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Soil Sickness of *Panax gingseng* : Current Status and Future Perspectives

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CONTENTS

ABSTRACT

This paper reviews the main causal factors (Autotoxicity and microbes and allelochemicals and microbial interactions) of ginseng soil sickness. Prevention and control measures of ginseng soil sickness viz., crop rotation and intercropping, breeding, soil sterilization, reducing residues and removing autotoxins substances have been Discussed. However, studies are not done on the interactions between monomer autotoxins and microorganisms and the gene expression. This review lays the foundation for further research to solve the problem of soil sickness in ginseng.

Keywords: Allelochemicals, allelopathy, autotoxicity, autotoxins, crop rotation, current status, Future researches, ginseng, interactions, intercropping, microorganism, *Panax ginseng*, soil microbes, soil sickness.

1. INTRODUCTION

Soil sickness is a typical negative plant-soil feedback, which reduces the crops growth and yield. This soil-borne diseases occurs when the same crop or its related species are cultivated successively on the same soil (11,46,48). The problem of soil sickness dates

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back to the beginning of agriculture (9). Most Chinese herbs cause soil borne diseases [viz., *Angelica sinensis* (Oliv.) Diels (65), *Pseudostellaria heterophylla* (Miq.) (30), *Pana xnotoginseng* (Burk.) (59), *Radix panacis quinquefolii* (5) etc]. Ginseng is herbaceous perennial plant and cultivated since ancient times in China and Korea (4,63). It is one of the most traded medicinal herb for health and disease treatment and is currently sold in 35 countries. It is also used as food, dietary supplements, health products and medicines etc (3). In 2018 alone, the total output value of ginseng in China and South Korea was about $4942 million. (27).

A. Ginseng roots harvested after 4-Years in healthy soil

B. Ginseng roots harvested after 4-Years in sick soil

Figure 1. Plant ginseng roots harvested after 4 years in healthy soil and in sick soil.

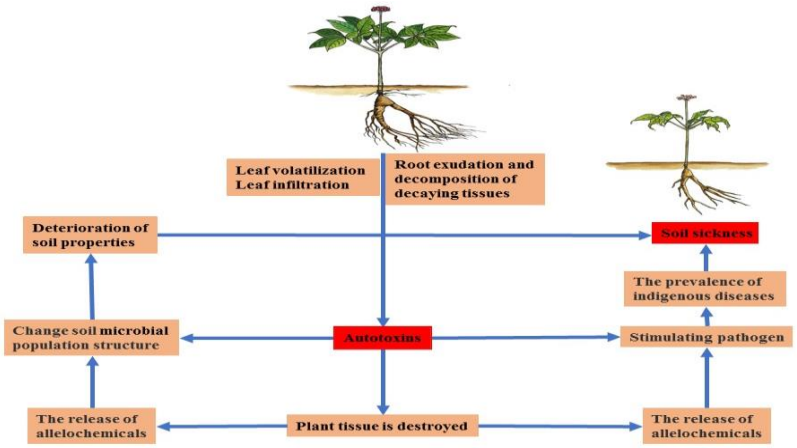

Figure 2**.** Diagram showing the modes of release of allelochemicals from the plants, interactions among the allelochemicals, microorganisms and autotoxicity in ginseng.

Ginseng is most seriously affected by the problem of soil sickness. When ginseng is grown continuously on the same soil, it decreases the crop yields and is affected by soil borne diseases (Fig. 2) (51).

The soil sickness of ginseng may be caused by allelopathy, autotoxicity and microbial interactions (Fig. 2). The solution of the problem of ginseng soil sickness is of great significance to the sustainable development of ginseng industry. There were few studies on ginseng soil diseases in past, but the interest and the number of papers on ginseng soil disease continues to grow rapidly in recent years. Based on the existing research, this paper summarizes the possible causes of ginseng soil sickness. The ginseng soil sickness may be caused by (i). autotoxicity, (ii). soil microbial community changes and (iii). accumulation of pathogenic microorganisms in rhizosphere soil. The etiology of ginseng soil sickness is complex, and several examples of such research have been discussed in this article.

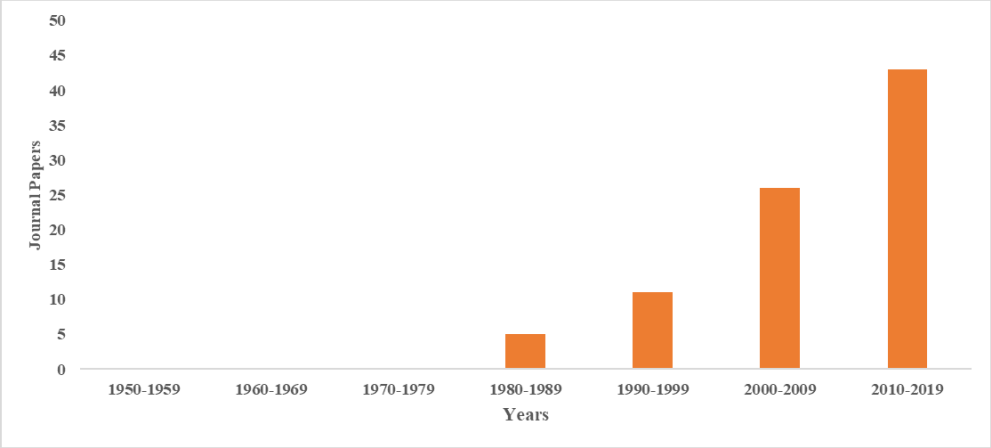

Figure 3. Journal papers accessed on 'SciFinder®, web of science and Google Scholar' using the search term *Panax ginseng* (soil sickness, autotoxicity, autotoxins, allelopathy or allelochemical) for each decade of past 70 years. (Since ginseng related articles were mainly published in China and Korea, hence, some articles published in Chinese or Korean may not be searchable in the database. However, this statistic showed the trend in the number of articles published internationally on *Panax ginseng* soil sickness).

2. ROLE OF AUTOTOXICITY

Allelopathy is a biological phenomenon, in which an organism releases one or more biochemical substances into the environment these may be directly or indirectly harmful or beneficial to other plants or microorganisms (40). Autotoxicity is a type of intraspecific allelopathy, in which plants release toxic chemicals into the environment to inhibit the growth of their own or related plants (16,42). Plant autotoxins are released into the environment through leaf leachates, volatilization, root exudates and decomposition of

plant residues (42). Autotoxicity has been studied for long time and it affects the plant physiological and biochemical processes (19,42,61). The accumulation of autotoxins is the key factor causing ginseng soil sickness (47). The ginseng autotoxins researches have foccussed on (i). Autotoxins activity, (ii). Effects of physiological and biochemical changes in plants and (iii). Effects on the morphology and structure of ginseng. The methanol extract from ginseng rhizosphere soil inhibits the growth (radicle and shoot length) of ginseng plants (28). The production and removal of reactive oxygen species (ROS) and the balance of redox reaction (REDOX) state in cells play an important role in autotoxicity. After exposure to auto-toxic substances, the recipient plants rapidly produces ROS in the contact area (57,68). Total ginsenoside increases the activity of superoxide dismutase (SOD), peroxidase (POD) and catalase (CAT) in ginseng callus (26). Autotoxics substances can change the content of plant growth regulators, or cause the imbalance of various plant hormones, inhibits the seed germination and seedling growth of plants. Most phenolic autotoxins can stimulate the activity of Indole-3-acetic acid (IAA) oxidase and inhibit the reaction of POD with IAA, bind the Gibberellin (GA) or IAA, thus adversely affecting the endogenous hormone levels. However, little is known about the effects of autotoxicity on ginseng hormone levels. The autotoxins also affects the plant gene expression (10). After treatment with benzoic acid, the expression of plant stress-related transcription factors such as AP2s/ERFs (APETALA 2 transcription factor/ethylene responsive factor), MYBs (transcription factor containing a Myb DNA binding domain) and WRKYs (WRKYGQK) in ginseng root were up-regulated (52).

3. ROLE OF SOIL MICROBIAL COMMUNITIES

Soil contains a wide variety of microorganisms that are essential to the functioning of terrestrial ecosystems (12). Traditional culture methods have been used for decades to monitor microbial communities. But now culture- independent methods [phospholipids fatty acids analysis (PLFA) and Polymerase Chain Reaction-Denaturing Gradient Gel Electrophoresis (PCR-DGGE) analysis] are used to assess the microbial diversity (25,33,38). After continuous cucumber planting, the population size of cultivated fungi and Fusarium in the soil increased significantly (70). The functional and genetic diversity of soil microbial communities (shown by Random Amplified Polymorphic DNA marker) is significantly reduced by autotoxins like cinnamic acid (53). In recent years, high throughput sequencing has been used to characterize the soil microbial communities (8,31,32). The increase in years of ginseng cultivation, decreased the bacterial diversity and increased the fungal diversity (54).

Microorganisms have beneficial, harmful or neutral effects on plants (43). Long-term continuous monoculture increases the proportion of harmful microorganisms in rhizosphere and non-rhizosphere soil, thus inhibiting the growth of black pepper and cucumber plants (29,69). Some becteria spp (*Pseudomonas* and *Bacillus*) inhibits the pathogenic fungi, which causes the ginseng root rot (14). Ginsenosides are present in the root exudates of ginseng, these (i). change the soil microbial community and metabolic

activity, (ii). thereby changing the soil microbial ecology and (iii). Causes their accumulation in soil, which adversely affects the growth of ginseng (64). However it is unclear, how the root exudates of ginseng plants affect the microbial community and how specific microbial populations are related to these root exudates.

4. ALLELOCHEMICAL AND MICROBES INTERACTIONS

Soil sickness may be partly due to the interactions of autotoxins and microorganisms etc., leading to growth inhibition and the prevalence of soil-borne diseases (72). Interactions between plants and microorganisms expand over time and space. Allelopathic substances affects the composition of microbial communities in the rhizosphere and also the reproduction and pathogenicity of pathogenic bacteria (21). The effects of microorganisms on their bacterial toxins are both inhibitory or stimulatory. These interactions explains the various responses of plants to autotoxins or allelopathic chemicals in different soil types. There is growing evidence that autotoxins, or allelopathic chemicals, can change the prevalence of many soil-borne diseases (18,55). Autotoxins or allelochemicals can change the (i). Genetic diversity, (ii). Biological activity and (iii). Metabolic activity of soil microbes, thus changing the soil microbial ecology, which affects the plants growth (6). Allelochemicals can also affect the soil microbial communities and the soil microorganism can metabolize the compounds, decreasing the autotoxins contents in the soil (23,44,71).

The decrease in crop yields due to continuous crop cultivation has also been partly attributed to the synergistic interference of autotoxicity and soil-borne plant pathogens (42). The *Panax quiquefolium* L. root exudates releases ginsenocides in the soil, these promoted the pathogens growth in soil. Ginsenosides also stimulates the rhizosphere fungus growth, which increases the spread of disease in ginseng crop (35). Similarly, the pathogens of ginseng may promote their spread by converting the Protopanaxadiol (PPD) ginsenosides into growth factors or host recognition factors.

The decarbonizing ability of ginsenosides to PPD type of ginsenosides may be a pathogenic factor (67). The growth of ginseng pathogen *Cylindrocarpon. destructans* (Zinss) Scholten is enhanced by the ginsenosides Rb1 and Rb2 (50). But how these allelopathic substances stimulate the pathogens of ginseng and the interactions between the allelopathic substances and pathogens of ginseng is not clear.

5. APPROACHES TO OVERCOME THE GINSENG SOIL SICKNESS

Although ginseng soil sickness is complex phenomenon, but can be partially alleviated using following practices:

5.1. Crop rotation and intercropping: Intercropping or crop rotation changes the soil microbial communities, reduces the number of pathogens and decreases the autotoxins contents (22,23,41). The intercropping of watermelon and aerobic rice reduced the incidence of watermelon wilt by inhibiting the production of watermelon fusarium wilt

spores and changing the rhizosphere soil microbial community by the rice root exudates (39). Many plants root exudates contains nematicidal and anti-microbial substances. For example, e.g., kale (*Allium ampeloprasum* L.) intercropping or crop rotation reduced the incidence of bacterial wilt and the leek root exudates are most inhibitory to pathogens (42). Intercropping of maize and *Panax notoginseng* stabilized the soil microbial community, increased the beneficial microorganisms and improved the soil functions (66). We studied the ginseng rotation with germicidal medicinal plant *Asarum sieboldi* Mig, which decreased the incidence of ginseng root rot, and other root diseases (unpublished data). However, which compounds in the root exudates of such medicinal plants are (i). potent and (ii). had bactericidal effects needs to be determined.

5.2. Breeding of soil sickness resistant ginseng varieties：Intraspecies variations occur during the plant breeding. Studies on barley showed that its autotoxicity was affected by variety and seasonal changes (36). The natural variations in plants are determined by their genes (47). Ginseng has large and complex genome (56). Plants evolves different strategies to protect themselves from pathogens. The disease resistance gene is one important mechanism for defense against plant pathogens (15,60). The prevalence of Soil-borne disease is the main cause of ginseng soil sickness (13). Therefore, the soil borne diseases of ginseng can be controlled by developing the ginseng varieties resistant to such diseases. The question like, What is the relationship between soil sickness and disease infection needs to be answered.

5.3. Soil sterilization： The soil sickness problem can be solved by regulating the soil microbial community in rhizosphere of ginseng (13). Soil sterilization is done by chemical and physical methods. The chemical methods uses bromomethane and nitrochloroform (to fumigate the soil (62). Besides the use of bromomethane and chloride-bitter in actual ginseng production, there are also other ways to control the soil pathogens and the pathogenic soil bacteria. Solar sterilization is increasingly being used to control many soil-borne diseases, however, its effects on the degradation of soil toxins are unclear (34). The soil sterilization kills both harmful and beneficial microorganisms in the soil (45).

5.4. Plant residues at harvest: Ginseng crop at harvest left residues (About 1600 kg/ha) of stems, leaves and fibrous roots in the soil. Crop residues generally release autotoxins and allelopathic substances during the natural decomposition (6,20,49) which may help in pathogens proliferation (7). Therefore, removal of all ginseng residues at harvest may be an important step to overcome the ginseng soil sickness.

5.5. Removal of autotoxins: The addition of activated carbon or biochar to the soil, adsorbs the soil Autotoxins, thereby, the adverse effects of self-poisoning on the growth of asparagus, lettuce and residues were decreased (2). In addition, biochar also effectively eliminates the adverse effects of soil pathogens and autotoxins on *Panax notoginseng* (58). Hence, use of these approaches to alleviate the soil diseases of ginseng may be an effective way.

6. FUTURE LINES OF RESEARCH

The ginseng soil sickness is complex phenomenon, its specific pathogenesis has not been fully elucidated. The suggested Future Lines of Research are as under:

(i). Ginseng soil sickness is caused by autotoxicity, microbial community changes and allelopathic substances stimulating the microbial pathogens. Hence, the interactions between allelopathic chemicals, autotoxins and microbes needs to be studied.

(ii). The autotoxins potential of monomer autotoxins substance needs to be determined.

(iii). Develop scientific methods to find the allelopathic potential of autotoxins of ginseng or other crops,

(iv). Study the genetic evidence of autotoxins in ginseng,

(v). Investigate the genotypic differences in the metabolism, secretion of toxins in ginseng and effects of toxins on the growth processes.

(vi). Study the degradation of soil autotoxin over the time periods,

(vii). Study the synergistic effects of different autotoxic substances in the soil substrates,

(viii). Determine the direct or indirect effects of ginseng rhizosphere toxins on pathogens or other harmful microorganisms in the soil.

(ix). Many plant root exudates contains antimicrobial compounds, however, little research has been done on the effects of ginseng root exudates on soil microbes.

(x). Autotoxins are the thrust points in the study of soil sickness. Thus, search the key autotoxins of ginseng and understand their mechanisms in ginseng soil sickness.

(xi). In-depth studies on the mechanism of soil diseases are required, these may provide theoretical basis to solve the soil sickness problem in ginseng and other crops.

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