-deoxycarapin, and xylocensin K showed antifeedant activity toward the African cotton leafworm, *S. littoralis*. Among them, angolensins A and B showed activity at 500 $\mu\text{g}/\text{mL}$, while the others were active at 1000 $\mu\text{g}/\text{mL}$ [31].

Phragmalin-class limonoids: Entandrophragmin and bussein showed feeding inhibition activity toward the European corn borer, *O. nubilalis*, at 500 $\mu\text{g}/\text{mL}$ after 48 h [46].

2.2.3. Ring-Intact Limonoid

Presently, in this group, only one azadirone-class chemical, azadirone, has been isolated from the genus *Entandrophragma*. This chemical showed antifeedant activity toward the Colorado potato beetle, *L. decemlineata*, with AIs (antifeedant indices) values of 11.6 ± 6.3 , 22.4 ± 7.4 , and 26.9 ± 5.1 at 100, 300, and 500 $\mu\text{g}/\text{mL}$ (starved for 6 h and fed for 20 h) [5].

2.3. Guarea

In the genus *Guarea*, four species, *G. guidonia*, *G. grandiflora*, *G. thompsonii*, and *G. kunthiana*, have been reported to show insecticidal activities [17–21,79,80].

From these species, three tetracyclic triterpenes and five tetranortriterpenoids (three ring D-seco limonoids, one rings A,B-seco limonoid, and one rings B,D-seco limonoid) have been isolated. In detail, the three tetracyclic triterpenes included three protolimonoids (melianone, melianodiol, and 3 β -O-tigloylmelianol). The five tetranortriterpenoids included three ring D-seco limonoids (gedunin, 7-deacetoxy-7-oxogedunin, and 6 α -acetoxygedunin) [18], one rings A,B-seco limonoid (prieurianin-type chemical prieurianin) [17], and one rings B,D-seco limonoid (andirobin-class chemical methyl angolensate) [19–21,81].

Protolimonoid melianone showed poisonous and antifeedant activities toward the lower subterranean termite, *R. speratus*, at 100 $\mu\text{g}/\text{disc}$ after 30 days. The mortality of *R. speratus* at 30 days was 95% [41]. Melianodiol showed poisonous activity toward the larvae of the mosquito *A. aegypti*. The LC_{50} value was 14.44 mg/mL and the LC_{90} value was 17.54 mg/mL after 24 h. According to the results, melianodiol could be regarded as a potential candidate for use as an ecologically sound biocontrol agent for reducing the larval population of this vector [20]. The other chemical, 3 β -O-tigloylmelianol, was effective against the oogenesis and ecdysis of *R. (Boophilus) microplus* at concentrations of 0.01%, 0.005%, 0.0025%, and 0.00125%. After 48 h, the sexual gland index (GSI) decreased by 50% at all three concentrations [21].

At 100 $\mu\text{g}/\text{mL}$, the S_{50} values of ring D-seco type chemical 7-deacetoxy-7-oxogedunin was 9 days. It also prolonged the *S. frugiperda* larval phase by approximately 1.2 days at 50.0 $\text{mg}\cdot\text{kg}^{-1}$ [25,82]. Moreover, 6 α -acetoxygedunin reduced the growth of the European corn borer, *O. nubilalis*, at 50 $\mu\text{g}/\text{mL}$ after 20 days [18].

2.4. Khaya

A variety of studies have been carried out on the genus *Khaya*. In this genus, four species, *K. anthotheca*, *K. senegalensis*, *K. grandifoliola*, and *K. ivorensis*, have been reported to show insecticidal activities [22–26,83].

According to these reports, the ethanol extract of the stem bark of *K. ivorensis* had termiticidal activity [84]. The ethanol extracts of *K. grandifoliola* and *K. senegalensis* had ovicidal properties and larvicidal properties against the first-instar larvae of *C. maculatus* [85]. Moreover, the seed oil of *K. senegalensis* showed high potential for the control of the cowpea beetle, *C. maculatus* [86]. Further research revealed that the acetone, ethanol, hexane, and methanol extracts of *K. senegalensis* also showed insecticidal activity toward the mosquito *C. annulirostris* [87]. In addition, *K. senegalensis* gum could be employed as an emulsifying agent in the formulation industry [88].

From the abovementioned plants, a total of 13 rearranged limonoids, 7 ring-seco limonoids, and 2 ring-intact limonoids were reported to show insecticidal activities. In detail, all 13 rearranged limonoids (kxayanolide A, kxayanolide B, kxayanolide C, kxayanolide D, kxayanolide

E, 1-*O*-acetylkhayanolide A, 1-*O*-acetylkhayanoilde B, 2-hydroxyseneganolide, khayalactol, khayanone, 6-*O*-acetylswietenolide, swietenolide, and seneganolide) were 2,30-linkage type chemicals [33,34,54]. The seven ring-seco limonoids belonged to two subgroups, namely, ring D-seco chemicals (gedunin, 7-deacetylgedunin, and 7-deacetoxy-7-oxogedunin) and rings B,D-seco chemicals (khayanoside, methyl 6-hydroxyangolensate, methyl 6-acetoxyangolensate, and methyl angolensate). Additionally, the two ring-intact limonoids included one cedrelone-type limonoid (anthothecol) and one azadirone-class chemical (azadirone) [33,34,89–96].

2.4.1. Rearranged Limonoids: 2,30-Linkage Type Chemicals

In this group, 13 chemicals were reported to show insecticidal activity: khayanolide A, khayanolide B, khayanolide C, khayanolide D, khayanolide E, 1-*O*-acetylkhayanolide A, 1-*O*-acetylkhayanoilde B, 2-hydroxyseneganolide, khayalactol, khayanone, 6-*O*-acetylswietenolide, swietenolide, and seneganolid.

Among these chemicals, khayanolides A–D, 1-*O*-acetylkhayanolide A, 2-hydroxyseneganolide, and 1-*O*-acetylkhayanoilde B showed antifeedant activity toward the African cotton leafworm, *S. littoralis*. By the leaf disc method, they were active at 300, 1000, 100, 100, 200, 300, and 500 µg/mL with antifeeding activities of 21.7%, 24.8%, 57.1%, 31.4%, 38.4%, 17.3%, and 31.5%, respectively, after 6 h. In contrast, khayanolide E showed antifeedant activity toward the African cotton leafworm, *S. littoralis*, at 100 µg/mL [33,34,54]. In addition, khayanone, khayalactol, and seneganolide showed antifeeding potential with activities of 47.4%, 83.8%, and 48.0%, respectively, at 1000 µg/mL against *S. littoralis* after 6 h [34]. Studies also revealed that swietenolide and 6-*O*-acetylswietenolide possessed antifeedant activity toward *S. littoralis*. The AIs (antifeedant indices) were 94.10 ± 2.90 and 72.20 ± 19.60 at 1000 µg/mL [35]. In addition, khayanolide A, khayanolide B, 1-*O*-acetylkhayanoilde B, and khayalactol also showed growth-regulatory activity toward *S. littoralis* with EC_{50} (7 days) values of 14.65, 6.96, 16.75, and 11.48 mg/kg, respectively [54].

2.4.2. Ring-Seco Limonoids

In this group, seven chemicals were reported to show insecticidal activity. Among these chemicals, three belonged to the ring D-seco group: gedunin, 7-deacetylgedunin and 7-deacetoxy-7-oxogedunin. The other four belonged to the rings B,D-seco group: khayanoside, methyl 6-hydroxyangolensate, methyl 6-acetoxyangolensate, and methyl angolensate.

The insecticidal activity of the ring D-seco group could be found in several studies [5,25,50,77,78,82,97–99]. These chemicals possessed more than one type of activity, and the activities were obvious. For example, gedunin showed antifeedant activity toward the lower subterranean termite, *R. speratus* (PC_{95} , 113.7 µg/disc), and growth-inhibitory activity toward the cotton bollworm, *H. armigera* (EC_{50} , 50.8 µg/mL), and the tobacco cutworm, *S. litura* (EC_{50} , 40.4 µg/mL) [77,78]. The other two chemicals, 7-deacetylgedunin and 7-deacetoxy-7-oxogedunin, possessed insecticidal activity toward the leaf-cutting ant, *A. sexdens rubropilosa*. At 100 µg/mL, the S_{50} values of these chemicals on *A. sexdens rubropilosa* were 9 days and 11 days, respectively [24,25,82]. Further information can be obtained from the review paper by Lin [7].

Among the four rings B,D-seco group chemicals, three (methyl angolensate, methyl 6-hydroxyangolensate, and methyl 6-acetoxyangolensate) were andirobin-class chemicals. Methyl angolensate showed antifeedant and poisonous activity toward insects. It was effective at 1 µg/cm² toward the tobacco cutworm, *S. litura*, with a PFI (percentage feeding index) value (24 h) of 65.3 [40,91,97,100–102]. Additionally, this chemical also showed poisonous activity at 50 mg/kg toward the larva of the fall armyworm, *S. frugiperda*, with a mortality rate of 40% after 7 days [50,103]. Methyl 6-acetoxyangolensate and methyl 6-hydroxyangolensate showed antifeedant activity toward the African cotton leafworm, *S. littoralis*, at 500 µg/mL using the leaf disc method after 6 h. The antifeeding activities were 23.6% and 18.0%, respectively. In contrast, khayanoside showed weaker antifeedant activity toward *S. littoralis* than methyl 6-acetoxyangolensate and methyl 6-

hydroxyangolensate, and it was active at a higher concentration (1000 µg/mL) using the leaf disc method after 6 h, with an antifeeding activity of 15.1% [34].

2.4.3. Ring-Intact Limonoids: Anthothecol and Azadirone

The two chemicals of this group, anthothecol and azadirone, can be further classified into two subgroups. Anthothecol is a cedrelone-type limonoid, while azadirone is an azadirone-class chemical.

The cedrelone-type limonoid anthothecol showed larvicidal activity toward the diamondback moth, *P. xylostella*. At 1 mg/mL, the mortality was 80% after 48 h [48]. At the same concentration, anthothecol also induced 60% mortality of the green peach aphid, *M. persicae*, after 48 h [48].

The azadirone-class chemical azadirone showed antifeedant activity toward the Colorado potato beetle, *L. decemlineata*, with an antifeedant index of 11.6 ± 6.3 (100 µg/mL) (starved for 6 h and fed for 20 h) [5].

2.5. Melia

In the genus *Melia*, four species, *M. azedarach*, *M. toosendan*, *M. dubia*, and *M. volkensii*, have been reported to show insecticidal activities [27–30,44,87,95,104–165].

Table 2. Antifeedant activity of insecticidal triterpenoids of plants from five genera in Meliaceae.

Compound	Plant Source	Insect	Activity	Ref.
cineracipadesin G	<i>Cipadessa cinerascens</i>	<i>Drosophila melanogaster</i>	AI = 32.8% (1 mM)	[42]
febrifugin	<i>Cipadessa fruticosa</i>	<i>Spodoptera frugiperda</i>	AFD at 100 mg/kg	[43]
	<i>Cipadessa baccifera</i>			
3-deacetyl-cipadonoid D	<i>Cipadessa cinerascens</i>	<i>Drosophila melanogaster</i>	AI = 39.1% (1 mM) (17 h)	[42]
	<i>Entandrophragma angolense</i>	<i>Spodoptera littoralis</i>	AFD at 500 µg/mL	[31]
angolensin A	<i>Entandrophragma angolense</i>	<i>Spodoptera littoralis</i>	AFD at 500 µg/mL	[31]
angolensin B	<i>Entandrophragma angolense</i>	<i>Spodoptera littoralis</i>	AFD at 1000 µg/mL	[31]
angolensin C	<i>Entandrophragma angolense</i>	<i>Spodoptera littoralis</i>	AFD at 1000 µg/mL	[31]
3β-hydroxy-3-deoxy-carapin	<i>Entandrophragma angolense</i>	<i>Spodoptera littoralis</i>	AFD at 1000 µg/mL	[31]
xyloccensin K	<i>Entandrophragma angolense</i>	<i>Spodoptera littoralis</i>	AFD at 1000 µg/mL	[31]
entandrophragmin	<i>Entandrophragma cylindricum</i>	<i>Ostrinia nubilalis</i>	FI at 500 µg/mL (48 h)	[11,46,131,132]
	<i>Entandrophragma bussei</i>			
	<i>Entandrophragma spicatum</i>			
	<i>Entandrophragma caudatum</i>			
bussein	<i>Entandrophragma bussei</i>	<i>Ostrinia nubilalis</i>	FI at 500 µg/mL (48 h)	[11,46]
	<i>Entandrophragma caudatum</i>			
6-acetoxymethyl angolensate	<i>Entandrophragma angolense</i>	<i>Spodoptera littoralis</i>	MAC = 500 µg/mL	[11]
	<i>Entandrophragma angolense</i>			
	<i>Entandrophragma macrophyllum</i>			
methyl angolensate	<i>Guarea thompsonii</i>	<i>Spodoptera litura</i>	PFI = 65.3 (24 h)	[40]
	<i>Khaya anthotheca</i>			
	<i>Khaya senegalensis</i>			
	<i>Khaya grandifoliola</i>			
secomahoganin	<i>Entandrophragma angolense</i>	<i>Spodoptera littoralis</i>	AFD at 1000 µg/mL	[31]
	<i>Entandrophragma delevoyi</i>			
azadirone	<i>Khaya anthotheca</i>	<i>Leptinotarsa decemlineata</i>	AI = 11.6–26.9 at 100–500 µg/mL (20 h)	[5]
	<i>Entandrophragma angolense</i>			
	<i>Entandrophragma delevoyi</i>			
gedunin	<i>Entandrophragma macrophyllum</i>	<i>Reticulitermes speratus</i>	PC ₉₅ = 218.4 µg/disc (30 days)	[5,77,78]
	<i>Guarea grandiflora</i>			
	<i>Khaya grandifoliola</i>			
melianone	<i>Guarea grandiflora</i>	<i>Reticulitermes speratus</i>	antifeeding activity at 100 µg/disc (30 days)	[41]

Table 2. Cont.

Compound	Plant Source	Insect	Activity	Ref.
khayanolide D	<i>Khaya senegalensis</i>	<i>Spodoptera littoralis</i>	AI = 57.1 at 100 µg/mL (6 h)	[34]
khayanolide E	<i>Khaya senegalensis</i>	<i>Spodoptera littoralis</i>	MIC = 100 µg/mL	[33]
khayanolide A	<i>Khaya senegalensis</i>	<i>Spodoptera littoralis</i>	AI = 21.7 at 300 µg/mL (6 h)	[34]
khayanolide B	<i>Khaya senegalensis</i>	<i>Spodoptera littoralis</i>	AI = 24.8 at 1000 µg/mL (6 h)	[34]
2-hydroxysenega-nolide	<i>Khaya senegalensis</i>	<i>Spodoptera littoralis</i>	AI = 38.4 at 200 µg/mL (6 h)	[34]
1-O-acetylkhayanolide A	<i>Khaya senegalensis</i>	<i>Spodoptera littoralis</i>	AI = 31.4 at 100 µg/mL (6 h)	[34]
1-O-acetylkhayanolide B	<i>Khaya senegalensis</i>	<i>Spodoptera littoralis</i>	AI = 17.3 at 300 µg/mL (6 h)	[34]
khayanolide C	<i>Khaya senegalensis</i>	<i>Spodoptera littoralis</i>	AI = 31.5 at 500 µg/mL (6 h)	[34]
khayalactol	<i>Khaya senegalensis</i>	<i>Spodoptera littoralis</i>	AI = 83.8 at 1000 µg/mL (6 h)	[34]
khayanone	<i>Khaya senegalensis</i>	<i>Spodoptera littoralis</i>	AI = 47.4 at 1000 µg/mL (6 h)	[34]
6-O-acetylsiwietenolide	<i>Khaya grandifoliola</i>	<i>Spodoptera littoralis</i>	AI = 72.2 at 1000 µg/mL	[5,35]
swietenolide	<i>Khaya grandifoliola</i>	<i>Spodoptera littoralis</i>	AI = 94.1 at 1000 µg/mL	[5,35]
seneganolide	<i>Khaya senegalensis</i>	<i>Spodoptera littoralis</i>	AI = 48.0 at 1000 µg/mL (6 h)	[34]
azadirone	<i>Entandrophragma delevoyi</i>	<i>Leptinotarsa decemlineata</i>	AI = 11.6–26.9 at 100–500 µg/mL (20 h)	[5]
khayanoside	<i>Khaya senegalensis</i>	<i>Spodoptera littoralis</i>	AI = 15.1 at 1000 µg/mL (6 h)	[34]
methyl 6-hydroxyangolensate	<i>Khaya senegalensis</i>	<i>Spodoptera littoralis</i>	AI = 23.6 at 1000 µg/mL (6 h)	[34]
methyl 6-acetoxiangolensate	<i>Khaya senegalensis</i>	<i>Spodoptera littoralis</i>	AI = 18.0 at 1000 µg/mL (6 h)	[47]
meliacarpinin B	<i>Melia azedarach</i>	<i>Spodoptera exigua</i>	MIC = 50 µg/mL (2–24 h)	[36]
meliacarpinin C	<i>Melia azedarach</i>	<i>Spodoptera exigua</i>	MIC = 50 µg/mL (2–24 h)	[36]
meliacarpinin D	<i>Melia azedarach</i>	<i>Spodoptera exigua</i>	MIC = 50 µg/mL (2–24 h)	[36]
meliacarpinin A	<i>Melia azedarach</i>	<i>Spodoptera exigua</i>	MIC = 50 µg/mL (2–24 h)	[36]
salannal	<i>Melia toosendan</i>	<i>Pieris rapae</i>	AFC ₅₀ = 1.26 mM	[44]
3-O-acetylchinalol	<i>Melia toosendan</i>	<i>Pieris rapae</i>	AFC ₅₀ = 0.89 mM	[44]
salannin	<i>Melia toosendan</i>	<i>Pieris rapae</i>	AFC ₅₀ = 1.35 mM	[44]
ohchinal	<i>Melia azedarach</i>	<i>Spodoptera eridania</i>	MIC = 1000 µg/mL (2–24 h)	[37]
nimbolinin B	<i>Melia toosendan</i>	<i>Pieris rapae</i>	AFC ₅₀ = 1.79 mM	[44]
		<i>Spodoptera eridania</i>	MIC = 300 µg/mL (2–24 h)	
		<i>Pieris rapae</i>	AFC ₅₀ = 0.21 mM	
		<i>Peridroma saucia</i>	DC ₅₀ = 8.04 µg/cm ²	
		<i>Helicoverpa armigera</i>	FI ₅₀ = 56.6 µg/mL (6 h)	[5,32,37,39,44,57,
toosendanin	<i>Melia azedarach</i>	<i>Epilachna paenulata</i>	ED ₅₀ = 3.69 µg/cm ² (24 h)	58]
	<i>Melia toosendan</i>	<i>Spodoptera littoralis</i>	AFC ₅₀ = 200 µg/mL	
		<i>Spodoptera litura</i>	100% antifeedant rate at 0.01% toosendanin	
		<i>Spodoptera abyssinia</i>	76.5% antifeedant rate at 0.1% toosendanin	
nimboldin C	<i>Melia toosendan</i>	<i>Spodoptera eridania</i>	MIC = 500 µg/mL (2–24 h)	[37]
nimboldin D	<i>Melia toosendan</i>	<i>Spodoptera eridania</i>	MIC = 500 µg/mL (2–24 h)	[37]
nimboldin E	<i>Melia toosendan</i>	<i>Spodoptera eridania</i>	MIC = 500 µg/mL (2–24 h)	[37]
nimboldin F	<i>Melia toosendan</i>	<i>Spodoptera eridania</i>	MIC = 500 µg/mL (2–24 h)	[37]
3-O-acetylchinalol	<i>Melia toosendan</i>	<i>Spodoptera eridania</i>	MIC = 1000 µg/mL (2–24 h)	[37]
ohchinolide C	<i>Melia toosendan</i>	<i>Spodoptera eridania</i>	MIC = 1000 µg/mL (2–24 h)	[37]
volkensin	<i>Melia volkensii</i>	<i>Spodoptera frugiperda</i>	ED ₅₀ = 3.5 µg/cm ² (15 h)	[29]
hydroxylactone	<i>Melia volkensii</i>	<i>Spodoptera frugiperda</i>	ED ₅₀ = 6 µg/cm ² (15 h)	[29]
6-acetylsendanal	<i>Melia toosendan</i>	<i>Pieris rapae</i>	AFC ₅₀ = 1.32 mM	[44]
iso-chuanliansu	<i>Melia toosendan</i>	<i>Pieris rapae</i>	AFC ₅₀ = 0.46 mM	[44]
	<i>Melia toosendan</i>	<i>Spodoptera littoralis</i>	MIC = 300 µg/mL (2–24 h)	[29]
amoorastatone	<i>Melia toosendan</i>	<i>Pieris rapae</i>	AFC ₅₀ = 0.63 mM	[44]
12-hydroxyamoorastatone	<i>Melia toosendan</i>	<i>Pieris rapae</i>	AFC ₅₀ = 0.64 mM	[44]
mesendanin H	<i>Melia toosendan</i>	<i>Pieris rapae</i>	AFC ₅₀ = 0.11 mM	[44]
meliatosenin E	<i>Melia toosendan</i>	<i>Pieris rapae</i>	AFC ₅₀ = 1.03 mM	[44]
trichilin B	<i>Melia azedarach</i>	<i>Spodoptera exigua</i>	MIC = 200 µg/mL (6–24 h)	[36]
aphanastatin	<i>Melia azedarach</i>	<i>Spodoptera exigua</i>	MIC = 200 µg/mL (6–24 h)	[36]
azedarachin A	<i>Melia azedarach</i>	<i>Spodoptera exigua</i>	MIC = 200 µg/mL (6–24 h)	[36]
12-O-acetyltrichilin B	<i>Melia azedarach</i>	<i>Spodoptera exigua</i>	MIC = 400 µg/mL (6–24 h)	[36]
		<i>Spodoptera eridania</i>	MIC = 400 µg/mL (6–24 h)	[37]
1,12-di-O-acetyltrichilin B	<i>Melia azedarach</i>	<i>Spodoptera exigua</i>	MIC = 400 µg/mL (6–24 h)	[36]

Table 2. Cont.

Compound	Plant Source	Insect	Activity	Ref.
trichilin H	<i>Melia azedarach</i>	<i>Spodoptera exigua</i>	MIC = 400 µg/mL (6–24 h)	[36]
trichilin D	<i>Melia azedarach</i>	<i>Spodoptera exigua</i>	MIC = 400 µg/mL (6–24 h)	[36]
meliatoxin A ₂	<i>Melia azedarach</i>	<i>Spodoptera exigua</i>	MIC = 400 µg/mL (6–24 h)	[36]
12-O-acetylazedarachin A	<i>Melia azedarach</i>	<i>Spodoptera exigua</i>	MIC = 400 µg/mL (6–24 h)	[36]
12-O-acetylazedarachin B	<i>Melia azedarach</i>	<i>Spodoptera exigua</i>	MIC = 400 µg/mL (6–24 h)	[36]
azedarachin C	<i>Melia azedarach</i>	<i>Spodoptera exigua</i>	MIC = 400 µg/mL (6–24 h)	[36]
trichilin I	<i>Melia toosendan</i>	<i>Spodoptera eridania</i>	MIC = 400 µg/mL (2–24 h)	[37]
trichilin J	<i>Melia toosendan</i>	<i>Spodoptera eridania</i>	MIC = 400 µg/mL (2–24 h)	[37]
trichilin K	<i>Melia toosendan</i>	<i>Spodoptera eridania</i>	MIC = 400 µg/mL (2–24 h)	[37]
trichilin L	<i>Melia toosendan</i>	<i>Spodoptera eridania</i>	MIC = 400 µg/mL (2–24 h)	[37]
12-deacetyltoosendanin	<i>Melia toosendan</i>	<i>Spodoptera eridania</i> <i>Spodoptera littoralis</i>	MIC = 150 µg/mL (2–24 h) MIC = 250 µg/mL (2–24 h)	[37] [29]
1-O-acetyltrichilin H	<i>Melia toosendan</i>	<i>Spodoptera littoralis</i>	MIC = 300 µg/mL (2–24 h)	[29]
neozedarachin A	<i>Melia toosendan</i>	<i>Spodoptera littoralis</i>	MIC = 400 µg/mL (2–24 h)	[29]
neozedarachin B	<i>Melia toosendan</i>	<i>Spodoptera littoralis</i>	MIC = 400 µg/mL (2–24 h)	[29]
neozedarachin D	<i>Melia toosendan</i>	<i>Spodoptera littoralis</i>	MIC = 400 µg/mL (2–24 h)	[29]
meliartenin	<i>Melia azedarach</i>	<i>Epilachna paenulata</i>	ED ₅₀ = 0.80 µg/cm ² (24 h)	[39]
12-hydroxy-moorastatin	<i>Melia azedarach</i>	<i>Epilachna paenulata</i>	ED ₅₀ = 0.80 µg/cm ² (24 h)	[39]
1-cinnamoyltrichilin	<i>Melia volkensii</i>	<i>Spodoptera littoralis</i>	MAC = 1000 µg/mL	[45]

DC₅₀: concentration that deters feeding of fourth-instar larvae by 50%; ED₅₀ is the dosage required to give an antifeedant index of 50%; AI: antifeedant index; MIC: minimum inhibitory concentration; AFC₅₀: median antifeeding concentration; FI₅₀: dietary concentration showing 50% feeding inhibition; MAC: minimum antifeedant concentration.

From this genus, a total of 30 ring-intact limonoids and 19 ring-seco limonoids were reported to show insecticidal activities. In detail, the 30 ring-intact limonoids included 29 trichilin-type limonoids and one havanensin-class limonoid (6-acetylsendanal). Specifically, the 29 trichilin-type limonoids were toosendanin, 12-deacetyltoosendanin, trichilin B, trichilin D, trichilin H, trichilin I, trichilin J, trichilin K, trichilin L, 1, 12-di-O-acetyltrichilin B, 12-O-acetyltrichilin B, 1-O-acetyltrichilin H, 1-cinnamoyltrichilin, azedarachin A, azedarachin C, 12-O-acetylazedarachin A, 12-O-acetylazedarachin B, neozedarachin A, neozedarachin B, neozedarachin D, meliartenin, meliatoosendanin E, meliatoxin A₂, mesendanin H, amoorastone, 12-hydroxyamoorastone, 12-hydroxyamoorastatin, aphanastatin, and iso-chuanliansu. The 19 ring C-seco limonoids were meliacarpinin B, meliacarpinin C, meliacarpinin D, meliacarpinin A, 1,3-dicinnamoyl-11-hydroxymeliacarpin, 1-cinnamoyl-3-methacryl-11-hydroxymeliacarpin, 1-cinnamoyl-3-acetyl-11-hydroxymeliacarpin, salannin, salannal, ohchinal, 3-O-acetylohchinolal, nimbolin B, nimbolidin C, nimbolidin D, nimbolidin E, nimbolidin F, ohchinolide C, volkensin, and hydroxylactone [29,36–39,44,166–189].

2.5.1. Ring-Intact Limonoids

The most-studied chemical in this group was toosendanin. Toosendanin is a trichilin-class limonoid isolated from *M. toosendan* and *M. azedarach* [37,49]. The principle bioactive chemicals in *M. toosendan* are toosendanin-type limonoids known as tetranortriterpenoids and intact-ring protolimonoids, which are euphane- or tirucallane-type triterpenoids. It is believed that toosendanin and its derivatives are formed by the loss of four carbons from the side chain of the euphane (20R) or tirucallane (20S) skeleton, which then cyclize to form the 17β-furan ring [5].

Toosendanin and its derivatives demonstrate high insecticidal activity and are important insecticidal molecules derived from plants. In China, toosendanin is used as an important Chinese traditional insecticide and has been registered and commercialized. Studies on the insecticidal activity of various formulations of toosendanin and residue analysis using IC-ELISA can be easily found. The studied formulations include 2% toosendanin EW, 2% toosendanin ME, 2% toosendanin SL, and 2% toosendanin WP [190,191].

Toosendanin has shown various activities including antifeeding, deterring, growth-inhibitory, contact poisoning, and stomach poisoning activities [5,37,44,49,54,57,175,192–196].

Specially, toosendanin has marked systemic properties. It could control the newly hatched larvae of the rice yellow stem borer, *T. incertulas*, inside of the rice stem [195].

Table 3. Poisonous activity of insecticidal triterpenoids of plants from five genera in Meliaceae.

Compound	Plant Source	Insect	Activity	Ref.
cipadesin	<i>Cipadessa fruticosa</i> <i>Cipadessa baccifera</i> <i>Cipadessa fruticosa</i>	<i>Spodoptera frugiperda</i>	S ₅₀ = 7 days at 100 µg/mL	[51]
febrifugin	<i>Cipadessa baccifera</i> <i>Cipadessa cinerascens</i>	<i>Spodoptera frugiperda</i>	S ₅₀ = 6 days at 100 µg/mL	[51]
ruageanin A	<i>Cipadessa fruticosa</i>	<i>Atta sexdens rubropilosa</i>	S ₅₀ = 6 days at 100 µg/mL	[51]
swietemahonolide	<i>Cipadessa fruticosa</i>	<i>Atta sexdens rubropilosa</i>	S ₅₀ = 8 days at 100 µg/mL	[51]
mexicanolide	<i>Cipadessa fruticosa</i> <i>Cipadessa fruticosa</i>	<i>Atta sexdens rubropilosa</i>	S ₅₀ = 6 days at 100 µg/mL	[51]
cipadesin A	<i>Cipadessa baccifera</i> <i>Cipadessa cinerascens</i>	<i>Spodoptera frugiperda</i>	MR: less than 40% at 50 mg/kg	[47]
febrifugin A	<i>Cipadessa fruticosa</i>	<i>Spodoptera frugiperda</i>	MR: 73.3% at 50 mg/kg	[47]
khayasin T	<i>Cipadessa fruticosa</i> <i>Cipadessa baccifera</i>	<i>Spodoptera frugiperda</i>	MR: 50% at 50 mg/kg	[47]
melianodiol	<i>Guarea grandiflora</i> <i>Guarea kunthiana</i>	<i>Aedes aegypti</i>	LC ₅₀ = 14.44 µg/mL LC ₉₀ = 17.54 µg/mL (24 h)	[20]
melianone	<i>Guarea grandiflora</i> <i>Entandrophragma angolense</i> <i>Entandrophragma delevoyi</i>	<i>Reticulitermes speratus</i>	MR: 95% at 100 µg/disc (30 days)	[41]
gedunin	<i>Entandrophragma macrophyllum</i> <i>Guarea grandiflora</i> <i>Khaya grandifoliola</i> <i>Entandrophragma angolense</i> <i>Entandrophragma macrophyllum</i>	<i>Spodoptera frugiperda</i>	LM: LC ₅₀ = 39 µg/mL (30 days)	[5,77,78]
methyl angolensate	<i>Guarea thompsonii</i> <i>Khaya anthotheca</i> <i>Khaya senegalensis</i> <i>Khaya grandifoliola</i> <i>Khaya ivoremis</i>	<i>Spodoptera frugiperda</i>	MR: 40% at 50 mg/kg (7 days)	[50]
7-deacetoxy-7-oxo-gedunin	<i>Guarea grandiflora</i> <i>Guarea guidonia</i> <i>Carapa guianensis</i>	<i>Atta sexdens rubropilosa</i>	S ₅₀ = 9 days at 100 µg/mL	[25]
anthothecol	<i>Khaya anthotheca</i>	<i>Plutella xylostella</i> <i>Myzus persicae</i> <i>Sitophilus oryzae</i>	MR: 30–80% at 0.25–1 mg/mL (48 h) MR: 30%, 60% at 0.5, 1 mg/mL (48 h) LC ₅₀ = 675 µg/mL (6 weeks)	[48]
toosendanin	<i>Melia azedarach</i> <i>Melia toosendan</i>	<i>Cryptolestes ferrugineus</i> <i>Ostrinia furnacalis</i> <i>Spodoptera frugiperda</i>	LC ₅₀ = 1875 µg/mL (6 weeks) Mortality: 58.33% at 0.4 µg (average 3.1 days) LC ₅₀ = 7.0 µg/mL	[5,49,195]
1,3-dicinnamoyl-11-hydroxymeliacarpin	<i>Melia azedarach</i>	<i>Spodoptera littoralis</i>	LC ₅₀ = 2.36 µg/mL (12 days)	[52]
1-cinnamoyl-3-methacryl-11-hydroxymeliacarpin	<i>Melia azedarach</i>	<i>Spodoptera littoralis</i>	LC ₅₀ = 1.19 µg/mL (12 days)	[52]
1-cinnamoyl-3-acetyl-11-hydroxymeliacarpin	<i>Melia azedarach</i>	<i>Spodoptera littoralis</i>	LC ₅₀ = 0.48 µg/mL (12 days)	[52]
2'S-cipadesin A	<i>Cipadessa baccifera</i>	AChE	inhibitory activity (AChE) at 50 mM	[47]
granatumin E	<i>Cipadessa baccifera</i>	AChE	inhibitory activity (AChE) at 50 mM	[47]
3-O-detigloyl-3-O-isobutyrylfebrifugin A	<i>Cipadessa baccifera</i>	AChE	inhibitory activity (AChE) at 50 mM	[47]
cipadonoid B	<i>Cipadessa baccifera</i> <i>Cipadessa cinerascens</i>	insect nAChR	pI ₅₀ = 4.2	[47]
khayasin	<i>Cipadessa baccifera</i>	<i>Brontispa longissima</i>	LC ₅₀ = 7.28 µg/mL (24 h)	[53]

S₅₀: survival median; MR: mortality rate; LM: larval mortality; LC₅₀: median lethal concentration.

Toosendanin showed strong antifeedant activity toward insects such as *P. rapae*, *O. furnacalis*, *P. saucia*, *S. incertulas*, *O. furnacalis*, *L. compta*, *P. xylostrella*, *S. litura*, *A. citricidis*,

and *T. aurantia* [5,32,37,44,57,58]. Toosendanin at the concentration of 0.01% could result in a 100% antifeedant rate against the tobacco cutworm, *S. litura*, while toosendanin at the concentration of 0.1% could result in an antifeedant rate of 76.5% against the lawn caterpillar, *S. abyssinica* [196]. Using the leaf disc choice test, the DC₅₀ value (concentration deterring feeding by 50%) was 8.04 µg/cm² against the fourth-instar larvae of the variegated cutworm, *P. saucia* [57]. On the cotton bollworm, *H. armigera*, the EC₅₀ value (concentration inhibiting larval growth by 50% relative to controls) of toosendanin was 26.8 µg/mL 7 days after the treatment. The FI₅₀ (dietary concentration showing 50% feeding inhibition) value for toosendanin on the third-instar larvae of the cotton bollworm, *H. armigera*, was 56.6 µg/mL [32]. As for the ladybird beetle, *E. paenulata*, the ED₅₀ value of toosendanin was 3.69 µg/cm² after 24 h [100]. It was also effective against the third-instar larvae of the African cotton leafworm, *S. littoralis*, at 200 µg/mL [5]. Other studies showed that the MIC value of toosendanin was 300 µg/mL against the southern armyworm, *S. eridania*, in 2–24 h [37].

Table 4. Growth regulatory activity of insecticidal triterpenoids of plants from five genera in Meliaceae.

Compound	Plant Source	Insect	Activity	Ref.
cipadesin	<i>Cipadessa fruticosa</i> <i>Cipadessa baccifera</i>	<i>Spodoptera frugiperda</i>	LPE: 0.8 days	[43]
febrifugin	<i>Cipadessa fruticosa</i> <i>Cipadessa baccifera</i>	<i>Spodoptera frugiperda</i>	LPE: 1.8 days	[43]
khayasin T	<i>Cipadessa cinerascens</i> <i>Cipadessa fruticosa</i>	<i>Spodoptera frugiperda</i>	LPE: 1.2 days	[43]
cipadesin A	<i>Cipadessa baccifera</i> <i>Cipadessa fruticosa</i>	<i>Spodoptera frugiperda</i>	LPE: 2.1 days	[43]
prieurianin	<i>Entandrophragma candolei</i> <i>Guarea guidonia</i>	<i>Helicoverpa armigera</i>	GIL, EC ₅₀ = 18.8 µg/mL (7 days)	[32]
epoxyprieurianin	<i>Entandrophragma candolei</i>	<i>Helicoverpa armigera</i>	GIL, EC ₅₀ = 3.2 µg/mL (7 days)	[32]
prieurianin acetate	<i>Entandrophragma candolei</i>	<i>Helicoverpa armigera</i>	GIL, EC ₅₀ = 11.5 µg/mL (7 days)	[32]
epoxyprieurianin acetate	<i>Entandrophragma candolei</i>	<i>Helicoverpa armigera</i>	GIL, EC ₅₀ = 2.6 µg/mL (7 days)	[32]
6α-acetoxy-gedunin	<i>Guarea kunthiana</i>	<i>Ostrinia nubilalis</i>	Reduced growth at 50 µg/mL	[18,56]
3β-O-tigloyl melianol	<i>Guarea grandiflora</i> <i>Guarea kunthiana</i>	<i>Rhipicephalus microplis</i>	GSI reduced 50% (48 h)	[21]
7-deacetoxy-7-oxogedunin	<i>Guarea grandiflora</i> <i>Guarea guidonia</i>	<i>Spodoptera frugiperda</i>	LPE: 1.2 days	[50]
1-O-acetylkhayanoilide B	<i>Carapa guianensis</i> <i>Khaya senegalensis</i>	<i>Spodoptera littoralis</i>	GI, EC ₅₀ = 16.75 mg/kg (7 days)	[54]
khyanolide A	<i>Khaya senegalensis</i>	<i>Spodoptera littoralis</i>	GI, EC ₅₀ = 14.65 mg/kg (7 days)	[54]
khyanolide B	<i>Khaya senegalensis</i>	<i>Spodoptera littoralis</i>	GI, EC ₅₀ = 6.96 mg/kg (7 days)	[54]
khayalactol	<i>Khaya senegalensis</i>	<i>Spodoptera littoralis</i>	GI, EC ₅₀ = 11.48 mg/kg (7 days)	[54]
toosendanin	<i>Melia azedarach</i> <i>Melia toosendan</i>	<i>Peridroma saucia</i> <i>Ostrinia furnacalis</i> <i>Spodoptera frugiperda</i>	EC ₅₀ = 42.3 µg/mL after 7 days Inhibition of body weight and pupation Inhibition of body weight	[55,175,194]

EC₅₀: concentration reducing growth by 50% relative to controls; LPE: larval phase extended; GIL: inhibition of larval growth; GSI: sexual gland index; GI: growth inhibition.

Meanwhile, toosendanin also exhibited poisonous activity and insect growth-inhibitory activity. For example, toosendanin showed growth-inhibitory effects on the variegated cutworm, *P. saucia*, with an EC₅₀ value of 42.3 µg/mL 7 days after treatment [55]. When tested at a concentration of 0.05%, toosendanin could inhibit the body weight of the Asian corn borer, *O. furnacalis*, by 61.52% after 2 days of treatment [195]. Toosendanin possessed obvious poisonous activity toward the fall armyworm, *S. frugiperda*, with an LC₅₀ value of 7.0 µg/mL [5]. It also showed poisonous activity toward the rice weevil, *S. oryzae*, and the rusty grain beetle, *C. ferrugineus*. After 6 weeks, the LC₅₀ values of toosendanin on them were 675 and 1875 µg/mL, respectively [49]. Another study showed that, when tested using the method of topical application, 0.4 µg of toosendanin resulted in a mortality of 58.33% at an average of 3.1 days on the Asian corn borer, *O. furnacalis* [194]. Furthermore,

toosendanin, at 10 µg/mL, could deter the oviposition activity of the cabbage looper, *T. ni*, and the diamondback moth [139].

The meliacin-type limonoids 6-acetylsendanal, iso-chuanliansu, amoorastatone, 12-hydroxyamoorastatone, mesendanin H, and meliatoosenin E showed antifeedant activities toward the fifth-instar larvae of the cabbage worm, *P. rapae*, with AFC_{50} values of 1.32, 0.46, 0.63, 0.64, 0.11, and 1.03 mM, respectively. In contrast, the AFC_{50} value of toosendanin was 0.21 mM [36].

The minimum inhibitory concentrations (MICs), reflecting the antifeeding activity of trichilin-type limonoids against different insects, for trichilin B, aphanastatin, azedarachin A, 12-*O*-acetyltrichilin B, 1,12-di-*O*-acetyltrichilin B, trichilin H, trichilin D, meliatoxin A₂, 12-*O*-acetylzedarachin A, 12-*O*-acetylzedarachin B, and azedarachin C ranged from 200–400 µg/mL against *S. exigua* in 6–24 h [36]. For *S. eridania*, the MICs of 12-*O*-acetyltrichilin B, trichilin I, trichilin J, trichilin K, trichilin L, and 12-deacetyltoosendanin ranged from 150–400 µg/mL in 2–24 h. In contrast, the MIC of toosendanin was 300 µg/mL. It is noteworthy that the MIC of 12-deacetyltoosendanin was 150 µg/mL, which was lower than that of toosendanin [37]. More studies on *S. littoralis* showed that the MICs of 1-*O*-acetyltrichilin H, neoazedarachin A, neoazedarachin B, neoazedarachin D, 12-deacetyltoosendanin, and iso-chuanliansu varied from 250–400 µg/mL in 2–24 h [38].

The other two trichilin-type limonoids, meliartenin and 12-hydroxyamoorastatin, were interchangeable isomers and could inhibit the feeding activity of *E. paenulata*, with an ED_{50} value of 0.80 µg/cm² (24 h). They also showed poisonous activity, with an LD_{50} value of 0.76 µg/cm² at 96 h [110]. Furthermore, the trichilin-class limonoid 1-cinnamoyltrichilin showed antifeedant activity toward *S. littoralis* with a minimum antifeedant concentration (MAC) value of 1000 mg/L [45].

2.5.2. Ring C-Seco Limonoids

The azadirachtinin/meliacarpinin-class chemicals meliacarpinin A, meliacarpinin B, meliacarpinin C, and meliacarpinin D showed growth-inhibitory activity toward the beet armyworm, *S. exigua*, with a minimum inhibitory concentration (MIC) of 50 µg/mL (6–24 h) [36]. The azadirachtin/meliacarpin-class limonoids 1,3-dicinnamoyl-11-hydroxymeliacarpin, 1-cinnamoyl-3-methacryl-11-hydroxymeliacarpin, and 1-cinnamoyl-3-acetyl-11-hydroxymeliacarpin showed poisonous activity toward the neonate larvae of the cotton leafworm, *S. littoralis*, with LC_{50} values (12 days) of 2.36, 1.19, and 0.48 µg/mL, respectively [52].

The salannin-class limonoids salannal, 3-*O*-acetylchinalol, salannin, and ohchinal showed antifeedant activities toward the fifth-instar larvae of the cabbage worm, *P. rapae*, with AFC_{50} values of 1.26, 0.89, 1.35, and 1.79 mM, respectively [83]. However, when compared with toosendanin, salannin showed a relatively weaker antifeedant activity, with an MIC of 1000 µg/mL, toward the southern armyworm, *S. eridania*, in 2–24 h (compared to 300 µg/mL for toosendanin) [37].

The MICs of nimbolidin-type nimbolidin C, nimbolidin D, nimbolidin E, nimbolidin F, nimbin-type chemical 3-*O*-acetylchinalol, and nimbolinin-type chemical ohchinalide C were 500, 500, 500, 500, 1000, and 1000 µg/mL, respectively, against *S. eridania* in 2–24 h [37].

In addition, when compared with toosendanin, the nimbolinin-type chemical nimbolinin B showed a relatively weaker antifeedant activity toward *S. eridania* with an MIC of 1000 µg/mL in 2–24 h (compared to 300 µg/mL for toosendanin) [37]. Furthermore, studies on nimbolinin-type chemicals volkensin and hydroxylactone (isolated from *M. volkensii*) revealed that they were antifeedant agents against the third-instar larvae of the fall armyworm, *S. frugiperda*. In the choice assays using corn leaf discs, the ED_{50} values of the two molecules were 3.5 and 6 µg/cm², respectively (15 h) [29].

3. Structures and Structure–Activity Relationship (SAR) of the Insecticidal Chemicals

3.1. Structures of the Insecticidal Chemicals

A total of 116 insecticidal chemicals were summarized, including 34 ring-intact limonoids, 31 ring-seco limonoids, 48 rearranged limonoids, and 3 tetracyclic triterpenes. The structures of the chemicals are shown in Figures 3–19.

The 34 ring-intact limonoids included 29 trichilin-class chemicals, 3 azadirone-class chemicals, 1 cedrelone-class, and 1 havanensin-class limonoid. The 31 ring-seco limonoids consisted of 16 ring C-seco group chemicals, 8 rings B,D-seco group chemicals, 4 rings A,B-seco group chemicals, and 3 ring D-seco group chemicals. Furthermore, among the 48 rearranged limonoids, 46 were 2,30-linkage group chemicals and 2 were 10,11-linkage group chemicals. Specifically, the 46 chemicals belonging to the 2,30-linkage group could be subdivided into 24 mexicanolide-class chemicals and 22 phragmalin-class chemicals. Additionally, the three tetracyclic triterpenes were protolimonoids.

3.2. Structure–Activity Relationship (SAR) of the Insecticidal Chemicals

Structure–activity relationship (SAR) or quantitative structure–activity relationship (QSAR) analysis can be used for the rational design of novel drugs and pesticides. Substantial efforts have been dedicated to these issues [197–199]. Among these 116 chemicals, the SARs of toosendanin, khayanolide B, 1-*O*-acetylkhayanolide B, febrifugin, and melianodiol have been studied [20,43,45,47,54,200–202].

In continuation of the program aimed at the discovery and development of natural product-based insecticidal agents, according to the insecticidal activity of 12 semi-synthesized 28-acyloxy derivatives of toosendanin (2a–l) against the pre-third-instar larvae of the rice ear-cutting caterpillar, *M. separata*, in vivo at the concentration of 1 mg/mL, Xu et al. (2011) concluded that the butanoyloxy or phenylacryloyloxy moiety at the 28-position of toosendanin was essential for insecticidal activity [200]. Furthermore, Zhang et al. (2013) synthesized 18 alkyl/alkenylacyloxy derivatives at the C-28 position adopting the *exo*-configuration of toosendanin (3a–r) via the reaction of toosendanin with fatty acids in the presence of *N,N'*-diisopropylcarbodiimide and 4-dimethylaminopyridine. The activity of these 18 molecules tested on the pre-third-instar larvae of the rice ear-cutting caterpillar, *M. separata*, revealed that compounds 3e and 3o displayed more promising insecticidal activity than their natural precursor, toosendanin. It was revealed that, for the *n*-alkyloxyloxy series derivatives, the proper length of the side chain R at the C-28 position of toosendanin was very important for insecticidal activity [201]. Another structure–activity relationship study of toosendanin derivatives indicated that the sites around R4 and R5 also contributed to the activity [202].

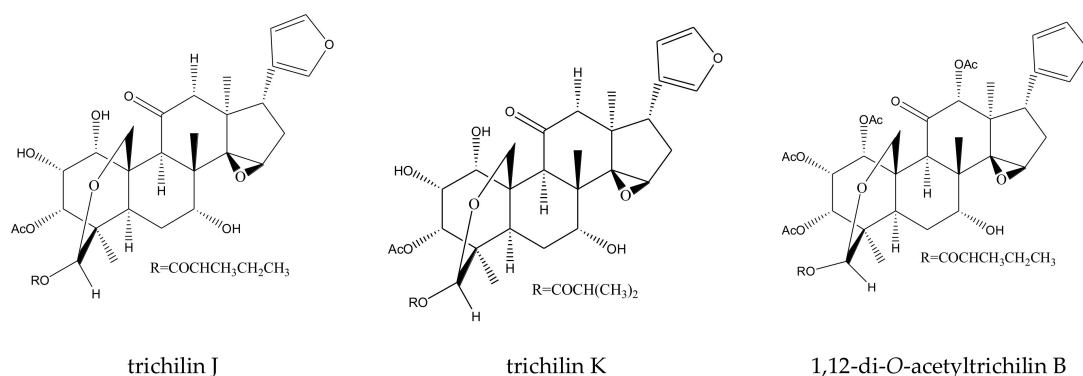


Figure 3. Cont.

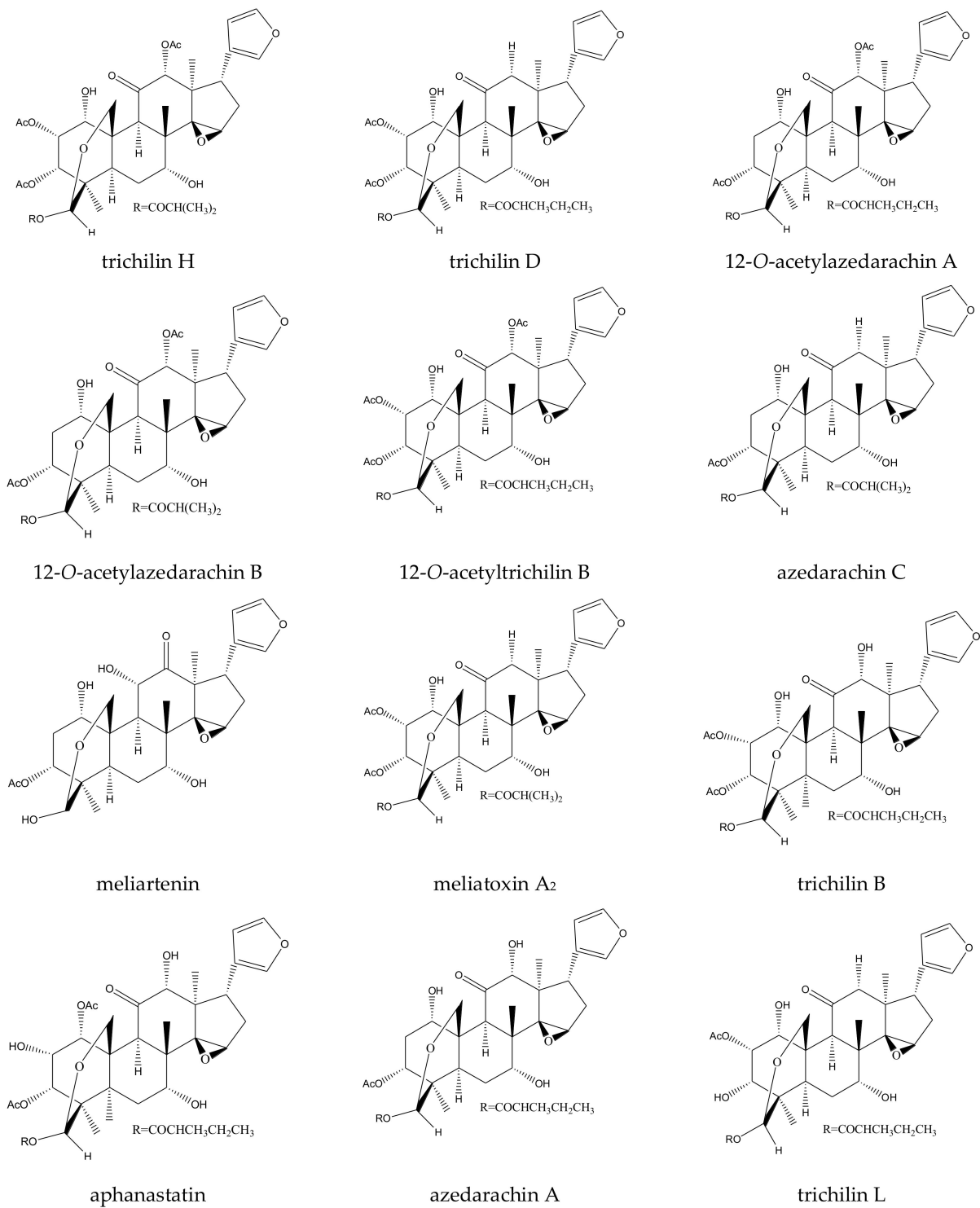


Figure 3. Cont.

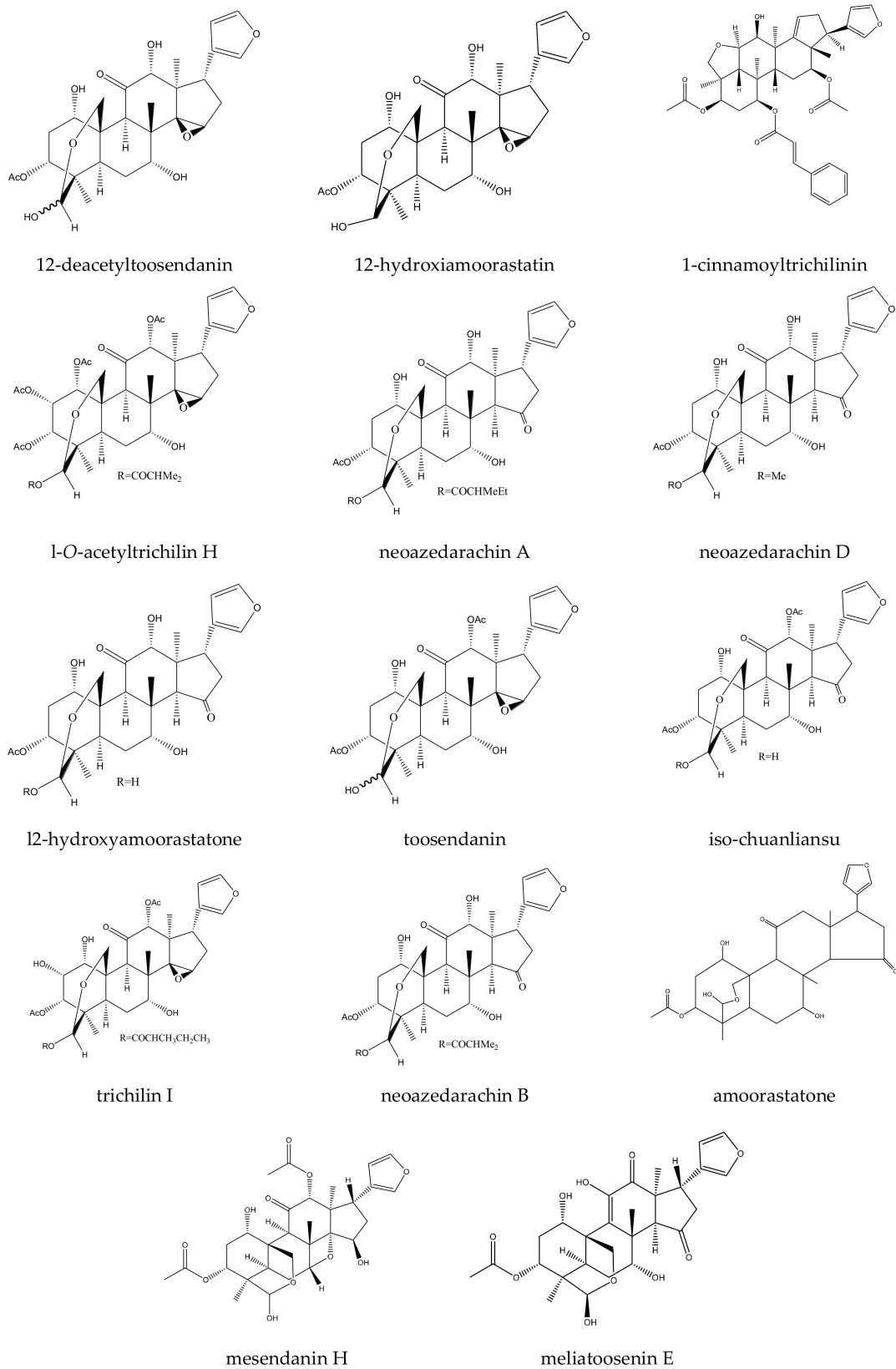


Figure 3. Structures of ring-intact limonoids: trichilin-class chemicals.

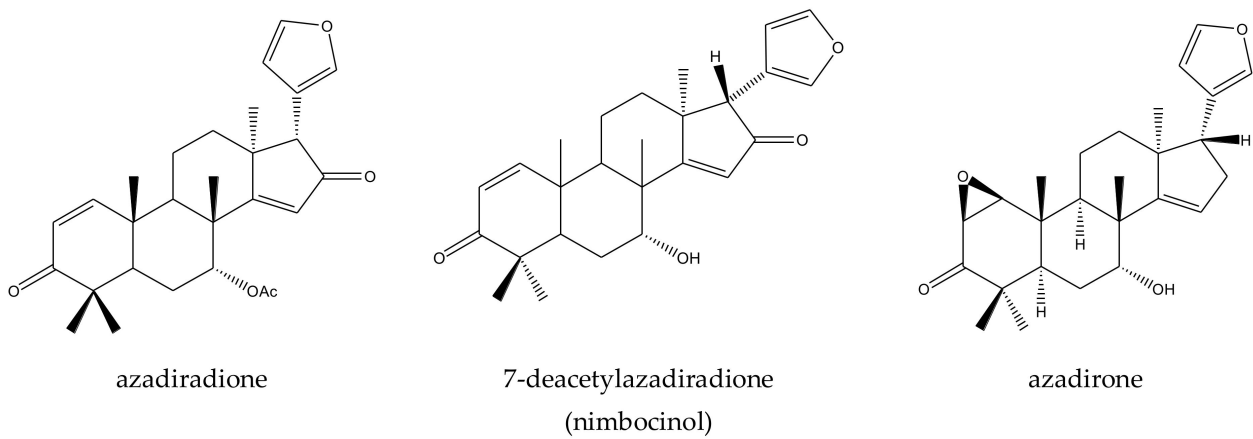


Figure 4. Structures of ring-intact limonoids: azadirone-class chemicals.

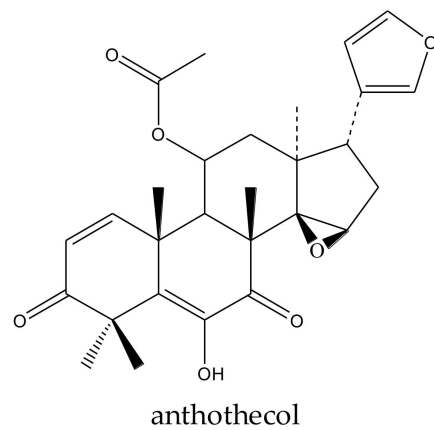


Figure 5. Structure of ring-intact limonoid: cedrelone-class chemical.

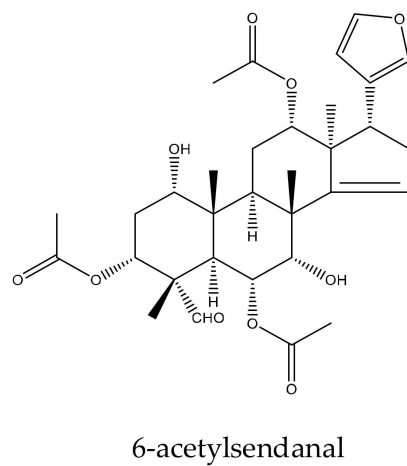


Figure 6. Structure of ring-intact limonoids: havanensin-class chemical.

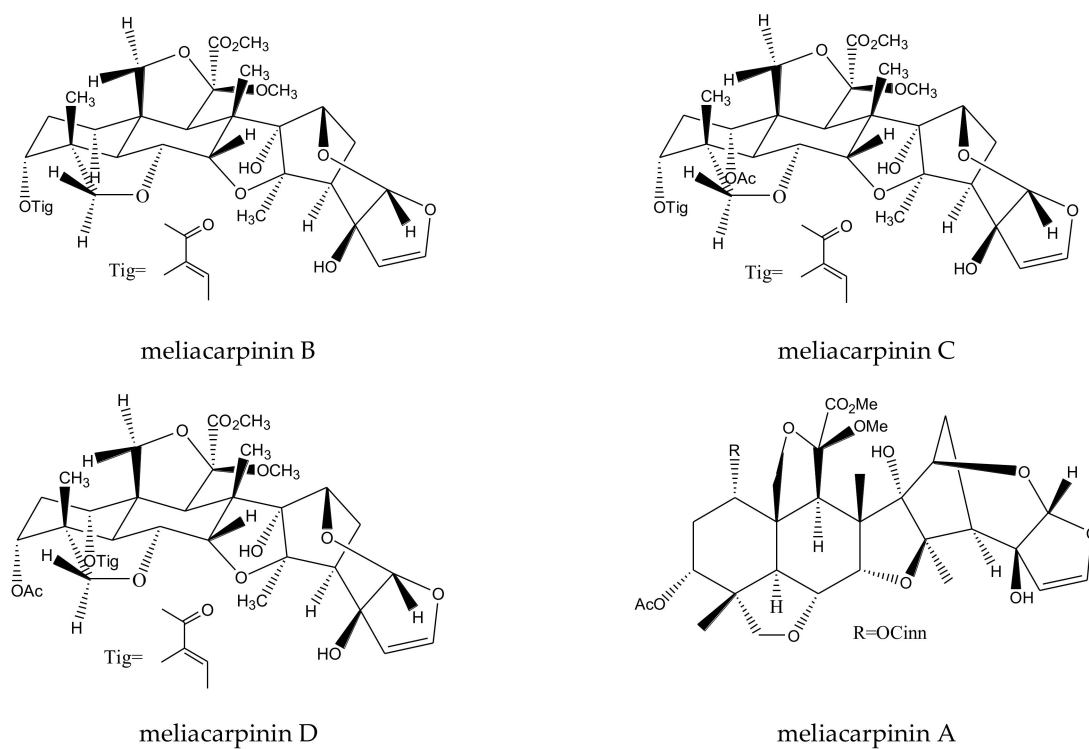


Figure 7. Structures of ring-seco limonoids: ring C-seco group (azadirachtinin/meliarpinin-class chemicals).

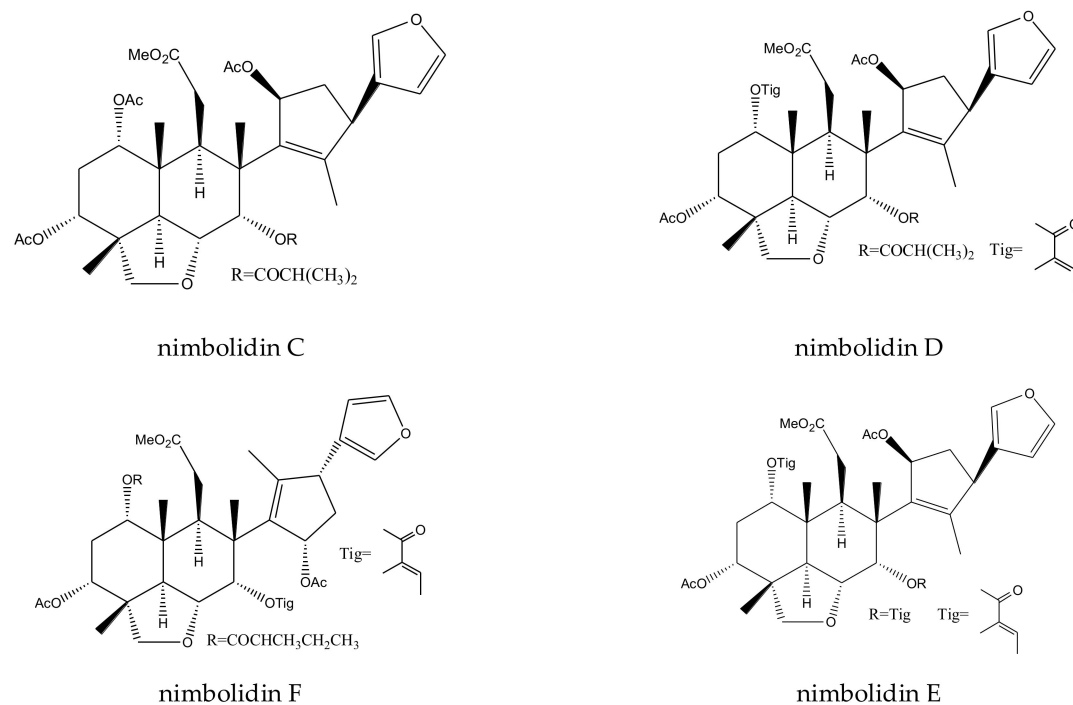


Figure 8. Structures of ring-seco limonoids: ring C-seco group (nimboldin-class chemicals).

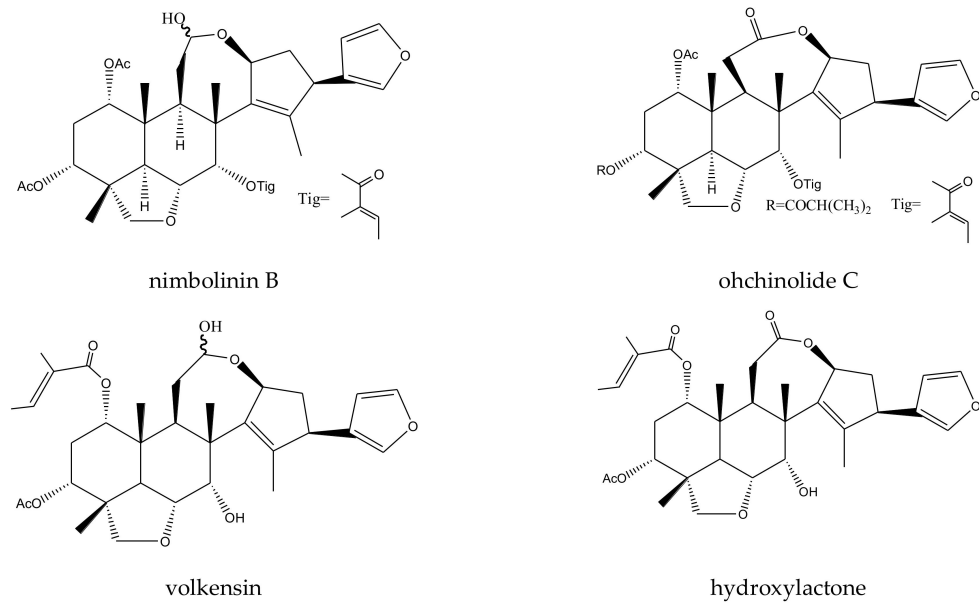


Figure 9. Structures of ring-seco limonoids: ring C-seco group (nimbolinin-class chemicals).

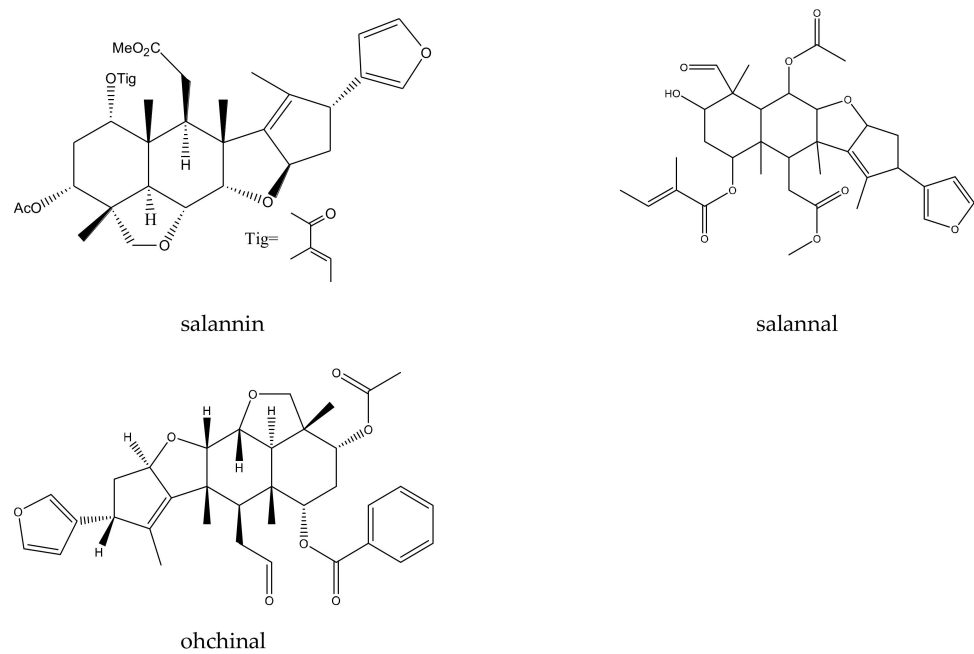


Figure 10. Structures of ring-seco limonoids: ring C-seco group (salannin-class chemicals).

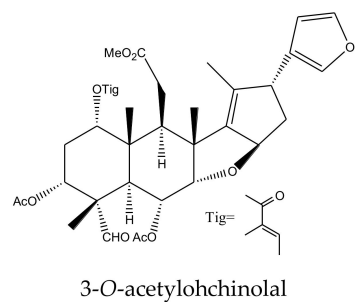


Figure 11. Structure of ring-seco limonoid: ring C-seco group (nimbin-class chemical).

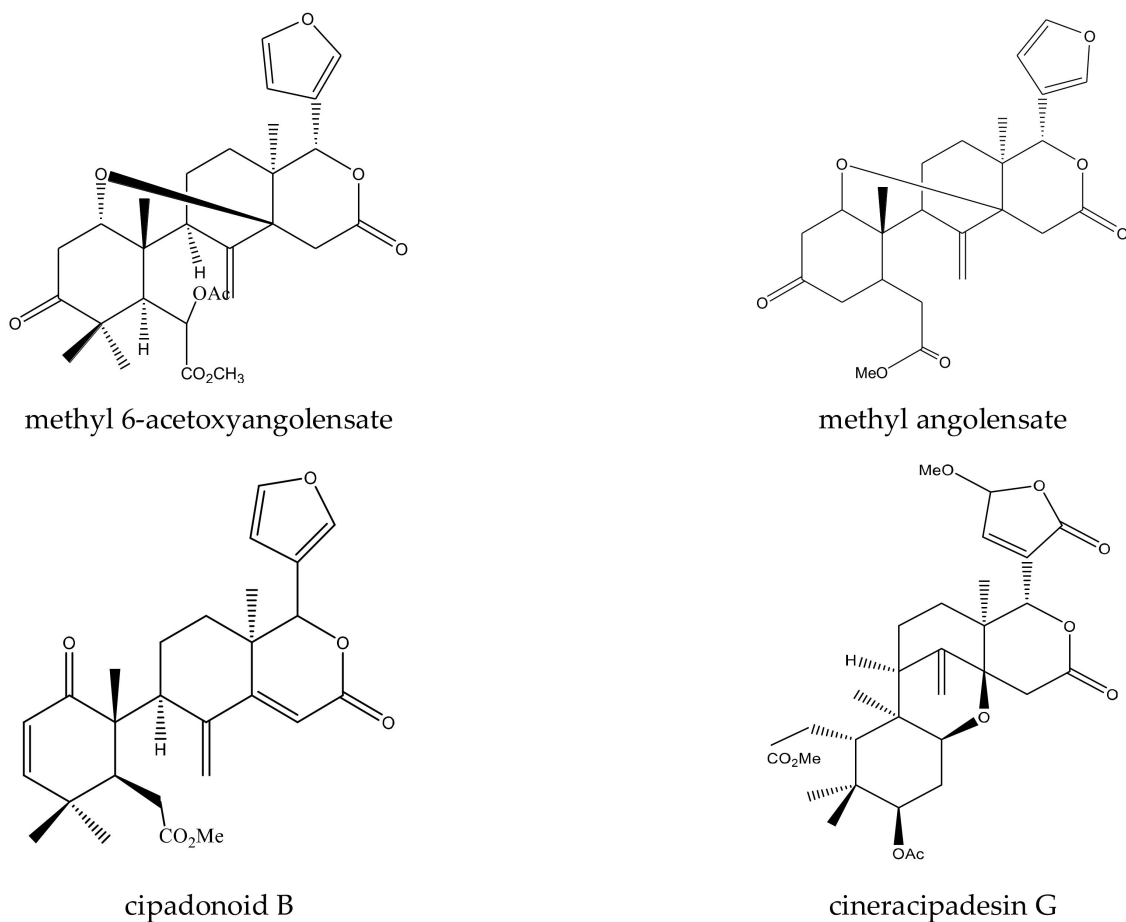


Figure 12. Structures of ring-seco limonoids: ring B,D-seco group (andirobin-class chemicals).

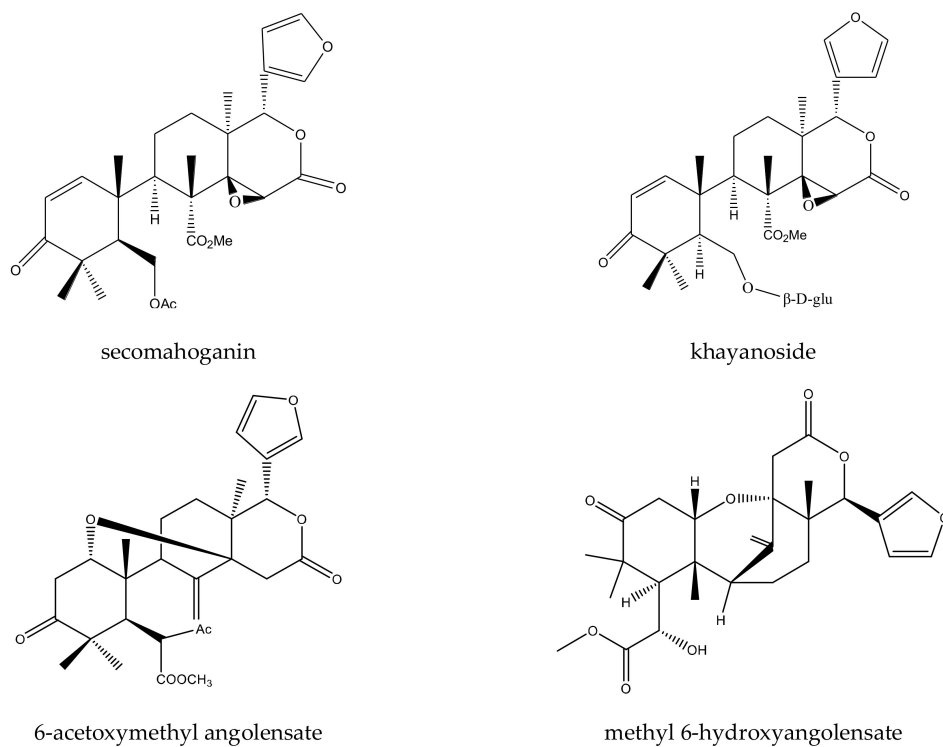


Figure 13. Structures of ring-seco limonoids: ring B,D-seco group (others).

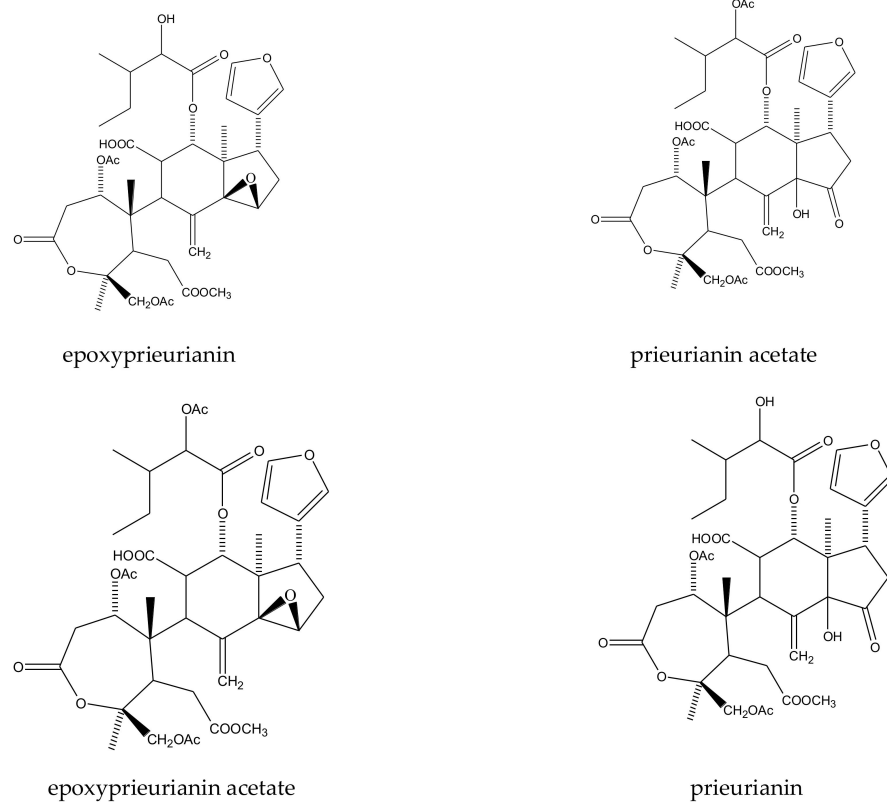


Figure 14. Structures of ring-seco limonoids: ring A,B-seco group (prieurianin-class chemicals).

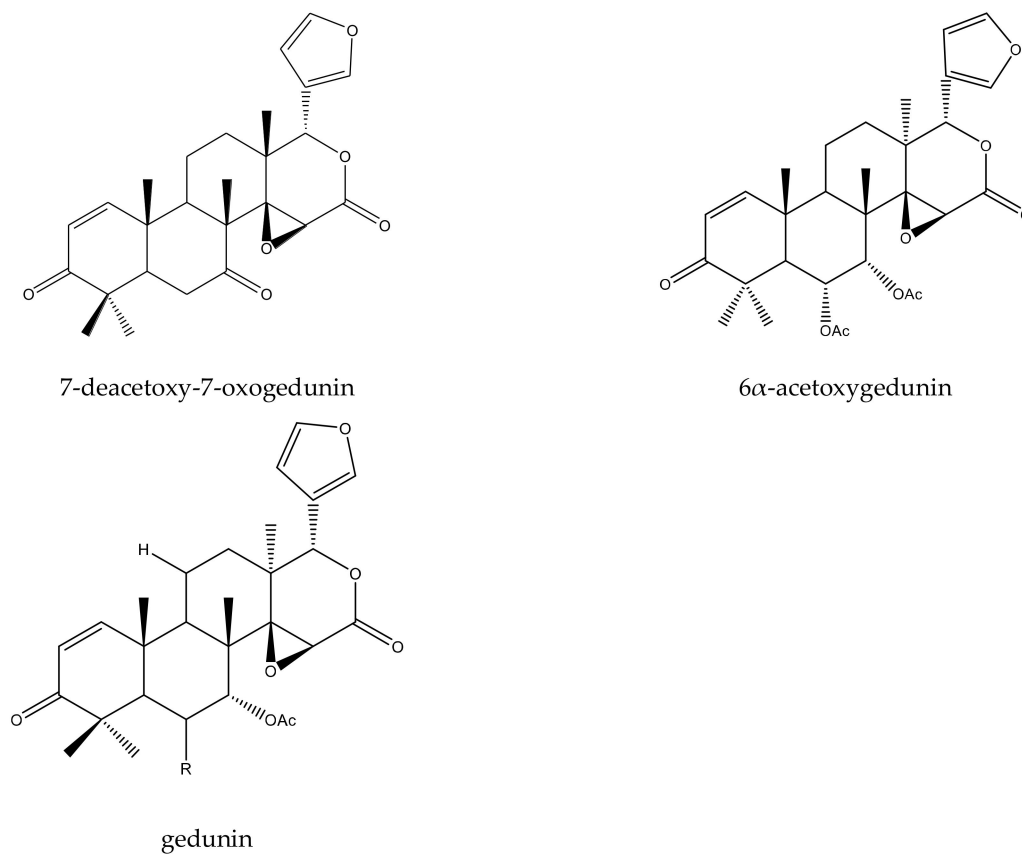


Figure 15. Structures of ring-seco limonoids: ring D-seco group chemicals.

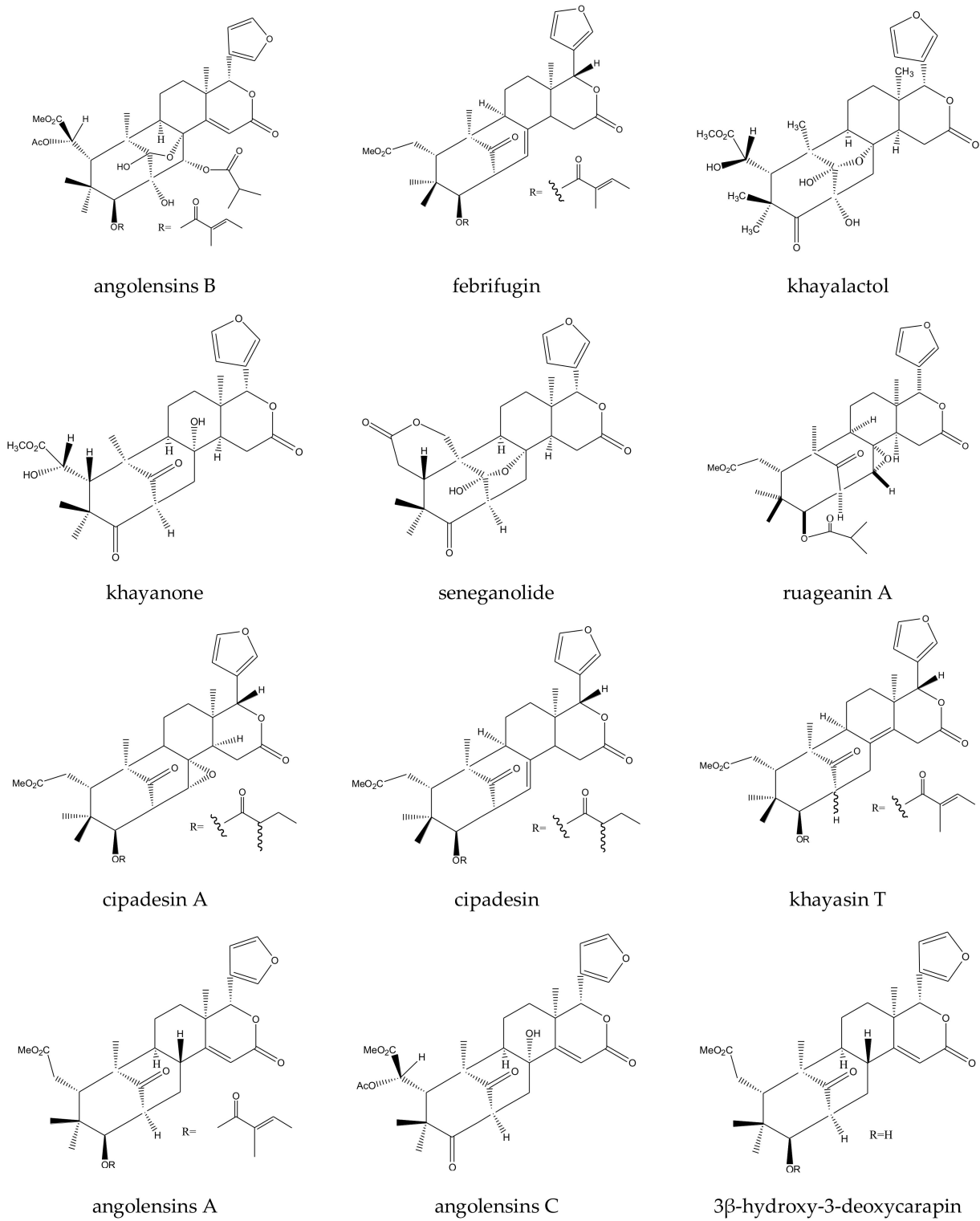


Figure 16. Cont.

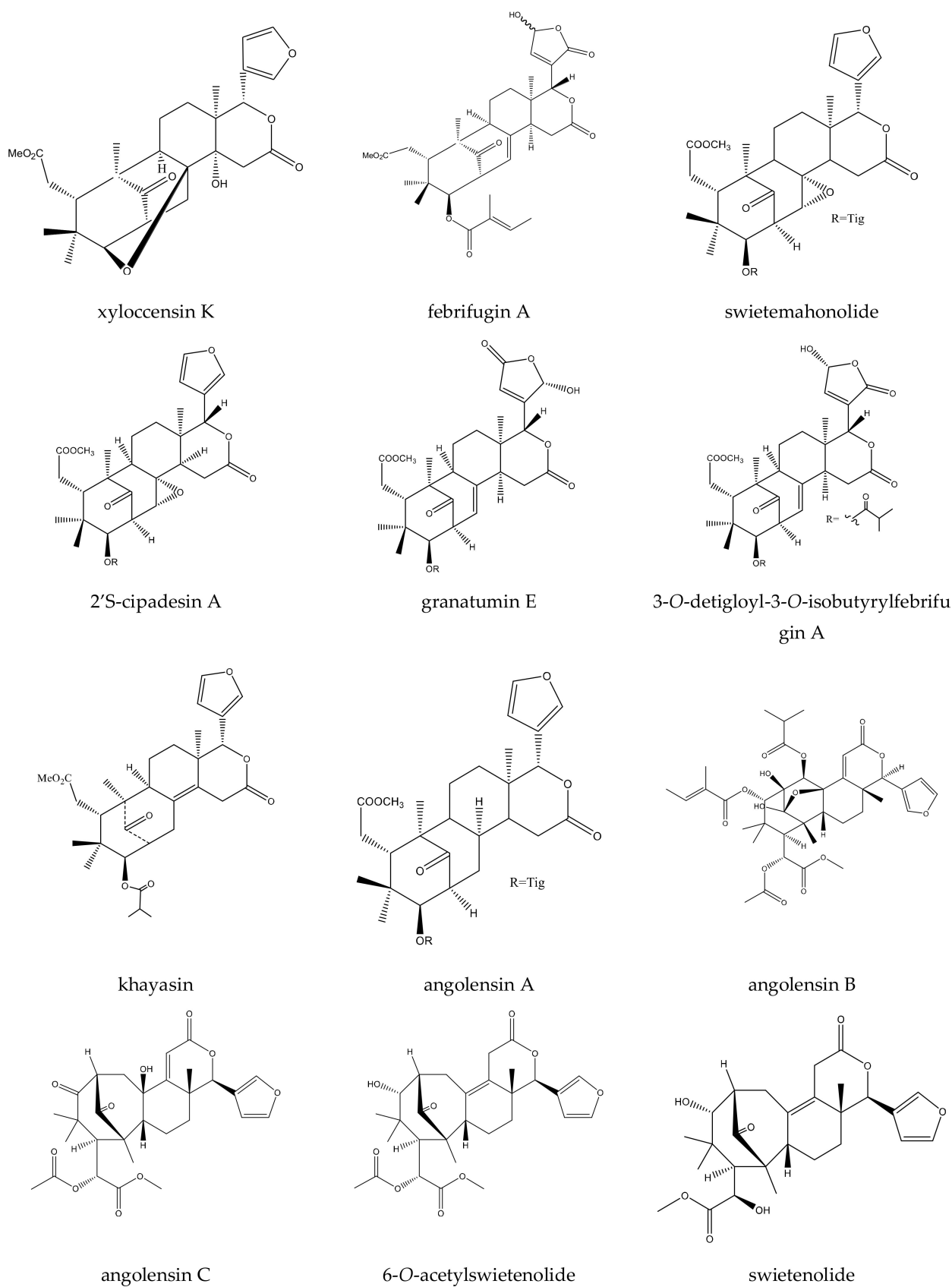


Figure 16. Structures of rearranged limonoids: ring 2,30-linkage group (mexicanolide-class chemicals).

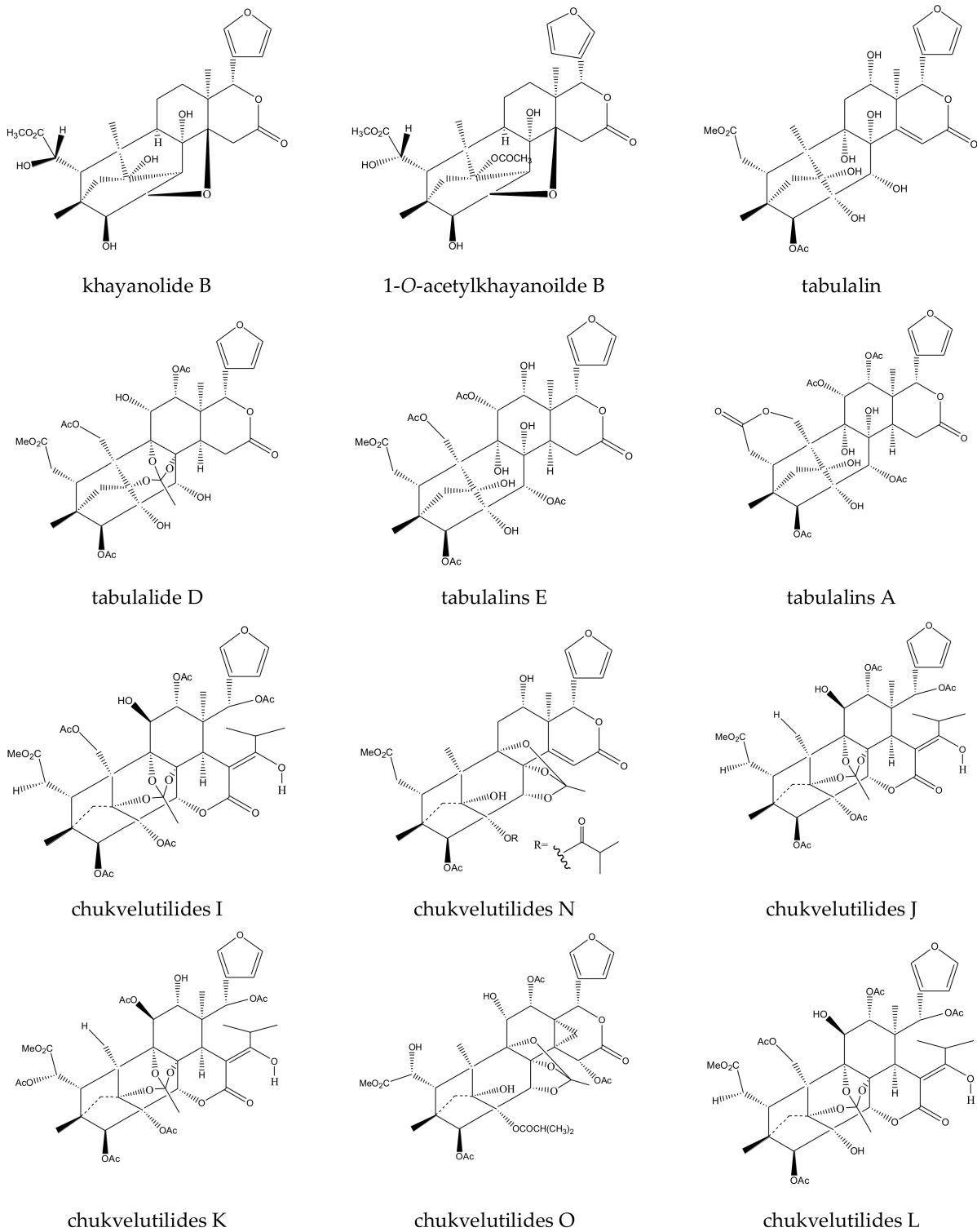


Figure 17. Cont.

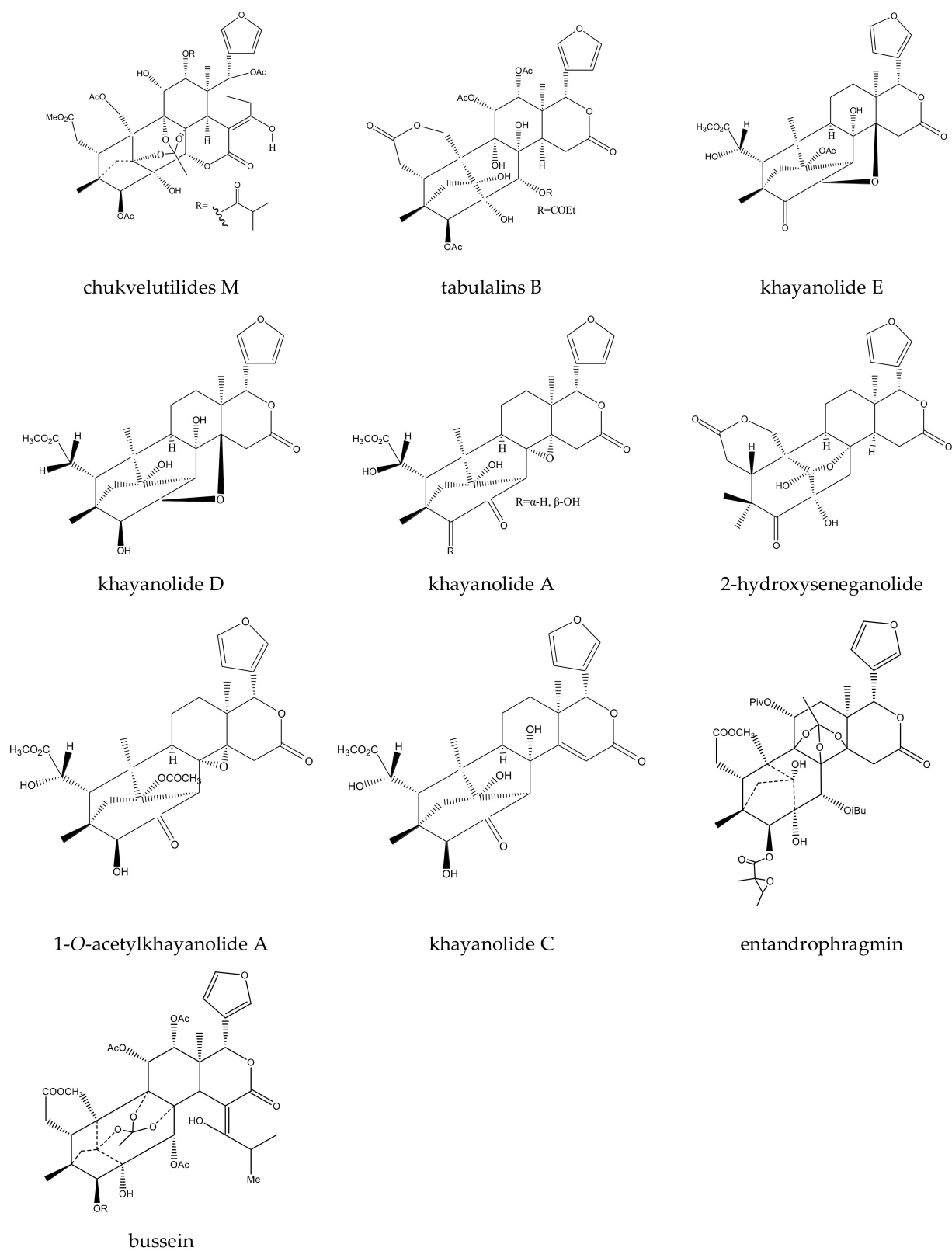


Figure 17. Structures of rearranged limonoids: ring 2,30-linkage group (phragmalin-class chemicals).



Figure 18. Structures of rearranged limonoids: ring 10,11-linkage group chemicals.

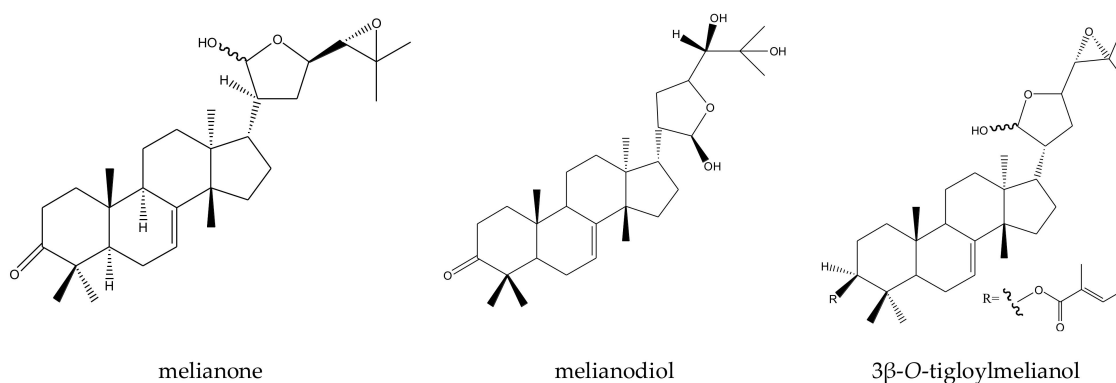


Figure 19. Structures of tetracyclic triterpenes: protolimonoids.

Khayanolide B and 1-*O*-acetylkhayanolide B with a C2–C14 ether linkage and hydroxyl group at C8 were more potent antifeedants than khayanolide A with a C8–C14 epoxide group and a keto-carbonyl group at C-2. The presence of a hydroxyl group at C-1 slightly enhanced the antifeedant activity of khayanolide B compared with the acetoxy group in 1-*O*-acetylkhayanolide B, indicating that the substituents at C-1 in this type of molecule had no marked effect on antifeedant activity [54].

Analysis revealed that febrifugin A had a furan-ring oxygenated group at C-21 and a hydroxy group at C-23, which contributed to the insecticidal activity. The high insecticidal activity of febrifugin A further confirmed that the hydroxyl group on C-23 and the carbonyl group on C-21 had a great influence on the activity. Compared with the furan ring oxygenated at C-21 and C-23, intact and seco-rings and an intact furan ring in the limonoids showed more significant antifeedant activity [43,47].

For the protolimonoid melianodiol, the presence of a carbonyl moiety at C-3 in the 21,23-epoxy-21,24,25-trihydroxy-tirucall-7-ene-type skeleton played an important role in the insecticidal activity [20]. Additionally, the 12 α -OH function of trichilin-class limonoids was the most potent, followed by 12 β -OH, 12-desoxy, and 12 α -acetoxy groups in order of decreasing potency [45].

4. Insecticidal Mechanism of Action

The study of the insecticidal mechanism of action (MOA) of triterpenoids from these five genera mainly focused on the MOA of toosendanin. Several MOA studies of other molecules reported on the inhibition of certain enzymes. For example, khayanolide B was reported to show weak inhibitory activities toward the enzymes acetylcholinesterase (AChE), butyrylcholinesterase (BuChE), and lipoxygenase (LOX) in a concentration-dependent manner [203]. The inhibition of AChE by the mexicanolide limonoids 3-*O*-detigloyl-3-*O*-isobutyrylfebrifugin A, granatumin E, khaysin T, and 2'-*S*-cipadesin A have also been reported, and they showed moderate inhibitory activities against AChE at 50 mM [37]. In addition, prieurianin was reported as an antagonist of 20-hydroxyecdysone. When tested

with the *D. melanogaster* B-II cell line, the ED₅₀ value of prierianin was 10⁻⁵ M with a 20-hydroxyecdysone concentration of 5 × 10⁻⁸ M [204].

The MOA of toosendanin has been systemically studied. Using the electrophysiological technique, the mechanism study of toosendanin as a feeding deterrent for the larvae of the cabbage butterfly, *P. brassicae*, demonstrated that toosendanin stimulated a deterrent receptor cell located in the medial maxillary sensillum styloconicum. Toosendanin, even at the low concentration of 10⁻⁹ M, also inhibited the responses of both the sugar and the glucosinolate receptor cell localized in the lateral sensillum styloconicum, in a dose-dependent manner. However, the taste neurons responding to amino acids or deterrents in the lateral sensillum were not affected by toosendanin. Therefore, it could be concluded that the sensory code underlying feeding behavior was modulated by toosendanin via several different peripheral sensory mechanisms [205]. Further studies showed that toosendanin seemed to specifically induce feeding deterrence in the larvae of the cotton bollworm, *H. armigera*, and apparently stimulated deterrent receptor cells and reduced neural input from taste cells specialized to detect feeding stimulants [30].

The possible mechanism underlying the poisonous activity of toosendanin has also been analyzed. It was found that the activities of protease and microsome multifunctional oxidase (MFO) in the midgut tissue of the larvae of the cabbage worm, *P. rapae*, fed with toosendanin were inhibited. However, the activities of lipase, amylase, and acetylcholinesterase were not significantly affected. The physiological metabolism of the larvae was disturbed, and abnormal biological oxidation was carried out in the body, while the metabolic level decreased. Histological observation revealed degradation in the microvilli, hyperplasia of the smooth endoplasmic reticulum, and condensation of chromatin. Moreover, immunohistochemical analysis revealed that gold particles existed on the microvilli of columnar cells and goblet cells, and they gradually accumulated with the exacerbation of poisoning symptoms, showing that toosendanin targeted the microvilli of midgut cells. In addition, it inhibited the central nervous system of the larvae [206–209].

Furthermore, studies on the larvae and female adults of the mosquito, *A. aegypti*, revealed that topical application or ingested toosendanin dose-dependently disrupted yolk deposition in oocytes, blood ingestion and digestion, and ovary ecdysteroid production in blood-fed females [210]. It is noteworthy that medicinal studies demonstrated that toosendanin selectively affected neurotransmitter release, effectively antagonized botulism, induced cell differentiation and apoptosis, inhibited proliferation of various human cancer cells, and inhibited K⁺-channel and facilitated L-type Ca²⁺-channel activity [211]. These results are good starting points for further research on the MOA of toosendanin as an insecticidal molecule.

5. Environmental Toxicity

In fact, various extracts of plants or some pure chemicals in Meliaceae have been used as traditional medicines. The ethnomedical uses of the plant are as varied as the different cultures and geographical people that make use of the plant. For example, the stem bark of *K. senegalensis* has been used in the treatment of several conditions, including stomach pain, malaria, fever, and blennorrhagia, in Africa [212]. The pure chemical, toosendanin, isolated from *M. toosendan*, has been used to treat abdominal pain and as a digestive tract parasiticide in ancient China for about 1500 years [213].

Generally, these extracts or chemicals are comparatively safe to the environment, human beings, and natural enemies. It was reported that andiroba oil (including gedunin, 6 α -acetoxygedunin, 7-deacetoxy-7-oxogedunin, 7-deacetylgedunin, 1,2-dihydro-3 β -hydroxy-7-deacetoxy-7-oxogedunin, and andirobin) was not toxic in bioassays conducted with mice [214]. The ring-intact limonoid neoazedarachin B exhibited low toxicity in brine shrimp with an LC₅₀ value of 0.0098 μ M [215]. There were several reports about the safety of the extracts of *M. azedarach* to natural enemies. The aqueous leaf extracts of *M. azedarach* were reported to have no direct negative effects on the survival and foraging of parasitoids including *Cotesia plutellae* (Kurdjumov), *Diadromus collaris* (Gravenhorst), *Trichogramma*

evanescens Westwood, *Aphidius ervi* Haliday, *Aphidius colemani* Viereck, *Eretmocerus eremicus* (Rose & Zolnerowich), and *Encarsia formosa* (Gahan) [138,139]. Another study revealed that unripe *M. azedarach* fruit extracts (1%, w/w, obtained by the CEPROCOR, Cordoba-Argentina) demonstrated no detrimental effects on *Eriopsis connexa* (Germar) and could be compatible with *E. connexa* for pest control (Table 5) [216].

Normally, naturally derived plant extracts or chemicals are easily degraded and thus cause less residue to remain in the environment. For example, three days after the field application at five times the dose recommended by the manufacturer, the residue of salannin on strawberry (LOQ 0.01 mg/kg) was not detectable [217]. Another study demonstrated that toosendanin was easily degradable. At the recommended dose, the final residues of toosendanin detected by IC-ELISA were 0.009 mg/kg in cabbage and 0.043 mg/kg in tobacco. In soil, toosendanin residue was not detectable [218].

However, there were also some negative effects of these plant extracts or chemicals. Some extracts were reported to show a negative effect on rats. In detail, high doses of the crude water extract of *K. grandifoliola* reduced the Ca, P, Mg, and Zn levels of the bones and may have had an adverse effect on bone minerals in growing rats [219]. The methanol extracts of *K. ivorensis* were found to be relatively toxic, with an LD₅₀ value of 549 mg/kg per body weight of the mice [220]. The ethanolic extract of *K. senegalensis* adversely affected the function of the liver and kidneys of rats [221–223]. *M. azedarach* was also reported to possess a potent pregnancy interceptive property on the rat [224]. Isolated chemicals, such as methyl angolensate and toosendanin, were also reported to possess some negative effects. For example, methyl angolensate could cause the inhibition of smooth muscle and reduce the propulsive action of the gastrointestinal tract in mice [225]. The traditional medicinal chemical toosendanin had serious hepatotoxicity [226]. Severe cytoplasmic vacuolation and nuclear shrinkage were found in the liver of toosendanin-treated zebrafish [227]. Further studies revealed that toosendanin was pregnancy-toxic to animals (Table 5) [228].

Briefly, several studies have been conducted on the environmental toxicity of the extracts of plants or isolated chemicals from the five genera (*Cipadessa*, *Entandrophragma*, *Guarea*, *Khaya*, and *Melia*) in Meliaceae. Further studies are needed to elucidate the environmental toxicity of some important insecticidal chemicals for their future application in the field.

Table 5. Toxicity of isolated chemicals or plant extracts of the five genera (*Cipadessa*, *Entandrophragma*, *Guarea*, *Khaya*, and *Melia*) in Meliaceae on mice, aquatic organisms, and natural enemies.

Chemicals or Plant Extracts	Mice	Aquatic Organisms	Natural Enemies	Ref.
methyl angolensate	inhibition of smooth muscle, decrease of propulsive action of the gastrointestinal tract	-	-	[225]
toosendanin	serious hepatotoxicity, pregnancy-toxic	cytoplasmic vacuolation and nuclear shrinkage in liver of zebrafish	-	[226–228]
neoazedarachin B	-	low toxicity to brine shrimp, LC ₅₀ = 0.0059 µg/mL (48 h)	-	[215]
methanol extracts of <i>K. ivorensis</i>	relatively toxic, LD ₅₀ = 549 mg/kg	-	-	[220]
ethanolic extract of <i>K. senegalensis</i>	adverse effect on liver and kidney	-	-	[221–223]
chloroform fraction of <i>M. azedarach</i>	potent pregnancy interceptive property	-	-	[224]
andiroba oil (<i>C. guianensis</i> oil)	not toxic at 2000 mg/kg (14 d)	-	-	[214]
water extract of <i>K. grandifoliola</i>	adverse effect on bone minerals (at 500 mg/kg)	-	-	[219]

Table 5. Cont.

Chemicals or Plant Extracts	Mice	Aquatic Organisms	Natural Enemies	Ref.
aqueous leaf extracts of <i>M. azedarach</i>	-	-	no direct negative effects on the survival and foraging of <i>Cotesia plutellae</i> , <i>Diadromus collaris</i> , <i>Trichogramma evanescens</i> , <i>Aphidius ervi</i> , <i>Aphidius colemani</i> , <i>Eretmocerus eremicus</i> and <i>Encarsia formosa</i>	[138,139]
<i>M. azedarach</i> unripe fruit extracts	-	-	no detrimental effects on <i>Eriopsis connexa</i>	[216]

6. Future Outlook

The unique insecticidal properties of insecticidal plants, particularly Meliaceae, which are safe both for the environment and natural enemies, and their compatibility with the agroecosystem emphasize their potential value in the integrated control of insect pests [195].

The use of toosendanin as an agricultural insecticide, with marked systemic properties, showing various activities including antifeeding, deterring, growth-inhibitory, contact poisoning, and stomach poisoning activities, was recorded about 2000 years ago in ancient China. There are still various commercial formulations of toosendanin on the market. In addition, there are other molecules with obvious insecticidal activity that deserve further attention. Like toosendanin, gedunin possesses various activities toward insects and exhibits good potential to be used as a lead compound for the development of novel insecticides. Other chemicals, such as khayasin and 12-deacetyltoosendanin, also deserve further attention. Their activities toward insects should be systemically evaluated, and their effects on nontarget organisms and the environment should also be further studied.

Recently, knowledge of the biosynthesis of important bioactive molecules in plants has become increasingly important. Understanding the biosynthetic pathways and their regulation has led to attempts to metabolically engineer bioactive molecules more successfully and more easily in economically important plants.

However, despite the intensive investigation of limonoids over several decades, the biosynthetic pathway of these triterpenoids is less understood. Enzymes involved in the biosynthesis of limonoids have been partially identified and characterized in some plant species. For example, AiOSC1 from the neem tree produces a single triterpene, tirucalla-7,24-dien-3 β -ol, indicating the importance of its role in azadirachtin biosynthesis [229]. Toosendanin from *M. toosendan* was proposed to be synthesized in a manner similar to azadirachtin, by cyclizing the precursor 2,3-oxidosqualene into a tirucalla-7,24-dien-3 β -ol as the scaffold, followed by scaffold rearrangements and the formation of the furan ring [5]. Lian et al. (2020) elucidated that MtOSC1 was a key enzyme in the production of triterpene tirucalla-7,24-dien-3 β -ol, while MtOSC6 (a lupeol synthase) was a key enzyme in the production of lupeol in *M. toosendan*. The product of MtOSC1 was the precursor for the biosynthesis of toosendanin. This research provided a foundation for toosendanin biosynthesis and presented an important building block for the synthesis of insecticidal triterpenoids using the synthetic biology approach [230].

Using synthetic biology methods, the identified enzymes could be used to model a biosynthetic pathway to produce large quantities of insecticidal molecules, such as azadirachtin and toosendanin. Therefore, further research needs to be carried out for the clear elucidation of the biosynthetic pathway of certain highly effective plant-derived insecticidal molecules. The biosynthesis of important plant-derived insecticidal molecules in Meliaceae will be a significant research topic of interest in the coming years.

Author Contributions: Conceptualization, J.H. and L.Z.; writing—original draft preparation, M.L. and X.B.; writing—review and editing, L.Z.; Structure drawing and classifying, J.H. All authors have read and agreed to the published version of the manuscript.

Funding: This work was funded by the Science and Technology Planning Programs of Guangdong Province, China (2017A020208040) and the Department of Science and Technology of Guangdong Province (KTP20210359). And The APC was funded by the Science and Technology Planning Programs of Guangdong Province, China (2017A020208040).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Acknowledgments: This work was funded by the Science and Technology Planning Programs of Guangdong Province, China (2017A020208040) and the Department of Science and Technology of Guangdong Province (KTP20210359).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Sun, Z.Q.; Lv, M.; Huang, W.W.; Li, T.; Xu, H. Development of botanical pesticides: Exploration on the phenotype of vestigial wings of insect pests induced by plant natural products or their derivatives by blocking tyrosine phosphorylation of insulin receptor 1. *J. Agric. Food Chem.* **2022**, *70*, 2117–2126. [[CrossRef](#)] [[PubMed](#)]
2. Monteiro, R.A.; Camara, M.C.; Oliveira, J.L.; Carvalho, L.B.; Proença, P.L.F.; Casagrande, M.G.; Lima, R.; Nascimento, J.; Gonçalves, K.C.; Gonçalves, R.A.; et al. Zein based-nanoparticles loaded botanical pesticides in pest control: An enzyme stimuli-responsive approach aiming sustainable agriculture. *J. Hazard. Mater.* **2021**, *417*, 126004. [[CrossRef](#)] [[PubMed](#)]
3. Stephen, O.D.; Antonio, E.; Maurizio, V. Natural products in pest management: Innovative approaches for increasing their use. *Pest Manag. Sci.* **2019**, *75*, 2299–2300.
4. Lorschach, B.A.; Sparks, T.C.; Cicchillo, R.M.; Garizi, N.V.; Hahn, D.R.; Meyer, K.G. Natural products: A strategic lead generation approach in crop protection discovery. *Pest Manag. Sci.* **2019**, *75*, 2301–2309. [[CrossRef](#)] [[PubMed](#)]
5. Tan, Q.G.; Luo, X.D. Meliaceous limonoids: Chemistry and biological activities. *Chem. Rev.* **2011**, *111*, 7437–7522. [[CrossRef](#)]
6. Fan, W.X.; Fan, L.H.; Wang, Z.T.; Yang, L. Limonoids from the genus *Melia* (Meliaceae): Phytochemistry, synthesis, bioactivities, pharmacokinetics, and toxicology. *Front. Pharmacol.* **2021**, *12*, 795565. [[CrossRef](#)]
7. Lin, M.H.; Yang, S.F.; Huang, J.G.; Zhou, L.J. Insecticidal triterpenes in meliaceae: Plant species, molecules and activities: Part I (*Aphanamixis-Chukrasia*). *Int. J. Mol. Sci.* **2021**, *22*, 13262. [[CrossRef](#)]
8. Yu, J.H.; Zhang, H.; Zhou, B.; Zimbres, F.M.; Dalal, S.; Liu, Q.F.; Cassera, M.B.; Yue, J.M. Limonoids from *Cipadessa baccifera*. *J. Nat. Prod.* **2020**, *83*, 1751–1765. [[CrossRef](#)]
9. Yu, J.H.; Zhou, B.; Dalal, S.; Liu, Q.F.; Cassera, M.B.; Yue, J.M. Cipaferoids A–C, three limonoids represent two different scaffolds from *Cipadessa baccifera*. *Chin. J. Chem.* **2018**, *36*, 124–128. [[CrossRef](#)]
10. Yakusu, E.K.; Monthe, F.S.; Bourland, N.; Hardy, O.J.; Louppe, D.; Lokanda, F.B.M.; Hubau, W.; Muhongya, J.M.K.; Bulcke, J.V.D.; Acker, J.V.; et al. Entandrophragma: Taxonomy and ecology of a genus of African tree species with economic importance. A review. *Biotechnol. Agron. Soc. Environ.* **2018**, *22*, 113–127. [[CrossRef](#)]
11. Arnason, J.T.; Philogène, B.J.R.; Donskov, N.; Kubo, I. Limonoids from the meliaceae and rutaceae reduce feeding, growth and development of *Ostrinia nubilalis*. *Entomol. Exp. Appl.* **1987**, *43*, 221–226. [[CrossRef](#)]
12. Eckebil, P.P.T.; Verheggen, F.; Doucet, J.L.; Malaisse, F.; Dainou, K.; Cerutti, P.O.; Vermeulen, C. *Entandrophragma cylindricum* (Sprague) Sprague (Meliaceae), a competitive tree species in central Africa. A review. *Biotechnol. Agron. Soc. Environ.* **2017**, *21*, 80–97. [[CrossRef](#)]
13. Mulholland, D.A.; Schwikkard, S.L.; Sandor, P.; Nuzillard, J.M. Delevoyin C, a tetranortriterpenoid from *Entandrophragma delevoyi*. *Phytochemistry* **2000**, *53*, 465–468. [[CrossRef](#)]
14. Zhang, W.Y.; An, F.L.; Zhou, M.M.; Chen, M.H.; Jian, K.L.; Quasie, O.; Yang, M.H.; Luo, J.; Kong, L.Y. Limonoids with diverse frameworks from the stem bark of *Entandrophragma angolense* and their bioactivities. *RSC Adv.* **2016**, *6*, 97160–97171. [[CrossRef](#)]
15. Mulholland, D.A.; Osborne, R.; Roberts, S.L.; Taylor, D.A.H. Limonoids and triterpenoid acids from the bark of *Entandrophragma delevoyi*. *Phytochemistry* **1994**, *37*, 1417–1420. [[CrossRef](#)]
16. Connolly, J.D.; Phillips, W.R.; Mulholland, D.A.; Taylor, D.A.H. Spicatin, a protolimonoid from *Entandrophragma spicatum*. *Phytochemistry* **1981**, *20*, 2596–2597. [[CrossRef](#)]
17. Lukacova, V.; Polonsky, J.; Moretti, C.; Pettit, G.R.; Schmidt, J.M. Isolation and structure of 14,15 β -epoxyprieurianin from the south american tree *Guarea guidona*. *J. Nat. Prod.* **1982**, *45*, 288–294. [[CrossRef](#)]
18. Jimenez, A.; Villarreal, C.; Toscano, R.A.; Cook, M.; Arnason, J.T.; Bye, R.; Mata, R. Limonoids from *Swietenia humilis* and *Guarea grandiflora* (Meliaceae). *Phytochemistry* **1998**, *49*, 1981–1988. [[CrossRef](#)]
19. Housley, J.R.; King, F.E.; King, T.J.; Taylor, P.R. The chemistry of hardwood extractives. Part XXXIV. Constituents of *Guarea* species. *J. Chem. Soc.* **1962**, 5095–5104. [[CrossRef](#)]
20. Sarmiento, U.C.; Miguita, C.H.; Almeida, L.M.G.E.; Souza, A.S.; Garcez, W.S.; Garcez, F.R. Larvicidal efficacies of plants from midwestern Brazil: Melianodiol from *Guarea kunthiana* as a potential biopesticide against *Aedes aegypti*. *Mem. Inst. Oswaldo Cruz* **2016**, *111*, 469–474. [[CrossRef](#)]

21. Barbosa, C.D.S.; Borges, L.M.F.; Louly, C.C.B.; Rocha, T.L.; Morais, S.M.T.S.; Miguita, C.H.; Garcez, W.S.; Garcez, F.R. In vitro activity of 3 β -O-tigloylmelianol from *Guarea kunthiana* A. Juss (Meliaceae) on oogenesis and ecdysis of the cattle tick *Rhipicephalus (Boophilus) microplus* (Canestrini) (Acari: Ixodidae). *Exp. Parasitol.* **2016**, *164*, 5–11. [[CrossRef](#)] [[PubMed](#)]
22. Csdiz-Gurrea, M.D.; Sinan, K.I.; Zengin, G.; Bene, K.; Etienne, O.K.; Leyva-Jiménez, F.J.; Fernandez-Ochoa, A.; Villegas-Aguilar, M.C.; Mahomoodally, M.F.; Lobine, D.; et al. Bioactivity assays, chemical characterization, ADMET predictions and network analysis of *Khaya senegalensis* A. Juss (Meliaceae) extracts. *Food Res. Int.* **2021**, *139*, 109970. [[CrossRef](#)] [[PubMed](#)]
23. Zhang, H.; Tan, J.; Vanderveer, D.; Wang, X.; Wargovich, M.J.; Chen, F. Khayanolides from African mahogany *Khaya senegalensis* (Meliaceae): A revision. *Phytochemistry* **2009**, *70*, 294–299. [[CrossRef](#)] [[PubMed](#)]
24. Mukaila, Y.O.; Ajao, A.N.; Moteetee, A.N. *Khaya grandifoliola* CDC. (Meliaceae: Sapindales): Ethnobotany, phytochemistry, pharmacological properties, and toxicology. *J. Ethnopharmacol.* **2021**, *278*, 114253. [[CrossRef](#)]
25. Ambrozín, A.R.; Leite, A.C.; Bueno, F.C. Limonoids from andiroba oil and *Cedrela fissilis* and their insecticidal activity. *J. Braz. Chem. Soc.* **2006**, *17*, 542–547. [[CrossRef](#)]
26. Yuan, T.; Zhang, C.R.; Yang, S.P.; Yue, J.M. Limonoids and triterpenoids from *Khaya senegalensis*. *J. Nat. Prod.* **2010**, *73*, 669–674. [[CrossRef](#)]
27. Chiffelle, T.; Huerta, A.; Bobadilla, V.; Macuada, G.; Ceballos, R. Antifeedant and insecticidal effects of extracts from *Melia azedarach* fruits and *Peumus boldus* leaves on *Xanthogaleruca luteola* larvae. *Chil. J. Agric. Res.* **2019**, *79*, 609–615. [[CrossRef](#)]
28. Nakatani, M.; Zhou, J.B.; Minami, Y.; Yagi, F.; Tadera, K. Antifeeding limonoids from *Melia toosendan*. *Heterocycles* **1997**, *45*, 1781–1786. [[CrossRef](#)]
29. Rajab, M.S.; Bentley, M.D.; Alford, A.R.; Mendel, M.J. A new limonoid insect antifeedant from the fruit of *Melia volkensii*. *J. Nat. Prod.* **1988**, *51*, 168–171. [[CrossRef](#)]
30. Koul, O.; Multani, J.S.; Singh, G.; Wahab, S. Bioefficacy of toosendanin from *Melia dubia* (syn. *M. Azedarach*) against gram pod-borer, *Helicoverpa armigera* (Hübner). *Curr. Sci. India* **2002**, *83*, 1387–1391.
31. Kipassa, N.T.; Iwagawa, T.; Okamura, H.; Doe, M.; Morimoto, Y.; Nakatani, M. Limonoids from the stem bark of *Cedrela odorata*. *Phytochemistry* **2008**, *69*, 1782–1787. [[CrossRef](#)] [[PubMed](#)]
32. Koul, O.; Daniewski, W.M.; Multani, J.S.; Maria, G.; Gurmeet, S. Antifeedant effects of the limonoids from *Entandrophragma candolei* (Meliaceae) on the gram pod borer, *Helicoverpa armigera* (Lepidoptera: Noctuidae). *J. Agric. Food Chem.* **2003**, *51*, 7271–7275. [[CrossRef](#)] [[PubMed](#)]
33. Nakatani, M.; Abdelgaleil, S.A.; Kassem, S.M.; Takezaki, K.; Okamura, H.; Iwagawa, T.; Doe, M. Three new modified limonoids from *Khaya senegalensis*. *J. Nat. Prod.* **2002**, *65*, 1219–1221. [[CrossRef](#)] [[PubMed](#)]
34. Abdelgaleil, S.A.M.; Nakatani, M. Antifeeding activity of limonoids from *Khaya senegalensis* (Meliaceae). *J. Appl. Entomol.* **2003**, *127*, 236–239. [[CrossRef](#)]
35. Mootoo, B.S.; Ali, A.; Motilal, R.; Pingal, R.; Mclean, S. Limonoids from *Swietenia macrophylla* and *S. aubrevilleana*. *J. Nat. Prod.* **1999**, *62*, 1514–1517. [[CrossRef](#)]
36. Munehiro, N.; Huang, R.C.; Hiroaki, O.; Iwagawa, T.; Tadera, K.; Naokic, H. Three new antifeeding meliacarpinins from Chinese *Melia azedarach* Linn. *Tetrahedron* **1995**, *51*, 11731–11736.
37. Huang, C.R.; Zhou, J.B.; Suenaga, H.; Takezaki, K.; Nakatani, M. Insect antifeeding property of limonoids from Okinawan and Chinese *Melia azedarach* L., and from Chinese *Melia toosendan* (Meliaceae). *Biosci. Biotechnol. Biochem.* **1995**, *59*, 1755–1757. [[CrossRef](#)]
38. Zhou, J.B.; Tadera, K.; Minami, Y.; Wang, Z.T.; Bo, Y.Y. New limonoids from *Melia toosendan*. *Biosci. Biotechnol. Biochem.* **1998**, *62*, 496–500. [[CrossRef](#)]
39. Carpinel, C.; Defagó, M.T.; Valladares, G.; Palacios, S.M. Antifeedant and insecticide properties of a limonoid from *Melia azedarach* (Meliaceae) with potential use for pest management. *J. Agric. Food Chem.* **2003**, *51*, 369–374. [[CrossRef](#)]
40. Suresh, G.; Gopalakrishnan, G.; Wesley, D.; Singh, N.D.P.; Malathi, R.; Rajan, S.S. Insect antifeedant activity of the tetranortriterpenoids from the rutales. A perusal of structural relations. *J. Agric. Food Chem.* **2002**, *50*, 4484–4490. [[CrossRef](#)]
41. Hui, S.R.; Mujo, K.; Takehiko, Y.; Shozo, T. Antifeeding constituents of *Phellodendron chinense* fruit against *Reticulitermes speratus*. *J. Pestic. Sci.* **1990**, *15*, 567–572.
42. Fu, L.R.; Ma, Q.Y.; Huang, S.Z.; Dai, H.F.; Guo, Z.K.; Yu, Z.F.; Zhao, Y.X. Terpenoids and their anti-feedant activity from *Cipadessa cinerascens*. *J. Asian Nat. Prod. Res.* **2015**, *16*, 1054–1059. [[CrossRef](#)] [[PubMed](#)]
43. Matos, A.P.; Leite, A.C.; Batista-Pereira, L.G.; Vieira, P.C.; Fernandes, J.B.; Silva, M.F. Effects of limonoids from *Cipadessa fruticosa* on fall armyworm. *J. Biosci.* **2009**, *64*, 441–446. [[CrossRef](#)] [[PubMed](#)]
44. Wang, H.; Dong, H.Y.; He, Q.M.; Liang, J.L.; Zhou, L. Characterization of limonoids isolated from the fruits of *Melia toosendan* and their antifeedant activity against *Pieris rapae*. *Chem. Biodivers.* **2020**, *17*. [[CrossRef](#)]
45. Jaoko, V.; Taning, C.N.; Backx, S.; Mulatya, J.; Abeele, J.V.; Magomere, T.; Olubayo, F.; Mangelinckx, S.; Werbrouck, S.P.O.; Smagghe, G. The phytochemical composition of *Melia volkensii* and its potential for insect pest management. *Plants* **2020**, *9*, 143. [[CrossRef](#)] [[PubMed](#)]
46. Gervais, M.H.; Bonaventure, T.N.; Robert, G.I.; Simeon, F.K. Phytochemistry and pharmacology of the genus *Entandrophragma* over the 50 years from 1967 to 2018: A ‘golden’ overview. *J. Pharm. Pharmacol.* **2018**, *70*, 1431–1460.
47. Bandi, A.K.R.; Lee, D. Secondary metabolites of plants from the genus *Cipadessa*: Chemistry and biological activity. *Chem. Biodivers.* **2012**, *9*, 1403–1421. [[CrossRef](#)] [[PubMed](#)]

48. Park, E.S.; Bae, I.K.; Jeon, H.J.; Lee, S.E. Limonoid derivatives and its pesticidal activities. *Entomol. Res.* **2014**, *44*, 158–162. [[CrossRef](#)]
49. Xie, Y.S.; Fields, P.G.; Isman, M.B.; Chen, W.K.; Zhang, X. Insecticidal activity of *Melia toosendan* extracts and toosendanin against three stored-product insects. *J. Stored Prod. Res.* **1995**, *31*, 259–265. [[CrossRef](#)]
50. Sarria, A.L.F.; Soares, M.S.; Matos, A.P.; Fernandes, J.B.; Vieira, P.C.; Silva, M.F.G.F. Effect of triterpenoids and limonoids isolated from *Cabrlea canjerana* and *Carapa guianensis* (Meliaceae) against *Spodoptera frugiperda* (JE Smith). *Z. Naturforsch. C* **2011**, *66*, 245–250. [[CrossRef](#)]
51. Leite, A.C.; Bueno, F.C.; Oliveira, C.G.; Fernandes, J.B.; Vieira, P.C.; Silva, M.F.G.F.; Bueno, O.C.; Pagnocca, F.C.; Hebling, M.J.A.; Bacci, M., Jr. Limonoids from *Cipadessa fruticosa* and *Cedrela fissilis* and their insecticidal activity. *J. Braz. Chem. Soc.* **2005**, *16*, 1391–1395. [[CrossRef](#)]
52. Bohnenstengel, F.I.; Wray, V.; Witte, L.; Srivastava, R.P.; Proksch, P. Insecticidal meliacarpins (C-seco limonoids) from *Melia azedarach*. *Phytochemistry* **1999**, *50*, 977–982. [[CrossRef](#)]
53. Li, M.Y.; Zhang, J.; Feng, G.; Satyanandamurty, T.; Wu, J. Khayasin and 2'S-methylbutanoylproceranolide: Promising candidate insecticides for the control of the coconut leaf beetle, *Brontispa longissima*. *Balk. J. Geom. Appl.* **2011**, *36*, 22–26. [[CrossRef](#)]
54. El-Aswad, A.F.; Abdelgaleil, S.A.; Nakatani, M. Feeding deterrent and growth inhibitory properties of limonoids from *Khaya senegalensis* against the cotton leafworm, *Spodoptera littoralis*. *Pest Manag. Sci.* **2004**, *60*, 199–203. [[CrossRef](#)] [[PubMed](#)]
55. Chen, W.; Isman, M.B.; Chiu, S.F. Antifeedant and growth inhibitory effects of the limonoid toosendanin and extracts on the variegated cutworm, (Lep., Noctuidae). *J. Appl. Entomol.* **2010**, *119*, 367–370. [[CrossRef](#)]
56. Hofer, M.; Greger, H.; Mereiter, K. 6 α -Acetoxycedunin. *Acta Crystallogr. E* **2009**, *65*, 1942–1943. [[CrossRef](#)] [[PubMed](#)]
57. Chiu, S.F.; Zhang, X. A critical review of toosendanin a novel insecticide isolated from *Melia toosendan*. *J. South China Agric. Univ.* **1987**, *8*, 57–67.
58. Zhang, X.; Wang, X.L.; Feng, J.T.; Chiu, S.F. The development of botanical insecticides-toosendanin. *Acta Univ. Agric. Boreali-Occident.* **1993**, *21*, 1–5.
59. Ramkumar, G.; Karthi, S.; Muthusamy, R.; Natarajan, D.; Shivakumar, M.S. Adulticidal and smoke toxicity of *Cipadessa baccifera* (Roth) plant extracts against *Anopheles stephensi*, *Aedes aegypti*, and *Culex quinquefasciatus*. *Parasitol. Res.* **2014**, *114*, 167–173. [[CrossRef](#)]
60. Ramkumar, G.; Karthi, S.; Shivakumar, M.S.; Kweka, E.J. *Culex quinquefasciatus* egg membrane alteration and ovicidal activity of *Cipadessa baccifera* (Roth) plant extracts compared to synthetic insect growth regulators. *Res. Rep. Trop. Med.* **2019**, *10*, 145–151. [[CrossRef](#)]
61. Leite, A.C.; Oliveira, C.G.; Bacci, M. Toxicity of *Cipadessa fruticosa* to the leaf-cutting ants *Atta sexdens rubropilosa* (Hymenoptera: Formicidae) and their symbiotic fungus. *Sociobiology* **2005**, *46*, 17–26.
62. Malarvannan, S.; Sekar, S.; Subashini, H.D. Efficacy of *Cipadessa baccifera* leaf extracts against gram pod borer, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae). *J. Entomol. Res.* **2008**, *32*, 19–25.
63. Gan, L.S.; Wang, X.N.; Wu, Y.; Yue, J.M. Tetranortriterpenoids from *Cipadessa baccifera*. *J. Nat. Prod.* **2007**, *70*, 1344–1347. [[CrossRef](#)]
64. Faber, J.M.; Eger, W.A.; Williams, C.M. Enantioselective total synthesis of the mexicanolides: Khayasin, proceranolide, and mexicanolide. *J. Org. Chem.* **2012**, *77*, 8913–8921. [[CrossRef](#)]
65. Fang, X.; Di, Y.T.; Li, C.S.; Geng, Z.L.; Zhang, Z.; Zhang, Y.; Lu, Y.; Zheng, Q.T. Tetranortriterpenoids from the leaves of *Cipadessa cinerascens*. *J. Nat. Prod.* **2009**, *72*, 714–718. [[CrossRef](#)]
66. Yuan, Y.H.; Li, B.G.; Zhou, M.; Qi, H.Y.; Zhang, G.L. Cipadesins A–C: Novel tetranortriterpenoids from *Cipadessa cinerascens*. *Org. Lett.* **2005**, *7*, 5051–5053. [[CrossRef](#)]
67. Fang, X.; Zhang, Q.; Tan, C.J.; Zhen, M.S.; Lu, Y.; Lu, Y.B.; Zheng, Q.T.; Di, Y.T.; Hao, X.J. Cipadonoids B–G, six new limonoids from *Cipadessa cinerascens*. *Tetrahedron* **2009**, *65*, 7408–7414. [[CrossRef](#)]
68. Lin, L.G.; Tang, C.P.; Ke, C.Q.; Zhang, Y.; Ye, Y. Terpenoids from the stems of *Cipadessa baccifera*. *J. Nat. Prod.* **2008**, *71*, 628–632. [[CrossRef](#)]
69. Luo, X.D.; Wu, S.H.; Ma, Y.B.; Wu, D.G. Tirucallane triterpenoids from *Dysoxylum hainanense*. *Phytochemistry* **2000**, *54*, 801–805. [[CrossRef](#)]
70. Marpaung, L.; Nakamura, N.; Kakuda, H.; Hattori, M. Absolute configuration of cipadesin and febrifugin, from the seeds of *Cipadessa baccifera*. *Nat. Med.* **2001**, *55*, 220.
71. Leite, A.C.; Neto, A.P.; Ambrozini, A.R.P.; Fernandes, J.B.; Vieira, P.C.; Silva, M.F.G.F.; Albuquerque, S. Trypanocidal activity of flavonoids and limonoids isolated from Myrsinaceae and Meliaceae active plant extracts. *Rev. Brar. Farmacogn.* **2010**, *20*, 1–6. [[CrossRef](#)]
72. Faber, J.M.; Williams, C.M. A concise total synthesis of (\pm)-cipadonoid B from synthetic azedaralide. *Chem. Commun.* **2011**, *47*, 2258–2260. [[CrossRef](#)] [[PubMed](#)]
73. Akisanya, A.; Bevan, C.W.L.; Hirst, J.; Halsall, T.G.; Taylor, D.A.H. West African timbers. Part III. Petroleum extracts from the genus *Entandrophragma*. *J. Chem. Soc.* **1960**, *758*, 3827–3829. [[CrossRef](#)]
74. Daniewski, W.M.; Gumulka, M.; Anczewski, W.; Truszczyńska, D.; Błoszyk, E.; Drozd, B. Constituents of some Meliaceae plants and their antifeedant activity. Limonoids and sesquiterpenoids. *Pol. J. Chem.* **1996**, *70*, 1265–1269.
75. Adesida, G.A.; Taylor, D.A.H. The chemistry of the genus *Entandrophragma*. *Phytochemistry* **1967**, *6*, 1429–1433. [[CrossRef](#)]

76. Pettit, G.; Barton, G.H.R.; Herald, C.I.; Polonsky, J.; Schmidt, J.M.; Connolly, J.D. Evaluation of limonoids against the murine P388 lymphocytic leukemia cell line. *J. Nat. Prod.* **1983**, *46*, 379–390. [[CrossRef](#)] [[PubMed](#)]
77. Ishida, M.; Serit, M.; Nakata, K. Several antifeedants from neem oil, *Azadirachta indica* A. Juss. against *Reticulitermes speratus* Kolbe (Isoptera: Rhinotermitidae). *Biosci. Biotech. Biochem.* **2014**, *56*, 1835–1838. [[CrossRef](#)]
78. Koul, O.; Multani, J.S.; Singh, G. 6 β -hydroxygedunin from *Azadirachta indica*. Its potentiation effects with some non-azadirachtin limonoids in neem against lepidopteran larvae. *J. Agric. Food Chem.* **2003**, *51*, 2937–2942. [[CrossRef](#)] [[PubMed](#)]
79. Lago, J.H.G.; Claudia, B.B.; Roque, N.F. Terpenoids from *Guarea guidonia*. *Phytochemistry* **2002**, *60*, 333–338. [[CrossRef](#)]
80. Jessica, A.P.; Fabiana, G.; Mayara, C.S.; Luis, F.A.A.; Claudcir, C.M. Antimicrobial, insecticidal, and antioxidant activity of essential oil and extracts of *Guarea kunthiana* A. Juss. *J. Med. Plant Res.* **2015**, *9*, 48–55. [[CrossRef](#)]
81. Achnine, L.; Mata, R.; Lotina-Hennsen, B. Interference of the natural product 7-oxo-7-deacetoxygedunin with CF₀ of H⁺-ATPase of *Spinach Chloroplasts*. *Pestic. Biochem. Phys.* **1999**, *63*, 139–149. [[CrossRef](#)]
82. Bueno, F.C.; Godoy, M.P.; Leite, A.C.; Bueno, O.C.; Pagnocca, F.C.; Fernandes, J.B.; Hebling, M.J.A.; Bacci, J.M.; Vieira, P.C.; Silva, M.F.G.F. Toxicity of *Cedrela fissilis* to *Atta sexdens rubropilosa* (Hymenoptera: Formicidae) and its symbiotic fungus. *Sociobiology* **2005**, *45*, 389–399.
83. Okieimen, F.E.; Eromosele, C.O. Fatty acid composition of the seed oil of *Khaya senegalensis*. *Bioresour. Technol.* **1999**, *69*, 279–280. [[CrossRef](#)]
84. Adedeji, G.A.; Ogunsanwo, O.Y.; Eguakun, F.S.; Elufioye, O.T. Chemical composition and termiticidal activity of *Khaya ivorensis* stem bark extracts on woods. *Maderas-Cienc. Tecnol.* **2018**, *20*, 315–324. [[CrossRef](#)]
85. Babarinde, S.A.; Ewete, F.K. Comparative bioactivity of three *Khaya* species (Meliaceae) against *Callosobruchus maculatus* Fabricius (Coleoptera: Bruchidae). *J. Entomol. Res. Soc.* **2008**, *10*, 27–35.
86. Bamaiyi, L.J.; Ndams, I.S.; Toro, W.A.; Odekina, S. Effect of Mahogany *Khaya senegalensis* seed oil in the control of *Callosobruchus maculatus* on stored cowpea. *Plant Protec. Sci.* **2006**, *42*, 130–134. [[CrossRef](#)]
87. Shaalan, E.A.; Canyon, D.V.; Younes, M.W.F.; Hoda, A.W.; Abdel-Hamid, M. Efficacy of eight larvicidal botanical extracts from *Khaya senegalensis* and *Daucus carota* against *Culex annulirostris*. *J. Am. Mosquito Cont.* **2006**, *22*, 433–436. [[CrossRef](#)]
88. Kuevi, D.N.O.; Kuntworbe, N.; Ayertey, E. Effects of pH and electrolytes on castor oil emulsions with various stabilisers using *Khaya senegalensis* gum as an emulsifier. *Adv. Pharm. Pharm. Sci.* **2021**, *2021*, 7049332. [[CrossRef](#)]
89. Verma, R.K.; Yu, W.; Singh, S.P.; Shankar, S.; Srivastava, R.K. Anthothecol-encapsulated PLGA nanoparticles inhibit pancreatic cancer stem cell growth by modulating sonic hedgehog pathway. *Nanomed. Nanotechnol. Biol. Med.* **2015**, *11*, 2061–2070. [[CrossRef](#)]
90. Halsall, T.G.; Troke, J.A. The structures of three new meliacins isolated from *Khaya anthotheca* heartwood. *J. Chem. Soc. Perkin Trans. 1* **1975**, *6*, 1758–1764.
91. Adesida, G.A.; Adesogan, E.K.; Okorie, D.A. The limonoid chemistry of the genus *Khaya* (Meliaceae). *Phytochemistry* **1971**, *10*, 1845–1853. [[CrossRef](#)]
92. Adesogan, E.K.; Okorie, D.A.; Taylor, D.A.H. Limonoids from *Khaya anthotheca* (Welw.) C.DC. *J. Chem. Soc.* **1970**, *205*, 205–211. [[CrossRef](#)]
93. Ekong, D.E.U.; Joseph, I.; Sondengam, B.L. The meliacins (limonoids): Minor constituents of *Khaya anthotheca*: Reduction of the meliacins with zinc–copper couple. *J. Chem. Soc. Perkin Trans. 1* **1975**, *21*, 2118–2122. [[CrossRef](#)]
94. Bevan, C.W.L.; Rees, A.H.; Taylor, D.A.H. West African timbers. part VII. anthothecol, an extractive from *Khaya anthotheca*. *J. Chem. Soc.* **1963**, 983–989. [[CrossRef](#)]
95. Bickii, J.; Njifutie, N.; Foyere, J.A.; Basco, L.K.; Ringwald, P. In vitro antimalarial activity of limonoids from *Khaya grandifoliola* C.D.C. (Meliaceae). *J. Ethnopharmacol.* **2000**, *69*, 27–33. [[CrossRef](#)]
96. Adesogan, E.K.; Taylor, D.A.H. Limonoid extractives from *Khaya ivorensis*. *J. Chem. Soc.* **1970**, *12*, 1710–1714. [[CrossRef](#)]
97. Luco, J.M.; Sosa, M.C.; Cesco, J.C. Molecular connectivity and hydrophobicity in the study of antifeedant activity of clerodane diterpenoids. *Pestic. Sci.* **1994**, *41*, 1–6. [[CrossRef](#)]
98. Koul, O.; Isman, M.B. Toxicity of the limonoid allelochemical cedrelone to noctuid larvae. *Entomol. Exp. Appl.* **2011**, *64*, 281–287. [[CrossRef](#)]
99. Madhusudana, R.M.; Meshulam, H.; Zelnik, R. Structure and stereochemistry of limonoids of *Cabralea eichleriana*. *Phytochemistry* **1975**, *14*, 1071–1075. [[CrossRef](#)]
100. Govindachari, T.R.; Narsimhan, N.S.; Suresh, G.; Partho, P.D.; Gopalakrishnan, G.; Kumari, G.N.K. Structure related insect antifeedant and growth regulating activities of some limonoids. *J. Chem. Ecol.* **1995**, *21*, 1585–1600. [[CrossRef](#)]
101. Braga, P.; Soares, M.S.M.; Fátima, G.F.; Vieira, P.C.; Fernandes, J.B.; Pinheiro, A.L. Dammarane triterpenes from *Cabralea canjerana* (Vell.) Mart. (Meliaceae): Their chemosystematic significance. *Biochem. Syst. Ecol.* **2006**, *34*, 282–290. [[CrossRef](#)]
102. Adesogan, E.K.; Taylor, D.A.H. Extractives from *Khaya senegalensis* (Desr.) A. Juss. *Chem. Comm.* **1968**, *16*, 790–791. [[CrossRef](#)]
103. Magrini, F.E.; Specht, A.; Gaio, J.; Girelli, C.P.; Miguez, I.; Heinzen, C.; Saldana, J.; Sartori, V.C.; Cesio, V. Antifeedant activity and effects of fruits and seeds extracts of *Cabralea canjerana canjerana* (Vell.) Mart. (Meliaceae) on the immature stages of the fall armyworm *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae). *Ind. Crops Prod.* **2015**, *65*, 150–158. [[CrossRef](#)]
104. Abdel-Ghany, H.S.M.; Fahmy, M.M.; Abuowarda, M.M.; Abdel-Shafy, S.; Hoballah, E.M. In vitro acaricidal effect of *Melia azedarach* and *Artemisia herba-alba* extracts on *Hyalomma dromedarii* (Acari: Ixodidae): Embryonated eggs and engorged nymphs. *J. Parasit. Dis.* **2019**, *43*, 696–710. [[CrossRef](#)] [[PubMed](#)]

105. Bhakayaraj, K.; Kumaraguru, S.; Gopinath, K.; Sabitha, V.; Arumugam, A. Eco-friendly synthesis of palladium nanoparticles using *Melia azedarach* leaf extract and their evaluation for antimicrobial and larvicidal activities. *J. Clust. Sci.* **2017**, *28*, 463–476. [[CrossRef](#)]
106. Ramanibai, R.; Velayutham, K. Bioactive compound synthesis of Ag nanoparticles from leaves of *Melia azedarach* and its control for mosquito larvae. *Res. Vet. Sci.* **2015**, *98*, 82–88. [[CrossRef](#)]
107. Ntalli, N.; Kopiczko, A.; Radtke, K.; Marciniak, P.; Rosinski, G.; Adamski, Z. Biological activity of *Melia azedarach* extracts against *Spodoptera exigua*. *Biologia* **2014**, *69*, 1606–1614. [[CrossRef](#)]
108. Ashrafju, M.; Ahmadi, K.; Hamidi, H. Different concentrations of *Melia azedarach* L. (Meliaceae) ethanolic extract on the developmental time and egg laying of *Tetranychus urticae* Koch. *Arch. Phytopathol. Plant Prot.* **2014**, *47*, 2242–2247. [[CrossRef](#)]
109. Maurya, R.P.; Kushwaha, M.L.; Yadav, L.B. Insecticidal activity of ethanolic extracts from seed and leaf of bakain (*Melia azedarach*) and its effect on oviposition and egg hatching of *Pieris brassicae* in mid hills of Uttarakhand. *Indian J. Agric. Sci.* **2013**, *83*, 866–871.
110. Jung, P.H.; Silveira, A.C.D.; Nieri, E.M.; Potrich, M.; Refatti, M. Insecticidal activity of *Eugenia uniflora* L. and *Melia azedarach* L. on *Atta laevigata* Smith. *Floresta Ambiente* **2013**, *20*, 191–196. [[CrossRef](#)]
111. Mckenna, M.M.; Hammad, A.F.; Farran, M.T. Effect of *Melia azedarach* (Sapindales: Meliaceae) fruit extracts on citrus leafminer *Phyllocnistis citrella* (Lepidoptera: Gracillariidae). *Springerplus* **2013**, *2*, 144. [[CrossRef](#)] [[PubMed](#)]
112. Inacio, M.D.F.; Carvalho, M.G.D. Insecticidal activity of dichloromethane and methanolic extracts of *Azadirachta indica* (A. Juss), *Melia azedarach* (L.) and *Carapa guianensis* (Aubl.) (Meliaceae) on the subterranean termite *Coptotermes gestroi* (Wasmann) (Isoptera, Rhinotermitidae). *Biosci. J.* **2012**, *28*, 676–683.
113. Bullangpoti, V.; Wajnberg, E.; Audant, P.; Feyerreisen, R. Antifeedant activity of *Jatropha gossypifolia* and *Melia azedarach* senescent leaf extracts on *Spodoptera frugiperda* (Lepidoptera: Noctuidae) and their potential use as synergists. *Pest Manag. Sci.* **2012**, *68*, 1255–1264. [[CrossRef](#)]
114. Orhan, I.E.; Guner, E.; Ozcelik, B.; Senol, F.S.; Caglar, S.S.; Emecen, G.; Kocak, O.; Sener, B. Assessment of antimicrobial, insecticidal and genotoxic effects of *Melia azedarach* L. (Chinaberry) naturalized in Anatolia. *Int. J. Food Sci. Nutr.* **2012**, *63*, 560–565. [[CrossRef](#)] [[PubMed](#)]
115. Sharma, M.K.; Sharma, I.D.; Sharma, K.C. Effect of *Melia* extracts on oviposition, gonad development and field infestation of melon fruit fly (*Bactrocera tau*) in cucumber (*Cucumis sativus*). *Indian J. Agric. Sci.* **2012**, *82*, 523–527.
116. Roy, S.; Mukhopadhyay, A. Bioefficacy assessment of *Melia azedarach* (L.) seed extract on tea red spider mite, *Oligonychus coffeae* (Nietner) (Acari: Tetranychidae). *Int. J. Acarol.* **2012**, *38*, 79–86. [[CrossRef](#)]
117. Chiffelle, I.; Huerta, A.; Azua, F.; Puga, K.; Araya, J.E. Antifeeding and insecticide properties of aqueous and ethanolic fruit extracts from *Melia azedarach* L. on the elm leaf beetle *Xanthogaleruca luteola* Müller. *Chil. J. Agric. Res.* **2011**, *71*, 218–225. [[CrossRef](#)]
118. Maroneze, D.M.; Gallegos, D.M.N. Effect of *Melia azedarach* aqueous extract on the development of immature and reproductive stages of *Spodoptera frugiperda* (J. E. Smith, 1797) (Lepidoptera: Noctuidae). *Semin. Cienc. Agrar.* **2009**, *30*, 537–550.
119. Defagó, M.T.; Dumón, A.; Avalos, D.S.; Palacios, S.M.; Valladares, G. Effects of *Melia azedarach* extract on *Cotesia ayerza*, parasitoid of the alfalfa defoliator *Colias lesbia*. *Biol. Control* **2011**, *57*, 75–78. [[CrossRef](#)]
120. Brunherotto, R.; Vendramim, J.D.; Oriani, M.A.D.G. Effects of tomato genotypes and aqueous extracts of *Melia azedarach* leaves and *Azadirachta indica* seeds on *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). *Neotrop. Entomol.* **2010**, *39*, 784–791. [[CrossRef](#)]
121. Cabral, M.M.O.; Crescente, E.R.F.; Mendonça, P.M.; Gomes, C.M.S.; Oliveira, V.C.; Kelecom, A. Extratos de *Melia azedarach* L. extracts and their activity on *Musca domestica* L. (Diptera: Muscidae). *Rev. Bras. Farmacogn.* **2008**, *18*, 699–702. [[CrossRef](#)]
122. Trudel, R.E.; Bomblies, A. Larvicidal effects of Chinaberry (*Melia azedarach*) powder on *Anopheles arabiensis* in Ethiopia. *Parasite Vector.* **2011**, *4*, 72. [[CrossRef](#)] [[PubMed](#)]
123. Prophiro, J.S.; Rossi, J.C.N.; Pedroso, M.F.; Kanis, L.A.; Silva, O.S. Leaf extracts of *Melia azedarach* Linnaeus (Sapindales: Meliaceae) act as larvicide against *Aedes aegypti* (Linnaeus, 1762) (Diptera: Culicidae). *Rev. Soc. Bras. Med. Trop.* **2008**, *41*, 560–564. [[CrossRef](#)] [[PubMed](#)]
124. Kim, D.I.; Kim, S.G.; Kang, B.R.; Ko, S.J.; Kim, J.S.; Kim, S.S. Management of two spotted spider mite, *Tetranychus urticae*, on organic strawberry field in jeonnam area and toxicity of natural enemies against crude extract of *Chrysanthimum cinerariaefolium* and *Melia azedarach*. *Korean J. Org. Agric.* **2009**, *17*, 211–226.
125. Farag, M.; Ahmed, M.H.M.; Yousef, H.; Abdel-Rahman, A.A.H. Repellent and insecticidal activities of *Melia azedarach* L. against cotton leafworm, *Spodoptera littoralis* (Boisd.). *Z. Naturforsch. C* **2011**, *66*, 129–135. [[CrossRef](#)] [[PubMed](#)]
126. Nathala, E.; Dhingra, S.; Walia, S.; Shankar, G.K. Antifeedant and toxic activity of *Melia azedarach* seed extracts against *Helicoverpa armigera* (Lepidoptera: Noctuidae). *Pestic. Res. J.* **2008**, *20*, 16–20.
127. Rossetti, M.R.; Defagó, M.T.; Carpinella, M.C.; Palacios, S.M.; Valladares, G. Biological activity of extracts of *Melia azedarach* on larvae of *Spodoptera eridania* (Lepidoptera: Noctuidae). *Rev. Soc. Entomol. Argent.* **2008**, *67*, 115–125.
128. Ibrahim, M.; Seedo, M.; Abdollah, J. Biological effectiveness of *Melia azedarach* L., fruits extract on potato tuber moth, *Phthorimaea operculella* (Zeller), (Lepidoptera: Gelechiidae) under lab conditions. *Dirasat Agric. Sci.* **2010**, *35*, 11–12.
129. Sharma, A.; Sharma, K.K. Effect of *Melia azedarach* extract on the feeding of *Diorhabda lusca* (Maulik) on *Celtis australis* Linn. *J. Entomol. Res.* **2008**, *32*, 117–118.
130. Sharma, A.; Sehgal, R.N.K.C.; Kumar, R.; Gupta, R. Field efficacy of various extracts of *Melia azedarach* (Linn) seeds against *Ascotis imparta* Hubn. (Lepidoptera: Geometridae) larvae. *J. Entomol. Res.* **2007**, *31*, 47–49.

131. Rachokarn, S.; Piyasaengthong, N.; Bullangpoti, V. Impact of botanical extracts derived from leaf extracts *Melia azedarach* L. (Meliaceae) and *Amaranthus viridis* L. (Amaranthaceae) on populations of *Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae) and detoxification enzyme activities. *Commun. Agric. Appl. Biol. Sci.* **2008**, *73*, 451–457.
132. Defagó, M.; Valladares, G.; Banchio, E.; Carpinella, C.; Palacios, S. Insecticide and antifeedant activity of different plant parts of *Melia azedarach* on *Xanthogaleruca luteola*. *Fitoterapia* **2006**, *77*, 500–505. [[CrossRef](#)] [[PubMed](#)]
133. Rossi, J.C.N.; Prophiro, J.S.; Mendes, A.M.; Kanis, L.A.; Silva, O.S. Larvicidal effect of ethanolic extracts from *Melia azedarach* dried leaves and ripe fruits in *Aedes albopictus* larvae. *Lat. Am. J. Pharm.* **2007**, *26*, 737–740.
134. Coria, C.; Almiron, W.; Valladares, G.; Carpinella, C.; Luduena, F.; Defago, M.; Palacios, S. Larvicide and oviposition deterrent effects of fruit and leaf extracts from *Melia azedarach* L. on *Aedes aegypti* (L.) (Diptera: Culicidae). *Bioresour. Technol.* **2008**, *99*, 3066–3070. [[CrossRef](#)] [[PubMed](#)]
135. El-Sawi, S.A. Toxicity and bioactivity of *Melia azedarach* L. on the two spotted spider mite *Tetranychus urticae* Koch (Acari: Tetranychidae), and its predacious mite, *Euseius scutalis* (Athais-Henriot) (Acari: Phytoseiidae). *Egypt. J. Biol. Pest Control* **2008**, *18*, 289–295.
136. Mitchell, P.L.; Thielen, J.B.; Stell, F.M.; Fescemyer, H.W. Activity of *Melia volkensii* (Meliaceae) extract against southern green stink bug (Hemiptera: Heteroptera: Pentatomidae). *J. Agric. Urban. Entomol.* **2004**, *21*, 131–141.
137. Nathan, S.S.; Sehoon, K. Effects of *Melia azedarach* L. extract on the teak defoliator *Hyblaea puera* Cramer (Lepidoptera: Hyblaeidae). *Crop Prot.* **2006**, *25*, 287–291. [[CrossRef](#)]
138. Charleston, D.S.; Kfir, R.; Dicke, M.; Vet, L.E.M. Impact of botanical extracts derived from *Melia azedarach* and *Azadirachta indica* on populations of *Plutella xylostella* and its natural enemies: A field test of laboratory findings. *Biol. Control* **2006**, *39*, 105–114. [[CrossRef](#)]
139. Charleston, D.S.; Gols, R.; Hordijk, K.A.; Kfir, R.; Vet, L.E.M.; Dicke, M. Impact of botanical pesticides derived from *Melia azedarach* and *Azadirachta indica* plants on the emission of volatiles that attract parasitoids of the diamondback moth to cabbage plants. *J. Chem. Ecol.* **2006**, *32*, 325–349. [[CrossRef](#)]
140. Bounechada, M.; Doumandji, S.E.; Laouer, H. Laboratory evaluation of *Melia azedarach* L. and *Eucalyptus globulus* Labill. extracts in order to control *Ocneridia volxemi* Bolivar (Orthoptera, Pamphaginae) hoppers. *Commun. Agric. Appl. Biol. Sci.* **2004**, *69*, 235–244.
141. Wandscheer, C.B.; Duque, J.E.; Silva, M.A.N.D.; Fukuyama, Y.; Wohlke, J.L.; Adelman, J.; Fontana, J.D. Larvicidal action of ethanolic extracts from fruit endocarps of *Melia azedarach* and *Azadirachta indica* against the dengue mosquito *Aedes aegypti*. *Toxicon* **2004**, *44*, 829–835. [[CrossRef](#)]
142. Gursharan, S.; Vishaldeep, K.; Darshan, S. Lethal and sublethal effects of different ecotypes of *Melia azedarach* against *Plutella xylostella* (Lepidoptera: Plutellidae). *Int. J. Trop. Insect Sci.* **2006**, *2*, 92–100.
143. Nathala, E.; Dhingra, S. Relative effect of various extracts of *Melia azedarach* (Linn) leaf against *Helicoverpa armigera* (Hübner) and their comparison with seed extracts. *J. Entomol. Res.* **2005**, *29*, 201–206.
144. Haryadi, Y.; Yuniarti, S. Study on the insecticidal effects of custard apple (*Annona reticulata* L.) and mindi (*Melia azedarach* L.) leaves against *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae). In Proceedings of the 8th International Working Conference on Stored Product Protection, York, UK, 22–26 July 2002; pp. 600–602.
145. Jazzar, C.; Hammad, A.F. The efficacy of enhanced aqueous extracts of *Melia azedarach* leaves and fruits integrated with the *Camptotylus reuteri* releases against the sweetpotato whitefly nymphs. *Bull. Insectology* **2003**, *56*, 169–275.
146. Juan, A.; Sans, A.; Riba, M. Antifeedant activity of fruit and seed extracts of *Melia azedarach* and *Azadirachta indica* on larvae of *Sesamia nonagrioides*. *Phytoparasitica* **2000**, *28*, 311–319. [[CrossRef](#)]
147. Hoste, B.; De, L.A. Effect of an insecticidal *Melia azedarach* extract on food transport in the gut of insects. In Proceedings of the 52nd International Symposium on Crop Protection, PTS I and II, Ghent, Belgium, 9 May 2000; Volume 65, pp. 423–430.
148. Breuer, M.; Schmidt, G.H. Effect of *Melia azedarach* extract incorporated into an artificial diet on growth, development and fecundity of *Spodoptera frugiperda* (J. E. Smith) (Lep., Noctuidae). *Acta Neurochir.* **1996**, *103*, 171–194.
149. Schmidt, G.H.; Ahmed, A.A.I.; Breuer, M. Effect of *Melia azedarach* extract on larval development and reproduction parameters of *Spodoptera littoralis* (Boisd.) and *Agrotis ipsilon* (Hufn.) (Lep. Noctuidae). *Anzger Schdlingskunde Pflanzenschutz Umweltschutz* **1997**, *70*, 4–12. [[CrossRef](#)]
150. Koul, O.; Jain, M.P.; Sharma, V.K. Growth inhibitory and antifeedant activity of extracts from *Melia dubia* to *Spodoptera litura* and *Helicoverpa armigera* larvae. *Indian J. Exp. Biol.* **2000**, *38*, 63–68. [[PubMed](#)]
151. Breuer, M.; Schmidt, G.H. Influence of a short period treatment with *Melia aedarach* extract on food intake and growth of the larvae of *Spodoptera frugiperda* (J.E. Smith) (Lep., Noctuidae). *Z. Pflanzenk. Pflanzen.* **1995**, *102*, 633–654.
152. Tillman, P.G.; Cottrell, T.E.; Buntin, G.D. Potential of *Melia azedarach* L. (Meliaceae) as a host plant for *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae). *Fla. Entomol.* **2019**, *102*, 222–226.
153. Nardo, E.A.B.D.; Costa, A.S.D.; Loureno, A.L. *Melia azedarach* extract as an antifeedant to *Bemisia tabaci* (Homoptera: Aleyrodidae). *Fla. Entomol.* **1997**, *80*, 92–94. [[CrossRef](#)]
154. Irungu, L.W.; Mwangi, R.W. Effects of a biologically active fraction from *Melia volkensii* on *Culex quinquefasciatus*. *Int. J. Trop. Insect Sci.* **1995**, *16*, 159–162. [[CrossRef](#)]
155. Dilawari, V.K.; Singh, K.; Dhaliwal, G.S. Effects of *Melia azedarach* L. on oviposition and feeding of *Plutella xylostella* L. *Int. J. Trop. Insect Sci.* **1994**, *15*, 203–205. [[CrossRef](#)]

156. Yousef, H.; El-Lakwah, S.F. Effects of *Melia azedarach* ripe fruit extract on some enzyme activities of the cotton leafworm *Spodoptera littoralis* (Boisd.). *Egypt. J. Pest Control* **2014**, *24*, 315–320.
157. Scapinello, J.; Oliveira, J.V.; Ribeiros, M.L. Effects of supercritical CO₂ extracts of *Melia azedarach* L. on the control of fall armyworm (*Spodoptera frugiperda*). *J. Supercrit. Fluids* **2014**, *93*, 20–26. [[CrossRef](#)]
158. Mwangi, R.W.; Mukiyama, T.K. Evaluation of *Melia volkensii* extract fractions as mosquito larvicides. *J. Am. Mosquito Control* **1988**, *4*, 442–447.
159. Raja, N. Field evaluation of aqueous extract of *Melia azedarach* Linn. seeds against cabbage aphid, *Brevicoryne brassicae* Linn. (Homoptera: Aphididae), and its predator *Coccinella septempunctata* Linn. (Coleoptera: Coccinellidae). *Arch. Phytopathol. Plant Prot.* **2012**, *45*, 1273–1279.
160. Souza, B.H.S.; Costa, E.N.; Forim, M.R. Formulations of *Melia azedarach* to control *Diabrotica speciosa* (Germar) (Coleoptera: Chrysomelidae) larvae in corn and plant enhancement. *Neotrop. Entomol.* **2015**, *44*, 173–179. [[CrossRef](#)]
161. Kebede, Y.; Gebre-Michael, T.; Balkew, M. Laboratory and field evaluation of neem (*Azadirachta indica* A. Juss) and Chinaberry (*Melia azedarach* L.) oils as repellents against *Phlebotomus orientalis* and *P. bergeroti* (Diptera: Psychodidae) in Ethiopia. *Acta Trop.* **2010**, *113*, 145–150. [[CrossRef](#)]
162. Al-Mehmadi, R.M.; Al-Khalaf, A.A. Larvicidal and histological effects of *Melia azedarach* extract on *Culex quinquefasciatus* Say larvae (Diptera: Culicidae). *J. King Saud Univ. Sci.* **2010**, *22*, 77–85. [[CrossRef](#)]
163. Kamaraj, C.; Rahuman, A.A.; Bagavan, A.; Mohamed, M.J.; Elango, G.; Rajakumar, G.; Zahir, A.A.; Santhoshkumar, T.; Marimuthu, S. Ovicidal and larvicidal activity of crude extracts of *Melia azedarach* against *Haemonchus contortus* (Strongylida). *Parasitol. Res.* **2010**, *106*, 1071–1077. [[CrossRef](#)]
164. Shrestha, S.S.; Ferrarese, I.; Sut, S.; Zengin, G.; Grana, S.; Ak, G.; Pant, D.R.; Dall'Acqua, S.; Rajbhandary, S. Phytochemical investigations and in vitro bioactivity screening on *Melia azedarach* L. leaves extract from Nepal. *Chem. Biodivers.* **2021**, *18*, e2001070. [[CrossRef](#)] [[PubMed](#)]
165. Abiy, E.; Gebre-Michael, T.; Balkew, M.; Medhin, G. Repellent efficacy of DEET, MyggA, neem (*Azadirachta indica*) oil and chinaberry (*Melia azedarach*) oil against *Anopheles arabiensis*, the principal malaria vector in Ethiopia. *Malaria J.* **2015**, *14*, 187. [[CrossRef](#)] [[PubMed](#)]
166. Zhou, J.B.; Minami, Y.; Yagi, F.; Tadera, K.; Nakatani, M. Ring C-seco limonoids from *Melia toosendan*. *Phytochemistry* **1997**, *46*, 911–914. [[CrossRef](#)]
167. Munehiro, N. Limonoids from *Melia toosendan* (Meliaceae) and their antifeedant activity. *Heterocycles* **1999**, *118*, 313–318.
168. Huang, R.C.; Okamura, H.; Iwagawa, T.; Nakatani, M. The structures of azedarachins, limonoid antifeedants from Chinese *Melia azedarach* Linn. *B. Chem. Soc. Jpn.* **1994**, *67*, 2468–2472. [[CrossRef](#)]
169. Nakatani, M.; Huang, R.C.; Okamura, H.; Naokia, H.; Iwagawa, T. Limonoid antifeedants from Chinese *Melia azedarach*. *Phytochemistry* **1994**, *36*, 39–41. [[CrossRef](#)]
170. Oelrichs, P.B.; Hill, M.W.; Vallely, P.J.; Macleod, J.K.; Molinski, T.F. Toxic tetranortriterpenes of the fruit of *Melia azedarach*. *Phytochemistry* **1983**, *22*, 531–534. [[CrossRef](#)]
171. Takeya, K.; Qiao, Z.S.; Hirobe, C.; Itokawa, H. Cytotoxic azadirachtin-type limonoids from *Melia azedarach*. *Phytochemistry* **1996**, *42*, 709–712. [[CrossRef](#)]
172. Valladares, G.R.; Ferreyra, D.; Defago, M.T.; Carpinella, M.C.; Palacios, S. Effects of *Melia azedarach* on *Triatoma infestans*. *Fitoterapia* **1999**, *70*, 421–424. [[CrossRef](#)]
173. Valladares, G.; Defago, M.T.; Palacios, S. Laboratory evaluation of *Melia azedarach* (Meliaceae) extracts against the elm leaf beetle (Coleoptera: Chrysomelidae). *J. Econ. Entomol.* **1997**, *90*, 747–750. [[CrossRef](#)]
174. Itokawa, H.; Qiao, Z.S.; Hirobe, C.; Takeya, K. Cytotoxic limonoids and tetranortriterpenoids from *Melia azedarach*. *Chem. Pharm. Bull.* **1995**, *43*, 1171–1175. [[CrossRef](#)] [[PubMed](#)]
175. Céspedes, C.L.; Calderón, J.S.; Lina, L.; Aranda, E. Growth inhibitory effects on fall armyworm *Spodoptera frugiperda* of some limonoids isolated from *Cedrela* spp. (Meliaceae). *J. Agric. Food Chem.* **2000**, *48*, 1903–1908. [[CrossRef](#)] [[PubMed](#)]
176. Isman, M.B.; Koul, O.; Luczynski, A.; Kaminski, J. Insecticidal and antifeedant bioactivities of neem oils and their relationship to azadirachtin content. *J. Agric. Food Chem.* **1990**, *38*, 1406–1411. [[CrossRef](#)]
177. Carpinella, M.C.; Defago, M.T.; Valladares, G.; Palacios, S.M. Chapter 5: Role of *Melia azedarach* L. (Meliaceae) for the control of insects and acari: Present status and future prospects. *Adv. Phytomed.* **2006**, *3*, 81–123.
178. Wiart, C. A note on *Melia toosendan* Siebold & Zucc. *Toxicology* **2012**, *295*, 68.
179. Araújo, S.A.C.D.; Teixeira, M.; Dantas, T.; Melo, V.S.P.; Lima, F.E.S.; Ricarte, A.R.F.; Costa, E.C.; Miranda, A.M. Usos potenciais de *Melia azedarach* L. (Meliaceae): Um levantamento. *Arq. Inst. Biol.* **2009**, *76*, 141–148. [[CrossRef](#)]
180. Carpinella, C.; Ferrayoli, C.; Valladares, G.; Defago, M.; Palacios, S. Potent limonoid insect antifeedant from *Melia azedarach* (organic chemistry). *Biosci. Biotech. Bioch.* **2002**, *66*, 1731–1736. [[CrossRef](#)]
181. Zhou, J.B.; Okamura, H.; Iwagawa, T.; Nakatani, M. Limonoid antifeedants from *Melia toosendan*. *Phytochemistry* **1996**, *41*, 117–120. [[CrossRef](#)]
182. Huang, R.C.; Okamura, H.; Iwagawa, T.; Tadera, K.; Nakatani, M. Azedarachin C, a limonoid antifeedant from *Melia azedarach*. *Phytochemistry* **1995**, *38*, 593–594. [[CrossRef](#)]

183. Sombatsiri, K.; Ermel, K.; Schmutterer, H.; Ascher, K.R.S.; Zebitz, C.P.W.; Naqvi, S.N.H. Other meliaceous plants containing ingredients for integrated pest management and further purposes: Sections 8.2.1.3–8.2.1.10. In *The Neem Tree*; Wiley-VCH Verlag GmbH Co. KGaA: Weinheim, Germany, 2005; pp. 606–612. [\[CrossRef\]](#)
184. Nakatani, M.; Zhou, J.B.; Iwagawa, T.; Okamura, H. Isolation of two limonoid antifeedants from *Melia toosendan*. *Heterocycles* **1996**, *3*, 739–743. [\[CrossRef\]](#)
185. Nakatani, M.; Fukuman, Y.; Sakumoto, T.; Yamashita, N.; Okamura, H.; Iwagawa, T. Nimbolinins, C-Seco limonoids from the fruits of *Melia toosendan*. *Heterocycles* **2000**, *53*, 689–695. [\[CrossRef\]](#)
186. Huang, R.C.; Tadera, K.; Yagi, F.; Minami, Y.; Okamura, H.; Iwagawa, T.; Nakatani, M. Limonoids from *Melia azedarach*. *Phytochemistry* **1996**, *43*, 581–583. [\[CrossRef\]](#)
187. Nakatani, M.; Zhou, J.B.; Nakayama, N.; Okamura, H.; Iwagawa, T. Nimbolidins C-E, limonoid antifeedants from *Melia toosendan*. *Phytochemistry* **1996**, *41*, 739–743. [\[CrossRef\]](#)
188. Kraus, W.; Bokel, M.; Klenk, A.; Pöhl, H. The structure of azadirachtin and 22,23-dihydro-23 β -methoxyazadirachtin. *Tetrahedron Lett.* **1985**, *26*, 6435–6438. [\[CrossRef\]](#)
189. Kraus, W.; Bokel, M.; Bruhn, A.; Cramer, R.; Klaiber, I.; Klenk, A.; Nagl, G.; Pöhl, H.; Sadlo, H.; Vogler, B. Structure determination by NMR of azadirachtin and related compounds from *Azadirachta indica* A. Juss. *Tetrahedron* **1987**, *43*, 2817–2830. [\[CrossRef\]](#)
190. Zhou, Y.W.; Li, H.; Feng, J.T. Preliminary study on the relationship between bioactivity and formulation of toosendanin. *J. Hebei Agric. Univ.* **2018**, *41*, 6–11.
191. Zhang, J.; Feng, G.; Luo, L.; Yu, X.Y.; Ma, Z.Q.; Feng, J.T.; Liu, X.J.; Zhang, X. Development of an enzyme-linked immunosorbent assay for toosendanin. *Anal. Chim. Acta.* **2008**, *622*, 182–188. [\[CrossRef\]](#)
192. Busato, M.A.; Lutinski, J.A.; Hermes, D.; Magro, J.D.; Bordignon, C.M.; Bohn, A.; Simoes, D.A. Larvicidal effects of supercritical extract of *Melia azedarach* and *Bacillus thuringiensis* var. *israelensis* product on late instar of *Aedes aegypti* (Diptera: Culicidae). *Rev. Colomb. Entomol.* **2018**, *44*, 39–43. [\[CrossRef\]](#)
193. Wang, W.L.; Wang, Y.I.; Shinfoon, C. The toxic chemical factors in the fruits of melia azedarach and their bio-activities toward *Pieris rapae*. *Acta Entomol. Sinica.* **1994**, *37*, 20–24.
194. Chiu, S.F.; Huang, D.P.; Zhang, X. The antifeedant and growth disruption effects of extracts from some meliaceous plants to the Asiatic corn borer. *Acta Entomol. Sin.* **1985**, *28*, 450–453.
195. Chiu, S.F.; Zhang, X. Experiments on the antifeedant and systemic properties of some botanical insecticides against the rice yellow stem borer. *J. Integr. Agric.* **1982**, *2*, 55–62.
196. Zhang, X.; Chiu, S.F. The antifeeding and repellent effects of meliaceous plants to some insect pests. *J. South China Agric. Univ.* **1983**, *4*, 1–7.
197. Wei, T.; Wen, X.; Niu, C.; An, S.J.; Wang, D.W.; Xi, Z.; Wang, N.N. Design of acetohydroxyacid synthase herbicide-resistant germplasm through MB-QSAR and CRISPR/Cas9-mediated base-editing approaches. *J. Agric. Food Chem.* **2022**, *70*, 2817–2824. [\[CrossRef\]](#)
198. Lin, X.D.; Li, Y.; Zhong, W.Q.; Hong, T.; Li, L.H.; Song, S.Y.; He, D.H. Synthesis, bioactivity, and QSAR Study of 3, 4-dichlorophenyl isoxazole-substituted stilbene derivatives against the phytopathogenic fungus *Botrytis cinerea*. *J. Agric. Food Chem.* **2021**, *69*, 9520–9528. [\[CrossRef\]](#)
199. Duran, A.G.; Chinchilla, N.; Molinillo, J.M.G.; Macias, F.A. Structure-activity relationship studies on naphthoquinone analogs. The search for new herbicides based on natural products. *Pest Manag. Sci.* **2019**, *75*, 2517–2529. [\[CrossRef\]](#)
200. Xu, H.; Zhang, J.L. Natural products-based insecticidal agents 9. Design, semisynthesis and insecticidal activity of 28-acyloxy derivatives of toosendanin against *Mythimna separata* Walker in vivo. *Bioorg. Med. Chem. Lett.* **2011**, *21*, 1974–1977. [\[CrossRef\]](#)
201. Zhang, J.L.; Qu, H.; Yu, X.; Zhi, X.Y.; Chen, H.; Xu, H. Combinatorial synthesis of a series of alkyl/alkenylacyloxy derivatives at the C-28 position of toosendanin as insecticidal agents. *Comb. Chem. High Throughput Screen.* **2013**, *16*, 394–399. [\[CrossRef\]](#)
202. Kawasaki, A.; Hashimoto, H.; Shimotoyodome, Y.; Ito, S.; Ishikawa, J.; Sugai, Y.; Fujimori, T. Limonoids and unsaturated fatty acids present in *Melia toosendan* increase ceramide production in keratinocytes. *Fitoterapia* **2021**, *155*, 105058. [\[CrossRef\]](#)
203. Jabeen, B.; Riaz, N.; Saleem, M.; Naveed, M.A.; Ahmed, M.; Tahir, M.N.; Pescitelli, G.; Ashraf, M.; Ejaz, S.A.; Ahmed, I.; et al. Isolation and characterization of limonoids from *Kigelia africana*. *Z. Naturforsch. B* **2013**, *68*, 1041–1048. [\[CrossRef\]](#)
204. Sarker, S.D.; Savchenko, T.; Whiting, P.; Sik, V.; Dinan, L. Two limonoids from *Turraea obtusifolia* (Meliaceae), prierianin and rohitukin, antagonise 20-hydroxyecdysone action in a drosophila cell line. *Arch. Insect Biochem. Physiol.* **1997**, *35*, 211–217. [\[CrossRef\]](#)
205. Schoonhoven, L.M.; Luo, L.E. Multiple mode of action of the feeding deterrent, toosendanin, on the sense of taste in *Pieris brassicae* larvae. *J. Comp. Physiol. A* **1994**, *175*, 519–524. [\[CrossRef\]](#)
206. Zhang, X.; Chiu, S.F. Effects of toosendanin on several enzyme systems of the cabbage worm *Pieris rapae* L. *Acta Entomol. Sin.* **1992**, *35*, 171–177.
207. Zhang, X.; Chiu, S.F. Study on the histopathology of the midgut of cabbage worm *Pieris rapae* L. caused by toosendanin. *Acta Entomol. Sin.* **1991**, *34*, 501–502.
208. Zhang, X.; Chiu, S.F. Effects of toosendanin on the respiration and other physiological parameters of the imported cabbage worm (*Pieris rapae* L.). *J. South China Agric. Univ.* **1992**, *13*, 5–11.
209. Li, H.; Zhang, J.; Ma, T.; Li, C.; Ma, Z.Q.; Zhang, X. Acting target of toosendanin locates in the midgut epithelium cells of *Mythimna separate* Walker larvae (Lepidoptera: Noctuidae). *Ecotox. Environ. Safe* **2020**, *201*, 110828. [\[CrossRef\]](#)

210. Ma, Z.Q.; Monika, G.N.; Zhang, X.; Brown, M.R. Effects of the botanical insecticide, toosendanin, on blood digestion and egg production by female *Aedes aegypti* (Diptera: Culicidae): Topical application and ingestion. *J. Med. Entomol.* **2013**, *50*, 112–122. [[CrossRef](#)]
211. Shi, Y.L. Toosendanin modifies K^+ and Ca^{2+} channel activity and intracellular Ca^{2+} concentration. *Prog. Biochem. Biophys.* **2007**, *34*, 132–137.
212. Olurische, T.; Kwanashie, H.; Anuka, J. Effect of *Khaya senegalensis* on uterine contractility in rats. *J. Bioresour. Bioprod.* **2006**, *3*, 30–35. [[CrossRef](#)]
213. Dong, Y.; Zhu, G.; Wang, S.F.; Keon, K.A.; Rubinstein, J.L.; Zeng, S.X.; Zhang, S.; Chen, Q.L.; Fu, J.; Li, M.; et al. Toosendanin, a novel potent vacuolar-type H^+ -translocating ATPase inhibitor, sensitizes cancer cells to chemotherapy by blocking protective autophagy. *Int. J. Biol. Sci.* **2022**, *18*, 2684–2702. [[CrossRef](#)]
214. Miranda, R.N.C.; Dolabela, M.F.; da Silva, M.N.; Povoia, M.M.; Maia, J.G.S. Antiplasmodial activity of the andiroba (*Carapa guianensis* Aubl., Meliaceae) oil and its limonoid-rich fraction. *J. Ethnopharmacol.* **2012**, *142*, 679–683. [[CrossRef](#)] [[PubMed](#)]
215. Fukuyama, Y.; Nakaoka, M.; Yamamoto, T.; Takahashi, H.; Minami, H. Degraded and oxetane-bearing limonoids from the roots of *Melia azedarach*. *Chem. Pharm. Bull.* **2006**, *54*, 1219–1222. [[CrossRef](#)] [[PubMed](#)]
216. Haramboure, M.; Mirande, L.; Smagghe, G.; Pineda, S.; Schneider, M.I. Compatibility of a *Melia azedarach* extract with *Eriopsis connexa* (Coleoptera: Coccinellidae). *Commun. Agric. Appl. Biol. Sci.* **2010**, *75*, 373–378. [[PubMed](#)]
217. Caboni, P.; Sarais, G.; Angioni, A.; Garcia, A.J.; Lai, F.; Dedola, F.; Cabras, P. Residues and persistence of neem formulations on strawberry after field treatment. *J. Agric. Food Chem.* **2006**, *54*, 10026–10032. [[CrossRef](#)] [[PubMed](#)]
218. Li, H.; He, S.; Liu, G.; Li, C.; Ma, Z.Q.; Zhang, X. Residue and dissipation kinetics of toosendanin in cabbage, tobacco and soil using IC-ELISA detection. *Food Chem.* **2021**, *335*, 127600. [[CrossRef](#)]
219. Bumah, V.V.; Essien, E.U.; Agbedahunsi, J.M.; Eka, O.U. Effects of *Khaya grandifoliola* on red blood cells and bone mineral content in rats. *Phytother. Res.* **2010**, *19*, 928–931. [[CrossRef](#)]
220. Nwozo, S.O.; Ajaiyeoba, E.O.; Oladeinde, F.O.; Olanrewaju, I. In vivo animal model toxicological studies of Nigerian medicinal plants II: *Eniantha chlorantha* and *Khaya ivorensis*. *Eur. J. Sci. Res.* **2006**, *14*, 133–138.
221. Adebayo, J.O.; Yakubu, M.T.; Egwim, E.C.; Owoyele, V.B.; Enaiibe, B.U. Effect of ethanolic extract of *Khaya senegalensis* on some biochemical parameters of rat kidney. *J. Ethnopharmacol.* **2003**, *88*, 69–72. [[CrossRef](#)]
222. Loica, Z.; Loetitia, M.; Tiburce, H.; Roland, K.; Joachim, G.; Alphonse, S. Chronophysiology of rat wistar under extracts from *Khaya Senegalensis*. *Int. J. Sci. Res.* **2018**, *7*, 65–71.
223. Yakubu, M.T.; Adebayo, O.J.; Egwim, E.C.; Owoyele, V.B. Increased liver alkaline phosphatase and aminotransferase activities following administration of ethanolic extract of *Khaya senegalensis* stem bark to rats. *Biokemistri* **2005**, *17*, 27–32. [[CrossRef](#)]
224. Keshri, G.; Bajpai, M.; Lakshmi, V.; Setty, B.S.; Gupta, G. Role of energy metabolism in the pregnancy interceptive action of *Ferula assafoetida* and *Melia azedarach* extracts in rat. *Contraception* **2004**, *70*, 429–432. [[CrossRef](#)] [[PubMed](#)]
225. Orisadipe, A.; Amos, S.; Adesomoju, A.; Binda, L.; Emeje, M.; Okogun, J.; Wambebe, C.; Gamani, K. Spasmolytic activity of methyl angolensate: A triterpenoid isolated from *Entandrophragma angolense*. *Biol. Pharm. Bull.* **2001**, *24*, 364–367. [[CrossRef](#)] [[PubMed](#)]
226. Wang, X.T.; Chang, C.H.; Wang, Z.T. Determination of toosendanin in rat plasma by ultra-performance liquid chromatography-electrospray ionization-mass spectrometry and its application in a pharmacokinetic study. *Biomed. Chromatogr.* **2013**, *27*, 222–227. [[CrossRef](#)] [[PubMed](#)]
227. Sun, M.; Liu, Q.; Liang, Q.X.; Gao, S.; Zhuang, K.Y.; Zhang, Y.; Zhang, H.Z.; Liu, K.C.; She, G.M.; Xia, Q. Toosendanin triggered hepatotoxicity in zebrafish via inflammation, autophagy, and apoptosis pathways. *Comp. Biochem. Phys. C* **2021**, *250*, 109171. [[CrossRef](#)] [[PubMed](#)]
228. Zhang, J.L.; Shi, W.Y.; Zhong, W.; Ma, A.T.; Wang, X.D.; Zhao, Y.T.; Wang, M.; Zhong, X.H. Effects of toosendanin on pregnancy and uterine immunity alterations in mice. *Am. J. Chin. Med.* **2010**, *38*, 319–328. [[CrossRef](#)] [[PubMed](#)]
229. Hodgson, H.; De, L.P.R.; Stephenson, M.J.; Thimmappa, R.; Vincent, J.L.; Sattely, E.S.; Osbourn, A. Identification of key enzymes responsible for protolimonoid biosynthesis in plants: Opening the door to azadirachtin production. *Proc. Natl. Acad. Sci. USA* **2019**, *116*, 17096–17104. [[CrossRef](#)]
230. Lian, X.; Zhang, X.; Wang, F.; Wang, X.N.; Xue, Z.Y.; Qi, X.Q. Characterization of a 2,3-oxidosqualene cyclase in the toosendanin biosynthetic pathway of *Melia toosendan*. *Physiol. Plant.* **2020**, *170*, 528–536. [[CrossRef](#)]