

Plant Autotoxicity Review - 1. Families: Acanthaceae to Campanulaceae

H.M. Liu and L.J. Zhou*

Key Lab of Natural Pesticides & Chemical Biology, Ministry of Education,
South China Agricultural University, Guangzhou, Guangdong, China, 510642
E-Mail: zhoulj@scau.edu.cn, zhoulj@scau@gmail.com

(Received in revised form: January 18, 2019)

CONTENTS

- 1. INTRODUCTION**
- 2. ACANTHACEAE**
 - 2.1. Genus *Andrographis*
- 3. AMARANTHACEAE**
 - 3.1. Genus *Amaranthus*
- 4. APIACEAE**
 - 4.1. Genus *Ammi*
 - 4.2. Genus *Angelica*
 - 4.3. Genus *Daucus*
 - 4.4. Others (*Carum*, *Coriandrum*, *Cuminum*, *Foeniculum*, *Pastinaca* and *Petroselinum*)
- 5. ARACEAE**
 - 5.1. Genus *Colocasia*
 - 5.2. Genus *Pinellia*
- 6. ARALIACEAE**
 - 6.1. Genus *Panax*
- 7. ARAUCARIACEAE**
 - 7.1. Genus *Araucaria*
- 8. ASPARAGACEAE**
 - 8.1. Genus *Asparagus*
- 9. ASTERACEAE**
 - 9.1. Genus *Ambrosia*
 - 9.2. Genus *Artemisia*
 - 9.3. Genus *Atractylodes*
 - 9.4. Genus *Cirsium*
 - 9.5. Genus *Dendranthema*
 - 9.6. Genus *Eupatorium*
 - 9.7. Genus *Parthenium*
 - 9.8. Genus *Mikania*
 - 9.9. Genus *Tithonia*
- 10. BRASSICACEAE**
 - 10.1. Genus *Brassica*
 - 10.2. Genus *Pugionium*

*Correspondence author

11. CAMPANULACEAE

11.1. Genus *Codonopsis*

12. CONCLUSIONS

ABSTRACT

Autotoxicity is one of the reasons that causes the continuous cropping problem in plants. It not only inhibits the growth of plants but also leads to some soil borne diseases, causes autotoxic soil and low crop yields. In this paper, 36 plant species from 28 genera in 10 families causing Autotoxicity have been briefly reviewed. Their autotoxicity leads to continuous cropping problem for agricultural crops or medicinal plants, or the difficulty in regeneration of forest plant species. The 10 families are: Acanthaceae, Amaranthaceae, Apiaceae, Araceae, Araliaceae, Araucariaceae, Asparagaceae, Asteraceae, Brassicaceae and Campanulaceae.

Key words: Autotoxicity, autotoxins, continuous cropping problem, crops, medicinal plants, forest plants, weeds

1. INTRODUCTION

Allelopathy includes harmful or beneficial effects of one plant on another plant through the production and release of chemical compounds into the environment (39). The autotoxicity is particular form of allelopathy. Autotoxicity occurs when a plant releases toxic chemical substances into the environment that inhibits its own germination and growth (35,42,55). Such autotoxicity reduces the intensity of intraspecific competition for scarce growth resource (e.g. water, nutrients, sunlight, space) under unfavourable environmental conditions (2).

Usually, monoculture of crops or medicinal plants leads to the decreased growth and yield in next season due to autotoxicity. Recently, numerous reports have proved the role of autotoxicity in replant failure and soil sickness. Soil sickness is an example of typical negative plant-soil feedback that reduces the quantity (yields) and quality of crop, when the same crop or its related species are grown successively on the same soil. In continuous monocropping systems, plants repeatedly release different kinds of autotoxins for many years, which gets accumulated resulting in significant changes in soil microorganisms species. Thus, autotoxicity could be partly responsible for soil sickness (29).

Autotoxicity occurs in wide range of taxonomically distant species (43). Residues of *Andrographis paniculata* (Burm. f.) Wall. ex Nees, *Daucus carota* L., *Artemisia vulgaris* L. and *Eupatorium adenophora* Spreng (6,21,36,64) and root exudates of *Panax quinquefolium* L., *Atractylodes lancea* (Thunb.) DC., *Panax notoginseng* (Burk.) F. H. Chen and *Eupatorium adenophora*. causes autotoxic growth inhibition (17,49,50, 54,58,59,64).

In this paper, autotoxicity of plants from 10 families has been briefly reviewed. The 10 families are: Acanthaceae, Amaranthaceae, Apiaceae, Araceae, Araliaceae, Araucariaceae, Asparagaceae, Asteraceae, Brassicaceae and Campanulaceae. Based on this information of each plant, suitable measures could be taken accordingly to deal with the continuous cropping problems of the plants.

2. ACANTHACEAE

2.1. *Andrographis*

Andrographis paniculata is herbaceous plant (family Acanthaceae) widely cultivated in many Asian countries and some parts of Europe. The plant has traditional medicinal usage since ancient times and still used as hepatostimulant, antibacterial, anti-inflammatory, antiviral, antioxidant and also as antidote (6). It also has been included as dietary supplement in USA (28). However, its monoculture causes continuous cropping problem due to autotoxicity. The aqueous extracts of its stems and leaves at 0.05 and 0.10 g/mL concentration are autotoxic to seed germination and seedlings growth. At 0.01-0.10 g/mL concentration the germination was decreased by 26.20 % and 47.20 %, respectively, while the seedlings growth inhibition was 80 %-84 % (30).



3. AMARANTHACEAE

3.1. *Amaranthus*

Bradow and Connick (11) determined the autotoxic effects of 9-methyl ketones identified in mixture of volatiles released by *Amaranthus palmeri* S. Wats. These volatiles strongly inhibited the seeds germination of *A. palmeri* and the inhibition rate depended on the exposure time and concentration. The activity of 9-methyl ketones followed the order: 2-octanone, 2-nonanone > 2-undecanone > 2-heptanone > 2-hexanone, 3-methyl-2-butanone, 2-pentanone, 3-hydroxy-2-butanone > 2-butanone (11). The 3-Pentanone identified in mixtures of volatiles released by *A. palmeri* residues also inhibited the *A. palmeri* seeds germination (12).



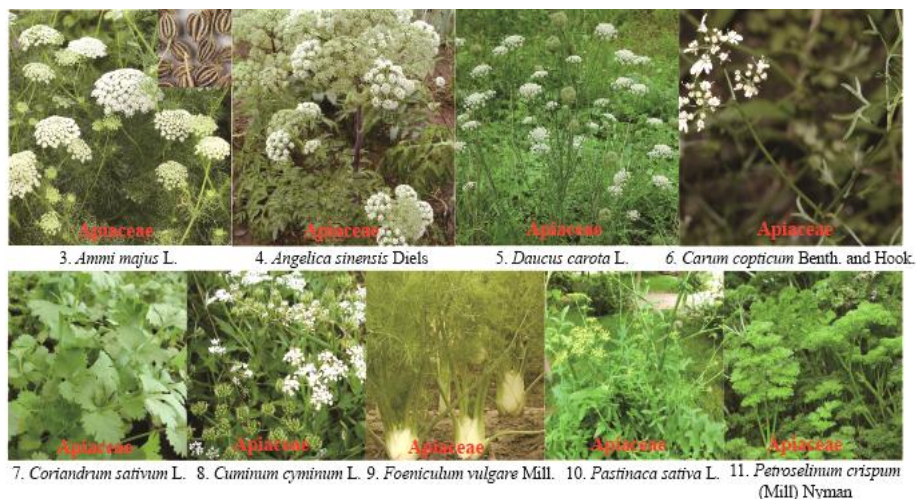
2. *Amaranthus palmeri* S. Wats.

4. APIACEAE

Plants from 9-genera (*Ammi*, *Angelica*, *Daucus*, *Carum*, *Coriandrum*, *Cuminum*, *Foeniculum*, *Pastinaca* and *Petroselinum*) show autotoxic effects.

4.1. Genus *Ammi*

The aqueous eluate from the fruit of *Ammi majus* L. had remarkable autotoxic effects. Further research suggested that the phytotoxins are compartmentalized between the inner and the outer fruit envelopes. The inner layer excludes inhibitors from the embryo and autotoxicity is thus avoided (15).



4.2. Genus *Angelica*

Angelica sinensis Diels is well-known Chinese traditional natural herbal medicine. It has many biological functions (promoting blood circulation, regulating the menstruation and lubricating the intestines). Its rhizomes are used in medicine. The continuous cropping problem in *A. sinensis* plantation causes not only yield loss but also decreases the quality. Especially, disease and insect attack are more on the rhizomes affected by autotoxicity. Li *et al.* (27) and Zhang *et al.* (52) also reported that *A. sinensis* is autotoxic. The aqueous extracts of its rhizomes at 1.50% (g plant material/g soil) concentration inhibited its own seed germination and seedling growth (52).

During the vegetative growth period, *A. sinensis* had strongest autotoxic effects, and the autotoxic effects from above-ground parts were stronger than roots. The ethyl acetate fraction of aqueous extract of above-ground part had stronger autotoxic activity. Li *et al.* (27) and Zhang *et al.* (54) also reported that *A. sinensis* was characterized by autotoxicity. The exudates from rhizomes of *A. sinensis* inhibited the seed germination and seedling growth at (g plant material/g soil) concentration 1.50 % (54).

A monoterpene, 2,6-dimethyl-bicyclo [3,1,0]-4,6-dimethanol, was isolated from its aqueous extract and this compound causes the root inhibition at 0.50 mg/mL concentration (20).

4.3. Genus *Daucus*

Carrot (*Daucus carota*) is widespread throughout the world. Water extract of carrot seeds reduced the carrot growth. Crotonic acid was identified in the extract as the compound responsible for autotoxicity (21).

4.4. Other Genus (*Carum*, *Coriandrum*, *Cuminum*, *Foeniculum*, *Pastinaca* and *Petroselinum*)

Chaturvedi and Muralia (13) found that seed exudates of four umbelliferae crops: carum (*Carum copticum* Benth. and Hook.), coriander (*Coriandrum sativum* L.), cumin (*Cuminum cyminum* L.) and fennel (*Foeniculum vulgare* Mill.) exerted inhibitory effects on the germination of their own seeds, but the inhibition decreased after 7 d. The exudates also inhibited the growth of root and hypocotyl of 16-day-old seedlings.

The essential oils of parsnip (*Pastinaca sativa* L.) and parsley [*Petroselinum crispum* (Mill.) Nyman.] rapidly decreased the photosynthetic capacity (16). Monoterpenes played important role in their autotoxicity (2). Parsley growth was restrained in non-renewed nutrient solution. Interestingly, adding charcoal to hydroponics decreased the autotoxic effects (4).

5. ARACEAE

5.1. Genus *Colocasia*

It was found that taro (*Colocasia esculenta* L.) possessed autotoxic effects. Takahashi (44) reported that taro plants did not grow well, if cultivated consecutively for years on the same land. Lactic, benzoic, m-hydroxybenzoic, p-hydroxybenzoic, vanillic, succinic and adipic acids were identified in the taro roots and all of them inhibited the growth of taro plantlets. The inhibitory effects of benzoic acid were the strongest. At 400 $\mu\text{mol/L}$ concentration, the root dry weight, shoot dry weight, root length and fresh weight of taro plantlets were reduced to 75 %, 53 %, 54 % and 54 %, respectively (3).



12. *Colocasia esculenta* L. 13. *Pinellia ternata* (Thunb.) Breit.

5.2. Genus *Pinellia*

Pinellia ternata (Thunb.) Breit., a traditional Chinese medicine, had replanting problems because of autotoxic effects. Eight compounds (chrysophanol, palmitic acid, methyl oleate, stigmasterol, di-*n*-butyl phthalate, benzofuran, 5-hydroxymethylfurfural, protocatechuic aldehyde) were isolated and identified from crude extract of its rhizosphere soil and the chrysophanol, benzofuran and protocatechuic aldehyde significantly inhibited the seedling growth of *P. ternata*. Moreover, these allelochemicals obviously affected the levels of protective enzymes of seedlings and caused membrane damage, which resulted in the reduction of cell vitality (33).

6. ARALIACEAE

6.1. Genus *Panax*

Panax is medicinally important genus, whose most species are used in traditional Chinese medicine (41). However, three autotoxic species in this genus are: (i). *Panax ginseng* C. A. Mey, (ii). American ginseng (*Panax quinquefolium*) and (iii). Sanqi ginseng [*Panax notoginseng* (Burk.) F. H. Chen]. All these spp. causes continuous cropping problems in their culture. Continuous cropping problem is mainly observed in *Panax ginseng* cultivation. Normally, the old ginseng continuous culture causes many problems (yield reduction, quality decline and high incidence of disease etc.).



14. *Panax ginseng* C. A. Mey 15. *Panax quinquefolium* L. 16. *Panax notoginseng* (Burk.) F. H. Chen

6.1.1. *Panax ginseng*

Inhibitory effects of the methanol extract from its rhizosphere soil on growth of its own seedlings was more obvious than the methanol extract from non-rhizosphere soil (30). Benzoic acid, 2, 2-bis(4-hydroxyphenyl) propane, palmitic acid and 1, 2-benzenedicarboxylic acid bis (2-methylpropyl) ester were isolated from the root exudates of *P. ginseng*. Benzoic acid, 2, 2-bis(4-hydroxyphenyl) propane and palmitic acid showed high inhibition of *P. ginseng* radicles and hypocotyls growth. Radicle growth and hypocotyl growth was significantly restrained by benzoic acid, 2, 2-bis(4-hydroxyphenyl) propane and palmitic acid at 1.00 mg/L, respectively. However, benzoic acid and 1, 2-benzenedicarboxylic acid bis (2-methylpropyl) ester) at 0.01 mg/L slightly promoted the hypocotyls growth (19).

6.1.2. *Panax quinquefolium*

The most active autotoxins of *Panax quinquefolium* were present in stems, leaves, roots and root exudates. Among these, ether fraction of water extract and alcohol extract from either stems, leaves or fibrous roots drastically inhibited the growth of ginseng roots, while the n-butyl alcohol fraction had little inhibitory effects. When the concentration of water soluble autotoxins from stems/leaves or fibrous roots in soil reached 1.00 g/kg soil, the 4-years old American ginseng plants did not grow. At 0.20 g/kg soil concentration, the survival rate of ginseng decreased to 25 % (59).

Zhao *et al.* (59) identified 26 compounds by GC-MS and 64 % of them were fatty acids and the remaining were furantone, sesquiterpenes, alkenes and alcohol. They also reported that 9-phenolic compounds [2-(4-hydroxy-3-methoxyphenyl) ethanol, vanillin and 3-vanilpropanol, salicylic, vanillic, syringic, 3-methoxy-4- hydroxyl- benzenepropanoic, 3-benzoyl-propionic and hydrocinnamic acids], in the soil from American ginseng caused

autotoxicity (18). Further, it was also investigated that *p*-hydroxybenzoic acid, vanillin, ferulic acid and benzoic acid at 0.10 to 10 mmol/L concentrations caused > 50 % inhibition in radicle and shoot growth of American ginseng (10). Nevertheless, degradation in soil and soil absorption decreases the autotoxicity of phenolic acids and ginsenosides. In laboratory bioassay, mixtures of phenolic acids (PCM) being autotoxins, containing trans-cinnamic, *p*-coumaric, ferulic, vanillic, vanillin, salicylic acid, syringic, benzoic and *p*-hydroxybenzoic acids had inhibitory effects on embryo and seedling growth of American ginseng. Root and shoot growth of American ginseng embryo were reduced by PCM at 0.55-4.4 mg/mL. PCM at 0.02-0.5 mg/mL affected the photosynthesis, resulting in seedlings growth inhibition of American ginseng. However weak autotoxicity was observed, when plants were grown in soil, due to degradation of the applied PCM (53). After 3-4 years continuous cropping, the content of three ginsenosides (marked as Rb₁, Rb₂ and Rd) reached 0.8-3.19 mg/kg in the rhizosphere soil and 4-6 mg/L in soil solution. The radicle lengths of American ginseng were decreased by 6 %-23 % in solution containing 0.2-125 mg/L ginsenoside extracts. After 20 d of growth in nutrient solution amended with 25 mg/L ginsenosides extracts, plant height of 3-year-old American ginseng seedling was decreased by 28 % than control, and the biomass of aerial parts was reduced by 50 %. However, this effect was weakened in field soil, as neither the radicle length nor shoot length were significantly affected by 0.2-125 mg/kg ginsenoside extract when American ginseng was cultivated in sterile or non-sterile soil, which might be caused by the adsorption of ginsenosides to soil (22).

6.1.3. *Panax notoginseng*

The root of *Panax notoginseng*, known as *Sanqi* in Chinese, is commonly used in traditional Chinese medicine due to its hemostatic and restorative properties. However, the continuous cropping obstacle of *P. notoginseng* could lead to less land being available for its cultivation. The autotoxicity of *Panax notoginseng* root residue has been reported (51). The powdered lateral roots of *P. notoginseng* showed stimulatory effects at low concentration, while high concentration inhibited the germination. Specifically, the powder of lateral roots had no inhibitory effects on germination 10 % (weight/weight, in soil) concentration. At 1.50 % concentration, the germination and survival rate of seedlings were 68.57 % and 83.33 %, respectively, but at 3 % concentration, no seedlings survive (54). The main autotoxins of *P. notoginseng* were ginsenosides. At 1.00 µg/mL, ginsenosides (R₁, Rg₁, Re, Rg₂ and Rd) obtained from the root exudates of *Sanqi* ginseng, reduces the seedling emergence and growth and decreases the root vigour (50). Rg₁ disrupted the membranes and cell walls and induce the over-accumulation of reactive oxygen species (ROS) (49). Additionally, phenolic acids (PAs) are also important autotoxins of *P. notoginseng* (58). Six phenolic acids [PAs] (*p*-hydroxybenzoic, vanillic, syringic, *p*-coumaric, ferulic and benzoic acids) were found in rhizosphere soil of *P. notoginseng*. The *p*-coumaric acid had the highest content and the lowest one was syringic acid.

7. ARAUCARIACEAE

7.1. Genus *Araucaria*

Autotoxicity is also present in coniferous forests, for example, hoop-pine (*Araucaria cunninghamii* Ait.) is autotoxic species. Four-weeks-old, non-mycorrhizal hoop-pine seedlings growing in sterilised sand, rainforest soil or soil supporting a *Pinus* plantation, were watered for ten months with leachates prepared by passing complete nutrient solution through sand in which advanced trees of hoop pine were grown. The leachates significantly reduced the dry-matter production and caused some mortality. Survivors exhibited varying degrees of necrosis and chlorosis on the sand, and stunting and browning on the soils. While nitrogen and potassium status of the shoots were unaffected, phosphorus levels and uptake were significantly reduced (9).



17. *Araucaria cunninghamii* Ait.

8. ASPARAGACEAE

8.1. Genus *Asparagus*

The quality and yield of asparagus (*Asparagus officinalis* L.) declined after few year's cultivation. It may be related to autotoxicity of asparagus.

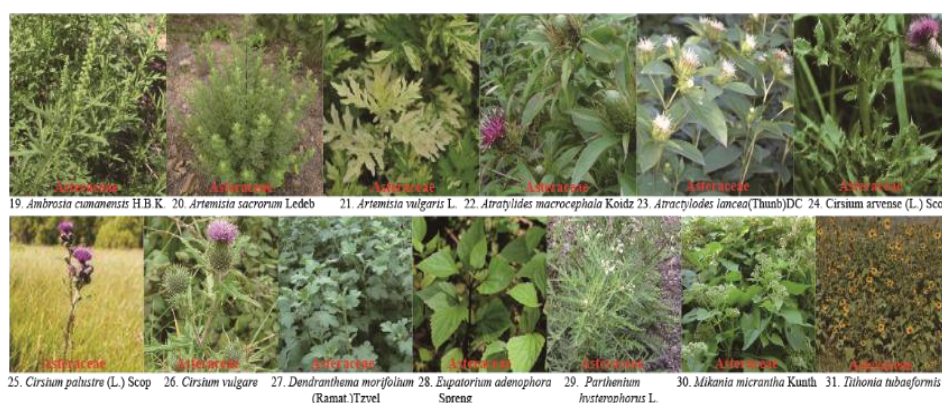
An aqueous methanol extract of 10-years-asparagus-cultivated soils was autotoxic and restrained the growth of asparagus seedlings, the autotoxic compound was identified as trans-cinnamic acid by spectral data. The IC_{50} value of the growth inhibition of asparagus were 24.1-41.6 μ M (24).



18. *Asparagus officinalis* L.

9. ASTERACEAE (COMPOSITAE)

The largest number of plants in pharmacopoeia are from this family Asteraceae (also known as Compositae). It includes large number of species, whose wide array of natural products are used to treat diseases. Plants from 9 genera (*Ambrosia*, *Artemisia*, *Atractylodes*, *Cirsium*, *Dendranthema*, *Eupatorium*, *Parthenium*, *Mikania* and *Tithonia*) had autotoxic effects.



9.1. Genus *Ambrosia*

Anaya and Amo (1) demonstrated that the root growth of *Ambrosia cumanensis* H.B.K. was inhibited by its own root and leaf extracts, while the stem growth was not affected. Growth of *Ambrosia* seedlings was inhibited by sterile and nonsterile soil with *A. cumanensis* roots, while leaf residues inhibited the roots and stimulated the stems of young plants.

9.2. Genus *Artemisia*

Artemisia mainly grows in arid and semiarid temperate climate of the northern and southern hemispheres (34). The methanol and aqueous extracts of the leaf and stem from *Artemisia sacrorum* Ledeb. had autotoxic effects, the methanol extract was more inhibitory than aqueous extract (45). Mugwort (*Artemisia vulgaris*) contains allelochemicals both in under- and above-ground plant parts that causes autotoxicity. In field experiment, mugwort stem number decreased by 75-% in residue-enriched plots at the end of third year. Soil to which mugwort materials has been introduced (roots and rhizomes) reduced the germination and seedling growth of mugwort, but the introduction of shoot biomass had no effect. Germination and seedling growth of mugwort were significantly inhibited by the aqueous extract. While mugwort seedlings were tolerant to foliar application of aqueous mugwort extracts (36).

9.3. Genus *Atractylodes*

Continuous cropping problem affected the plantation of medicinal plant *Atractylodes macrocephala* Koidz. Xu *et al.* (48) found that its aqueous extracts from leaf and stem at 0.05-0.2g/mL were most autotoxic to seedlings. The aqueous extract of root had no significant effects on the growth inhibition, but the organic solvents (acetone : ethyl

acetate=1:1) extract of root exerted significant growth inhibition. The inhibitory effect was dependent on the extract concentrations. An autotoxic compound [2,4-Ditertbutyl phenol (2,4-DP)], isolated from root exudates and rhizosphere soil of *A. macrocephala* was identified by gas chromatography-mass spectrometry (GC-MS). The researches showed that 2,4-DP remarkably inhibited the seed germination. The results suggested that 2,4-DP is inhibitory to plant immune system (60). The seed germination rate, radicle length and plantlet of *Atractylodes lancea* were reduced by 13 %, 32 % and 24 % respectively by the aqueous extract of root and stem of *A. lancea* at 200 mg/mL (17). Twenty compounds in the rhizome extract and 27 compounds in the rhizosphere soil extract were identified. Many compounds [2,5-octadecadynoic acid, methyl ester, n-hexadecanoic acid, pentadecanal, tetradecanoic acid, 1-naphthalenol, butylated hydroxytoluene, 2-methoxy-4-vinylphenol, β -eudesmol, hinesol, etc.] were allelopathic and detected in both extracts of rhizomes and rhizosphere soil. The sesquiterpenoid β -eudesmol at 100-250 mg/L significantly inhibited the growth of *A. lancea* plantlets (17).

9.4. Genus *Cirsium*

The establishment of some pasture and crop species face difficulty in fields infested with *C. arvense* (L.) Scop. The extracts from the root and foliage of *C. arvense* inhibited its own germination and seedling growth (8). The germination of *Cirsium palustre* (L.) Scop seeds was apparently inhibited by ethanol extracts from fresh leaves of *C. palustre* (5). De Jong and Klikhamer (14) reported that *Cirsium vulgare* litter may influence its own growth under conditions of nutrients deficiency. Especially, litter from flowering *C. vulgare* inhibited the growth of seedlings. When the concentration of leaf litter was equal to or > 0.4%, the dry weight of plants was strongly reduced.

9.5. Genus *Dendranthema*

Negative impact caused by autotoxicity also existed in plantation of chrysanthemum (*Dendranthema morifolium* (Ramat.) Tzvel.) in greenhouse or field. Zhou *et al.* (57) showed that the aqueous extract from the above-ground parts were highly autotoxic to seed germination and seedling growth and the autotoxicity increased with the increasing concentrations (57). Stalk length, inflorescence diameter and stem diameter of chrysanthemum were also significantly reduced by the aqueous extract of chrysanthemum at 1.60 g/mL (61).

Mechanism studies showed that the aqueous extract from the above-ground parts inhibited the enzymatic activities of isocitrate dehydrogenase (IDH) in roots and nitrate reductase (NR) in leaves and significantly stimulated the formation of malonylodialdehyde (MDA) in leaves (61). Meanwhile, the aqueous extract at 0.40-1.60 g/mL was inhibitory to root dehydrogenase, NR and phenylalanine ammonialyase (PAL) activities and soluble protein (62).

9.6. Genus *Eupatorium*

In 2014, Zhu (64) investigated the autotoxic effects of 4-allelochemicals [di(2-ethylhexyl) phthalate (DEHP), dibutylphthalate (DBP), amorpho-4, 7(11)-dien-8-one (DTD), 6-hydroxy-5-isopropyl-3,8-dimethyl- 4a,5,6,7,8,8a-hexahydraphthalen-2(1H)-one (HHO)] from *Eupatorium adenophora* [= *Ageratina adenophora* (Spreng.)] and their

biochemical mechanisms. The DBP from the root exudates was inhibitory to seed germination and seedling growth, but DEHP from the root exudates was not autotoxic. DTD and HHO from the leachates of *E. adenophora* inhibited either germination or seedling growth. Further, DEHP and DBP increased the activities of superoxide dismutase (SOD) enzyme. Whereas DTD had no significant effects on SOD activities and HHO inhibited the SOD activities. All these four allelochemicals did not influence the activity of peroxidase (POD). DEHP and DBP but caused the lipid peroxidation and damage to cell membrane of *E. adenophora* leaves.

Table 1. Autotoxic plants and their autotoxins

Family	Genus	Plant	Autotoxins	Reference
Amaranthaceae	<i>Amaranthus</i>	<i>A. palmeri</i>	2-Octanone, 2-Nonanone, 2-Undecanone, 2-Heptanone, 2-Hexanone, 3-Methyl-2-butanone, 2-pentanone, 3-Hydroxy-2-butanone, 2-Butanone	11
Apiaceae	<i>Angelica</i>	<i>A. sinensis</i>	2,6-Dimethyl, bicyclo[3,1,0]-4,6-dimethanol	20
	<i>Daucus</i>	<i>D. carota</i>	Crotonic acid	21
Araceae	<i>Colocasia</i>	<i>C. esculenta</i>	Lactic acid, Benzoic acid, M-hydroxybenzoic acid, P-hydroxybenzoic acid, Vanillic acid, Succinic acid, Adipic acid	3
	<i>Pinellia</i>	<i>P. ternata</i>	Chrysophanol, Benzofuran, Protocatechuic aldehyde	33
Araliaceae	<i>Panax</i>	<i>P. ginseng</i>	Benzoic, Palmitic acids, 2,2-Bis(4-hydroxyphenyl) propane, 1,2-Benzenedicarboxylic acid, Bis(2-methylpropyl) ester	19
		<i>P. quinquefolium</i>	Salicylic acid, Vanillic acid, Syringic acid, 3-Methoxy-4-hydroxy-1-benzenepropanoic acid, 3-Benzoyl-propionic acid, Hydrocinnamic acid, 3-Vanilpropanol, 2-(4-hydroxy-3-methoxyphenyl) ethanol, Vanillin, Ginsenoside, P-hydroxybenzoic acid, Ferulic acid, Benzoic acid, Trans-cinnamic acid, P-coumaric acid	10,18, 22,53
		<i>P. notoginseng</i>	Ginsenoside, P-hydroxybenzoic acid, Vanillic acid, Syringic acid, P-coumaric acid, Ferulic acid, Benzoic acid	50,58
Asteraceae	<i>Atractylodes</i>	<i>A. lancea</i>	2,5-Octadecadlynoic acid, N-hexadecanoic acid, Tetradecanoic acid, Hinesol methyl ester, Pentadecanal, 1-Naphthalenol, Butylated hydroxytoluene, 2-Methoxy-4-vinylphenol, β -eudesmol	17
		<i>A. macrocephala</i>	2,4-Ditertbutyl phenol	60
	<i>Eupatorium</i>	<i>E. adenophora</i>	Dis(2-ethylhexyl) phthalate, Dibutyl phthalate, 6-Hydroxy-5-isopropyl-3,8-dimethyl-4a,5,6,7,8,8a-hexahydraphthalen-2(1H)- one, amorpho-4,7(11)-dien-8-one	64
	<i>Parthenium</i>	<i>P. hysterophorus</i>	Sesquiterpene lactones, Parthenin and Coronopilin	37
	<i>Tithonia</i>	<i>T. tubaeformis</i>	5,3'-Dihydroxi-7,4'-dimetoxiflavone	23
Campanulaceae	<i>Codonopsis</i>	<i>C. pilosula</i>	Codonopilate A, Taraxeryl acetate, 2,4-methylenecycloartanol	46

9.7. Genus *Parthenium*

Parthenium hysterophorus L. showed autotoxic effects. The aqueous leaf leachates of *P. hysterophorus* at 0.5 g/mL decreased the total chlorophyll content to 1.0 and the cell survival to 52.6 % as compared to 1.7 mg/g and 100 %, respectively, in control. Besides, the aqueous leachate of inflorescence also significantly reduced the chlorophyll content and cell survival (26). Picman *et al.* (37) showed that sesquiterpene lactones, parthenin and coronopilin chemicals in *P. hysterophorus* were responsible for the autotoxicity.

9.8. Genus *Mikania*

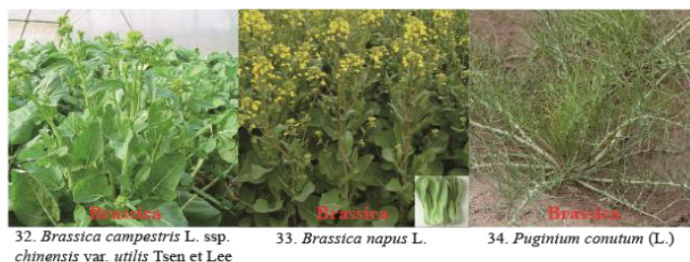
Various extracts from different parts of *Mikania micrantha* Kunth. inhibited the growth of its own seedlings. The magnitude of inhibition of 4-extract solvents followed the order: ethyl acetate > ethanol > aqueous > n-hexane. The seedling growth was completely suppressed with ethyl acetate extract of stem and leaf at 25 mg/mL. The inhibition rate on seedling growth by the aqueous extract of stem and leaf were 70.12 % and 90.70 %, respectively (47).

9.9. Genus *Tithonia*

Chloroform extract from stems and leaves of *Tithonia tubaeformis* was more inhibitory to the seed germination of *T. tubaeformis* than n-hexane and ethyl acetate extract. Flavonoid (5, 3'-dihydroxi-7,4'-dimetoxiflavone) obtained from the chloroform extract at 3.50 mg/mL was very inhibitory to germination of *T. tubaeformis* (23).

10. BRASSICACEAE

The Brassicaceae family consists of about 3500 species and 350 genera. Many genera of Brassicaceae include species of worldwide economic importance (38). Plants from 2 genera, *Brassica* and *Pugionium* are autotoxic. Post-harvest residues of roots, stems and leaves from Chinese cabbage inhibited the growth of succeeding Chinese cabbage in next season (32).



10.1. Genus *Brassica*

The aqueous extract from roots, stems and leaves of Chinese cabbage (*Brassica campestris* L. ssp. *chinensis* var. *utilis* Tsen et Lee) showed autotoxicity at 0.5-5g/L. After the treatment, leaf chlorophyll content declined, photosynthesis rate was affected, activities of SOD, POD and CAT were changed, MDA content increased and cell membrane was damaged (32).

Microspore cultures of older spores of *Brassica napus* L. could be used as toxic inoculant in fresh embryogenic cultures and it changed the embryogenesis and embryo morphology itself. When inoculation of embryogenic cultures was done at 100 μ L, on first day the initiation of embryos was reduced to 14% and was reduced to 0 % at 400 μ L. However, at 400 μ L, initiation of embryos was reduced by 50 % on day 3. This indicated that microspore development was easily disrupted within the first 24 h of culture (25).

10.2. Genus *Pugionium*

Bao *et al.* (7) reported that the aqueous extract of *P. conutum* at > 0.15 g/mL concentration decreased the germination rate, seedling height, root length, fresh weight and dry weight of *Pugionium conutum* (L.) seedlings. Autotoxicity capability of the aqueous extracts of different parts followed the sequence: leaf > peel > branch. With the increase in concentration (0.05-0.20 g/mL) of the aqueous extract, SOD and POD activities were significantly inhibited. CAT activity was first increased and then decreased, while the MDA content increased constantly (7).

11. CAMPANULACEAE

The medicinal plant *Codonopsis pilosula* (Franch.) Nannf. and *Platycodon grandiflorus* (Jacq.) A. DC. are autotoxic. Continuous cropping problem has been observed in *Codonopsis pilosula* and *Platycodon grandiflorus* continuous cultivation and caused seriously declines the yield and quality (40,46,56,63). *P. grandiflorus* (Jacq.) A. DC. possesses autotoxic activity. The aqueous extract from roots were more inhibitory than from seeds or leaves. At 0.1 g/mL, the methanol and water extract of whole plant decreased the germination (63).



35. *Codonopsis pilosula*
(Franch.) Nannf.

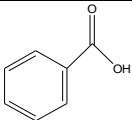
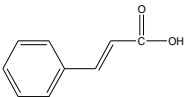
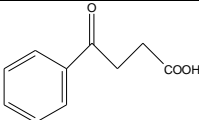
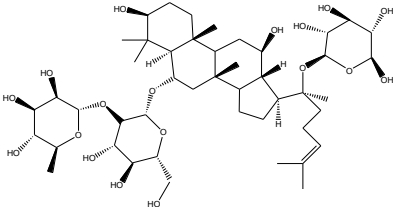
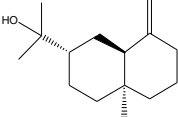
36. *Platycodon grandiflorus*
(Jacq.) A. DC.

11.1. Genus *Codonopsis*

Crude extract of rhizosphere soil of *C. pilosula* reduces the growth of root and stem at 400 μ g/mL (40). At 0.1 g FW/mL, the root aqueous extract of *C. pilosula* complete suppresses its own seed germination and thereby inhibits the seedling growth (56). The root aqueous extract at 0.025 g/mL inhibited the NR activity and root energy, increased MDA content and the activities of POD and SOD (56). Three autotoxins (codonopilate A, taraxeryl acetate and 24-methylenecycloartanol) were identified. The inhibition rates of codonopilate A at 200 μ g/mL on the root and stem growth of *C. pilosula* seedlings were 46.2 % and 44.6 %, respectively. Taraxeryl acetate and 24-methylenecycloartanol showed weaker toxicity (46).

Table 2. Chemical structures of autotoxins

Phenolic compounds		
Ferulic acid 10,53,58	p-coumaric acid 53,58	2,2-bis(4-hydroxyphenyl)propane 19
3-methoxy-4-hydroxybenzoic acid 18	1-naphthalenol 17	Salicylic acid 18
2-(4-hydroxy-3-methoxyphenyl)ethanol 18	Syringic acid 18,53,58	Butylated hydroxytoluene 17
R1=CHO, Vanilline 10,18,53 R1=COOH Vanillic acid 3,18,53,58	R1=OH, R2=H m-hydroxybenzoic 3 R1=H, R2=OH p-hydroxybenzoic acid 3,10,53,58	
Terpenoids		

Taraxeryl acetate 46	24-methylenecycloartanol 46	2,6-dimethyl,bicyclo[3,1,0]-4,6-dimethanol 51
Aromatic acids		
		
Benzoic acid 3,10,19,53,58	Trans-cinnamic acid 53	3-benzoyl-propionic acid 18
Ginsenosides		Steroids
		
Ginsenoside 22,50		β -eudesmol 17

12. CONCLUSIONS

Autotoxicity is the main reason causing continuous cropping problem in important agricultural crops and medicinal plants. In this review, autotoxicity of 10 families (36 species) were summarized. Most of these species are crops (*Daucus carota* and *Colocasia esculenta*, etc.) or medicinal plants (*Andrographis paniculata*, *Angelica sinensis*, *Panax quinquefolium*, *Panax notoginseng*, *Atractylodes macrocephala* and *Codonopsis pilosula*, etc.). Only a few of them are notorious invasive weed species (such as *Eupatorium adenophora* and *Mikania micrantha*). Owing to the economic importance, we mainly focused on the autotoxicity of crops and medicinal crops. In fact, the autotoxicity of some invasive species might play an important ecological role. Detailed studies are needed to find links between the chemical compounds present in the invasive plant and their dynamics after release into the soil.

The autotoxin isolation and identification studies showed that phenolic acids were the main autotoxins causing the autotoxicity of crop species. More autotoxins were found in medicinal plants and invasive weed species. The elucidation of autotoxins is not only important in solving the problem of continuous cropping problem, but also to find the new herbicidal chemicals. Therefore, the elucidation of autotoxins from more medicinal plants and invasive weed species deserves more attention.

ACKNOWLEDGMENTS

This work was funded by Science and Technology Planning Programs of Guangdong Province, China (2015A020209151).

REFERENCES

1. Anaya, A.L. and Amo, S.D. (1978). Allelopathic potential of *Ambrosia cumanensis*, H.B.K. (Compositae) in a tropical zone of Mexico. *Journal of Chemical Ecology* **4**: 289-304.
2. Armas, C. and Pugnaire, F.I. (2011). Belowground zone of influence in a tussock grass species. *Acta Oecologica* **37**: 284-289.
3. Asao, T., Asegawa, K.H., Sueda, Y., Omita, K.T. and Taniguchi, K. (2003). Autotoxicity of root exudates from taro. *Scientia Horticulturae* **97**: 389-396.
4. Asao, T., Taniguchi, K., Tomita, K. and Hosoki, T. (2001). Species differences in the susceptibility to autotoxicity among leaf vegetables grown in hydroponics. *Journal of the Japanese Society for Horticultural Science* **70**: 519-521.
5. Ballegaard, T.K. and Warncke, K. (2010). Observations on autotoxic effects on seed germination and seedling growth in *Cirsium palustre* from a spring area in Jutland, Denmark. *Ecography* **8**: 63-65.
6. Banerjee, M., Moulick, S., Bhattacharya, K.K., Parai, D., Chattopadhyay, S. and Mukherjee, S.K. (2017). Attenuation of *Pseudomonas aeruginosa* quorum sensing, virulence and biofilm formation by extracts of *Andropogon paniculata*. *Microbial Pathogenesis* **113**: 85-93.
7. Bao, H.C., Hao, L.Z., Zhang, F.L., Yang, Z.R. and Li, X.L. (2016). Autotoxicity of aquatic extracts from different parts of *Pugonium conutum* (L.) Gaertn. *Chinese Journal of Grassland* **38**: 103-110. (Chinese)
8. Bendall, G.M. (2010). The allelopathic activity of californian thistle (*Cirsium arvense* (L.) Scop.) in Tasmania. *Weed Research* **15**: 77-81.
9. Bevege, D.I. (1968). Inhibition of seedling hoop pine (*Araucaria cunninghamii* Ait.) on forest soils by phytotoxic substances from the root zones of *Pinus araucaria* and *flindersia*. *Plant and Soil* **29**: 263-273.
10. Bi, X.B., Yang, J.X., Gao, W.W. and Zeng R.S. (2010). Autotoxicity of phenolic compounds from the soil of American ginseng (*Panax quinquefolium* L.). *Allelopathy Journal* **25**: 115-121.
11. Bradow, J.M. and Connick, W.J., Jr. (1988a). Volatile methyl ketone seed-germination inhibitors from *Amaranthus palmeri* S. Wats. residues. *Journal of Chemical Ecology* **14**: 1617-1631.
12. Bradow, J.M. and Connick, W.J., Jr. (1988b). Seed-germination inhibition by volatile alcohols and other compounds associated with *Amaranthus palmeri* residues. *Journal of Chemical Ecology* **14**: 1633-1648.
13. Chaturvedi, S.N. and Muralia, R.N. (1975). Germination inhibitors in some umbellifer seeds. *Annals of Botany* **39**: 1125-1129.
14. de Jong, T.J. and Klinkhamer, P.G.L. (1985). The negative effects of litter of parent plants of *Cirsium vulgare* on their offspring: Autotoxicity or immobilization? *Oecologia* **65**: 153-160.
15. Friedman, J., Rushkin, E. and Waller, G.R. (1982). Highly potent germination inhibitors in aqueous eluate of fruits of bishop's weed (*Ammi majus* L.) and avoidance of autoinhibition. *Journal of Chemical Ecology* **8**: 55-65.
16. Gog, L., Berenbaum, M.R., Delucia, E.H. and Zangerl, A.R. (2005). Autotoxic effects of essential oils on photosynthesis in parsley, parsnip, and rough lemon. *Chemoecology* **15**: 115-119.
17. Guo, L.P., Huang, L.Q., Jiang, Y.X., Zhu, Y.G., Chen, B.D., Zeng, Y., Fu, G.F. and Fu, M.H. (2006). Bioactivity of extracts from rhizome and rhizosphere soil of cultivated *Atractylodes lancea* DC. and identification of their allelopathic compounds. *Acta Ecologica Sinica* **26**: 528-535. (Chinese)
18. He, C.N., Gao, W.W., Yang, J.X., Bi, W. and Zhang, X.S. (2009). Identification of autotoxic compounds from fibrous roots of *Panax quinquefolium* L. *Plant and Soil* **318**: 63-72.
19. Huang, X.F., Li, Y. and Ding, W.L. (2009). Autotoxicity effect of ginseng root exudates on seeds germination. *Seed* **28**: 4-7. (Chinese)
20. Hui, J.R. (2008). *Study on Autotoxicity of Angelica sinensis*. M.S. Dissertation, Department of Ecology, College of Life Sciences of Northwest Normal University, Northwest Normal University, Lanzhou: 1-51. (Chinese)
21. Jasicka-Misiak, L., Wiczorek, P., Kafarski, P., Del Re, A.A.M., Capri, E., Padovani, L. and Trevisan, M. (2003). Phytotoxic activity of the water extract and its constituents from the carrot seed (*Daucus carota* L.). *XII Symposium Pesticide Chemistry*, pp: 257-262, Piacenza, Italy.
22. Jiao, X.L., Bi, X.B., Zhang, X.S. and Gao, W.W. (2015). Autotoxic effects of ginsenoside extracts on growth of American ginseng in different medium. *China Journal of Chinese Materia Medica* **40**: 1433-1438. (Chinese).

23. Juarez, V.D. and Cazon, A.V. (2003). Autotoxicity in *Tithonia tubaeformis* as a mechanism of invasion control. *Ecologia Austral* **13**: 133-138.
24. Kato-Noguchi, H., Nakamura, K. and Okuda, N. (2018). Involvement of an autotoxic compound in asparagus decline. *Journal of Plant Physiology* **224**: 49-55.
25. Kott, L.S., Polsoni, L., Ellis, B. and Beversdorf, W.D. (1988). Autotoxicity in isolated microspore cultures of *Brassica napus*. *Revue Canadienne de Botanique* **66**: 1665-1670.
26. Kumari, A. and Kohli, R.K. (1987). Autotoxicity of ragweed parthenium (*Parthenium hysterophorus*). *Weed Science* **35**: 629-632.
27. Li, J., Hui, J.R. and Ma, R.J. (2008). Research on the auto-intoxication of *Angelica sinensis*. *Journal of Anhui Agricultural Sciences* **36**: 1083-1085. (Chinese)
28. Li, Q.Q., Zhang, J., Liu, J.H. and Yu, B.Y. (2018). Morphological and chemical studies of artificial *Andrographis paniculata* polyploids. *Chinese Journal of Natural Medicines* **16**: 81-89. (Chinese)
29. Li, X.G., Ding, C.F., Hua, K., Zhang, T.L., Zhang, Y.N. and Zhao, L. (2014). Soil sickness of peanuts is attributable to modifications in soil microbes induced by peanut root exudates rather than to direct allelopathy. *Soil Biology & Biochemistry* **78**: 149-159.
30. Li, Y., Huang, X.F. and Ding, W.L. (2011). Autotoxicity of *Panax ginseng* rhizosphere and non-rhizosphere soil extracts on early seedlings growth and identification of chemicals. *Allelopathy Journal* **28**: 145-154.
31. Li, Y.Q., Li, M., Tang, K., Zhao, P., Dong, S. and Huang, J.W. (2014). Study on autotoxicity of *Andrographis paniculata* (Burm. F.) vegetative. *Northern Horticulture* **21**: 157-160. (Chinese)
32. Liu, H.C., Song, S.W., Chen, R.Y. and Sun, G.W. (2013). Study on autotoxicity of aqueous extracts from different parts of flowering Chinese cabbage. *Advanced Materials Research* **641-642**: 962-966.
33. Liu, J. K., Yan, Z. Q., Li, X. Z., Jin, H., Yang, X. Y., Xie, M. and Su, A. X. (2018). Characterization of allelochemicals from the rhizosphere soil of *Pinellia ternate* (Thunb.) and their inhibition activity on protective enzymes. *Applied Soil Ecology* **125**: 301-306.
34. Miao, Y.F., Meng, Q.Q., Fang, X.M. and Yan, X.L. (2011). Origin and development of *Artemisia* (Asteraceae) in Asia and its implications for the uplift history of the Tibetan Plateau: A review. *Quaternary International* **236**: 3-12.
35. Miller, D.A. (1996). Allelopathy in forage crop systems. *Agronomy Journal* **88**: 854-859.
36. Onen, H. (2007). Autotoxic potential of mugwort (*Artemisia vulgaris*). *Allelopathy Journal* **19**: 323-335.
37. Picman, J. and Picman, A.K. (1984). Autotoxicity in *Parthenium hysterophorus* and its possible role in control of germination. *Biochemical Systematics & Ecology* **12**: 287-292.
38. Raiola, A., Errico, A., Petruk, G., Monti, D.M., Barone, A. and Rigano, M.M. (2018). Bioactive compounds in Brassicaceae vegetables with a role in the prevention of chronic diseases. *Molecules* **23**: 15. <https://doi.org/10.3390/molecules23010015>.
39. Rice, E.L. (1984). *Allelopathy*. 2nd ed. Academic Press, London. 435 pp.
40. Robles, C., Bonin, G. and Garzino, S. (1999). Autotoxic and allelopathic potentials of *Cistus albidus* L. *Les Comptes Rendus de l'Academie des Sciences Serie Sciences de la Vie* **322**: 677-685.
41. Shi, F.X., Li, M.R., Li, Y.L., Jiang, P., Zhang, C., Pan, Y.Z., Liu, B., Xiao, H.X. and Li, L.F. (2015). The impacts of polyploidy, geographic and ecological isolations on the diversification of *Panax* (Araliaceae). *BMC Plant Biology* **15**: 1-11.
42. Singh, H.P., Batish, D.R. and Kohli, R.K. (1999). Autotoxicity: Concept, organisms and ecological significance. *Critical Reviews in Plant Sciences* **18**: 757-772.
43. Sinkkonen, A. (2007). Modelling the effect of autotoxicity on density-dependent phytotoxicity. *Journal of Theoretical Biology* **244**: 218-227.
44. Takahashi, K. (1984). Replant failure problems in vegetables. *Research Data of National Research Institute of Vegetables*. **18**: 87-99 (Japanese).
45. Wang, H., Xie, Y.S. and She, X.Y. (2016). Autotoxicity and allelopathic effects of *Artemisia sacrorum* L. on dominant spp (*Stipa bungeana*, *Stipa grandis*, *Thymus mongolicus* and *Leymus secalinus*) of steppe from Loess Plateau, China. *Allelopathy Journal* **37**: 41-54.
46. Xie, M., Yan, Z.Q., Ren, X., Li, X.Z. and Qin, B. (2017). Codonopilate, a triterpenyl ester as main autotoxin in cultivated soil of *Codonopsis pilosula* (Franch.) Nannf. *Journal of Agricultural and Food Chemistry* **65**: 2032-2038.

47. Xu, G.F., Zhang, F.D., Li, T.L., Zhang, Y. and Zhang, Y.H. (2009). Allelopathic autotoxicity effects of *Mikania micrantha* H.B.K and its ecological significance. *Acta Agriculturae Boreali-Sinica* **24**: 220-224. (Chinese)
48. Xu, J.Z., Wang, Z.A., Sun, Y.M. and Yu, X.P. (2011). Autotoxicity of *Atractylodes macrocephala*. *Modern Chinese Medicine* **13**: 25-27. (Chinese)
49. Yang, M., Chuan, Y.C., Guo, C.W., Liao, J.J., Xu, Y.G., Mei, X.Y., Liu, Y.X., Huang, H.C., He, X.H. and Zhu, S.S. (2018). *Panax notoginseng* root cell death caused by the autotoxic ginsenoside Rg (1) is due to over-accumulation of ROS, as revealed by transcriptomic and cellular approaches. *Frontiers in Plant Science* **9**: 264-277.
50. Yang, M., Zhang, X., Xu, Y., Mei, X. and Jiang, B. (2015). Autotoxic ginsenosides in the rhizosphere contribute to the replant failure of *Panax notoginseng*. *Plos One* **10**: e0118555.
51. Zhang, J. Y., Cun, Z., Long, G. Q., Zhang, G. H., Meng, Z. G., Li, L. G., Yang, S. C. and Chen, J. W. (2018). Study on autotoxicity of *Panax notoginseng* root residue. *Plant Science Journal* **36**: 431-439.
52. Zhang, X.H., Zhang, E.H., Fu, X.Y., Huang, Y. and Lang, D.Y. (2010). Autotoxic effects of *Angelica sinensis* (Oliv.) *Allelopathy Journal* **26**: 1-11.
53. Zhang, X.S., Jiao, X.L., Du, J., Yang, J.X., Ji, C.H. and Gao, W.W. (2016). The impact of phenolic acids on the growth of American ginseng. *Allelopathy Journal* **37**: 77-90.
54. Zhang, Z.L., Gong, J.T., Cheng, X.Y., Hou, J.L. and Wang, W.Q. (2015). Study on autotoxicity effect of *Panax notoginseng* rootlets powder in soil. *Chinese Agricultural Science Bulletin* **31**: 143-148. (Chinese)
55. Zhang, Z.Y. and Lin, W.X. (2009). Continuous cropping obstacle and allelopathic autotoxicity of medicinal plants. *Chinese Journal of Eco-Agriculture* **17**: 189-196. (Chinese)
56. Zhao, Q.F., Chen, J., Guo, P.H., Li, Q.X. and Zhou, Z.J. (2010). Autotoxicity of *Codonopsis pilosula*. *Journal of Northwest Normal University* **46**: 75-78. (Chinese)
57. Zhao, Q.F., Li, H.Y., Zhang, B., Liu, Q.Q. and Liu, L. (2012). Research on primary isolation of autotoxins from *A. membranaceus* var *mongolicus*. *Journal of Northwest Normal University (Natural Science)* **48**: 80-83. (Chinese)
58. Zhao, Y., Wang, Y., Shao, D., Yang, J. and Liu, D. (2005). Autotoxicity of *Panax quinquefolium* L. *Allelopathy Journal* **15**: 67-74.
59. Zhao, Y.M., Cheng, Y.X., Ma, Y.N., Chen, C.J., Xu, F.R. and Dong, X. (2018). Role of phenolic acids from the rhizosphere soils of *Panax notoginseng* as a double-edge sword in the occurrence of root-rot disease. *Molecules* **23**: 819.
60. Zheng, F., Chen, L., Gao, J., Niu, F., Duan, X., Yin, L. and Tian, W. (2018). Identification of autotoxic compounds from *Atractylodes macrocephala* Koidz and preliminary investigations of their influences on immune system. *Journal of Plant Physiology* **230**: 33-39.
61. Zhou, K., Guo, W.M. and Wang, Z.F. (2010). Autotoxicity of aquatic extracts from different parts of Chrysanthemum. *Acta Botanica Boreali-Occidentalia Sinica* **28**: 0759-0764. (Chinese)
62. Zhou, K., Yang, X.Z., Hao, F., Wang, Z. and Guo, W. (2009). Autotoxic effects of Chrysanthemum (*Chrysanthemum morifolium* (Ramat) Tzvel.). *Allelopathy Journal* **24**: 91-101.
63. Zhu, L.X., Bi, S. and Liu, Y. (2013). Preliminary studies on autotoxicity of *Platycodon grandiflorum*. *Lishizhen Medicine and Materia Medica Research* **24**: 1992-1994. (Chinese)
64. Zhu, X.Z., Guo, J., Shao, H. and Yang, G.Q. (2014). Effects of allelochemicals from *Ageratina adenophora* (Spreng.) on its own autotoxicity. *Allelopathy Journal* **34**: 253-264.