Distribution, Pathotypes, and Metalaxyl Sensitivity of *Phytophthora sojae* from Heilongjiang and Fujian Provinces in China

Linkai Cui, Department of Plant Pathology, Nanjing Agricultural University, Nanjing 210095, China, and Forestry College, Henan University of Science and Technology, Luoyang 471003, China; and Weixiao Yin, Qinghua Tang, Suomeng Dong, Xiaobo Zheng, Zhengguang Zhang, and Yuanchao Wang, Department of Plant Pathology, Nanjing Agricultural University, China

ABSTRACT

Cui, L., Yin, W., Tang, Q., Dong, S., Zheng, X., Zhang, Z., and Wang, Y. 2010. Distribution, pathotypes, and metalaxyl sensitivity of *Phytophthora sojae* from Heilongjiang and Fujian provinces in China. Plant Dis. 94:881-884.

Phytophthora sojae causes root and stem rot, one of the most devastating diseases of soybean worldwide. In Heilongjiang and Fujian provinces in China, serious cases of *Phytophthora* stem and root rot have occurred and caused heavy losses in the past several years. To determine the current population status of this pathogen, we investigated the pathogen's distribution, pathotypes, and metalaxyl sensitivity in both provinces. *P. sojae* was baited and isolated from 258 soil samples in both provinces using the soybean leaf bait method. The pathotypes of all isolates were characterized on 13 differential soybean cultivars using the hypocotyl slit inoculation method, and the sensitivity of all isolates to metalaxyl was tested in vitro. In all, 75 isolates were recovered from 75 fields in 33 counties; of these, 31 counties were in Heilongjiang Province and 2 counties were in Fujian Province. Thirty-five new pathotypes were identified compared with the previously defined races. Less than 5% of the isolates were virulent to cultivars with individual *Rps* genes 1a, 1c, or 1k. No metalaxyl-resistant isolates were found; the half maximal effective concentration values of all isolates ranged from 0.04 to 0.22 $\mu\text{g ml}^{-1}$. These results suggest that effective management of the disease in both provinces can be accomplished through the use of resistant cultivars with *Rps* genes 1a, 1c, or 1k and the fungicide metalaxyl.

Phytophthora sojae Kaufm. & Gerd. is an oomycete pathogen of soybean, classified in the kingdom Stramenopila. *P. sojae* causes damping-off of soybean seedlings and root rot of established plants, referred to as *Phytophthora* stem and root rot of soybean. It is a devastating disease of soybean that occurs throughout the United States and around the world (24). This disease causes approximately \$1 to 2 billion in annual agricultural losses (22). *P. sojae* has a narrow host range and is restricted primarily to soybean. It can spread out as oospores carried in soybean seed as well as oospores in soil and diseased residues. The occurrence of this disease is commonly associated with high soil moisture during the growing season. Host resistance, soil drainage control, and fungicidal seed treatments such as metalaxyl are generally used to manage the disease (16) but resistant cultivars have been the cornerstone for management of *Phytophthora* stem and root rot.

Phytophthora stem and root rot of soybean is controlled mainly through the incorporation of race-specific resistant genes into soybean cultivars. However, *P. sojae* has been shown to be highly diverse in virulence and to adapt to changing deployment of *Rps* genes (14). Thus, monitoring the race or virulence structure of *P. sojae* populations is a key step in the management program for *Phytophthora* stem and root rot. *P. sojae* isolates are characterized to race based on soybean host differential reactions after inoculation via a hypocotyl inoculation method. Approximately 55 different races have been defined based on eight differentials (3,5) but many new pathotypes that have not been assigned a race number have been reported in recent studies (7,13,14).

In China, *P. sojae* was first isolated in 1989 (18). This pathogen has been under quarantine and currently is distributed in Heilongjiang and Fujian provinces (2,23). A limited number of studies has been conducted on distribution of this pathogen, because *P. sojae* was discovered recently and *Phytophthora* stem and root rot didn't cause serious losses in 1990s. However, an increase in this disease's occurrence has been a trend in recent years. A 3-year investigation (2001 to 2004) showed that serious cases of the disease occurred in five locations (Huanan, Linbu, Qitaihe, Jiamusi, and Longhai) from the two prov-

inces where majority of soybean plants were killed (23).

Soybean (*Glycine max* (L.) Merr.), which originated in China, is an important oilseed and food crop in China, with annual planting area larger than 9,000,000 ha. *Phytophthora* stem and root rot has become a major threat to soybean production in both Heilongjiang and Fujian Provinces. This research was initiated to control the disease effectively and safeguard future soybean production. The objectives were to determine the distribution, pathotypes, and metalaxyl sensitivity of *P. sojae* in both provinces.

MATERIALS AND METHODS

Soil sampling. Soil samples were collected from 258 soybean fields from Heilongjiang and Fujian Provinces during the 2007 growing season. The approximate size of a typical field was 2 acres. Fields were identified for sampling based on the presence of stem-rotting symptoms of *Phytophthora* stem and root rot, or low-lying areas where the soil is poorly drained after rain. The volume of a sample was 200 to 300 cm^3 . At least five individual samples were taken arbitrarily to a depth of 15 cm using a hand trowel from each field, and samples were well mixed to represent a single composite sample for each field, with a final volume of approximately 100 cm^3 . All soil samples were air dried, triturated, and then stored in paper pockets at room temperature.

Baiting and isolation. *P. sojae* was isolated from soil by modification of the soybean leaf baiting method (17). Soybean field soil (10 g) was moistened in a petri dish (9 cm in diameter), preincubated in the light at 25°C for a week, then flooded with 25 ml of sterile distilled water. Twenty leaf disks (10 mm in diameter), freshly cut with a paper punch from the unifoliate of 10-day-old Williams soybean seedlings were floated immediately on the surface of the water. After 12 h, the floating leaf disks were removed, washed, and placed in another petri dish with 25 ml of sterile distilled water. Sporangia emerging from the edge of the infected leaf discs were observed under stereomicroscopy after 48 h of incubation in the water.

Leaf discs with sporangia of *P. sojae* were placed in another petri dish (6 cm in diameter) with 10 ml of sterile distilled

Corresponding author: Y. C. Wang
E-mail: wangyc@njau.edu.cn

Accepted for publication 13 March 2010.

water. The entire set of petri dishes was placed in a refrigerator at 4°C for 30 min and then placed back at 25°C for 1 h to complete the process of zoospore release. Zoospore solution was spread on 1.5% water agar containing pentachloronitrobenzene at 25 µg ml⁻¹, carbendazim at 25 µg ml⁻¹, rifampicin at 20 µg ml⁻¹, and ampicillin at 50 µg ml⁻¹ and 12 h later the germinated zoospores were isolated and pure cultures were obtained. Cultures were stored on V8 juice agar (10% V8 juice filtered through four layers of cheesecloth, 1% CaCO₃, and 1.5% agar) at 12°C. The baiting process was repeated once for soil samples that did not yield *P. sojae* in the initial baiting attempt. All cultures were compared with a known culture of race 2 (from B. M. Tyler, Virginia Bioinformatics Institute) and examined carefully for hyphae, colony, sporangium, and oospore morphology (9) to verify that isolates were *P. sojae*.

Pathotype evaluation. Pathotypes of *P. sojae* were determined using the hypocotyl slit inoculation method (10) on differential cultivars carrying the 13 standard *Rps* genes that have been used to characterize virulence (1,3,8). The differential cultivars (from B. M. Tyler, Virginia Bioinformatics Institute) were Harlon (*Rps1a*), L77-1863 (*Rps1b*), Williams79 (*Rps1c*), PI103091 (*Rps1d*), Williams82 (*Rps1k*), L76-1988 (*Rps2*), Chapman (*Rps3a*), PRX146-36 (*Rps3b*), PRX145-48 (*Rps3c*), L85-2352 (*Rps4*), L85-3059 (*Rps5*), Harosoy62xx (*Rps6*), and Harosoy (*Rps7*). The universal susceptible cultivar was Williams.

Sets of 12 seeds of each of the differential cultivars were planted in 10-by-12-cm plastic pots containing vermiculite in the greenhouse. Inoculum was prepared by growing cultures of the isolates on V8 juice agar in the dark for a week. After having been thinned out, 10 7-day-old seedlings were inoculated. Immediately after inoculation, inoculated plants were maintained in high humidity and darkness at 25°C for 12 h. Thereafter, inoculated plants were kept in the greenhouse at 25°C

with a 14-h photoperiod and scored 5 days post inoculation as susceptible or resistant. Race 2 and an agar control were used as standard checks with all inoculation trials. Pathotype determination was repeated twice with each isolate. A differential was considered susceptible if 60% or more of the seedlings were killed, resistant if 40% or fewer of the seedlings were killed, and intermediate if 40 to 60% of the seedlings were killed (8,13).

Metalaxyl sensitivity testing. Metalaxyl (technical grade; Jiangsu Baoling Chemical Co., Nantong, Jiangsu, China) was dissolved in dimethyl sulfoxide before adding it to medium. Stock cultures from the isolates were grown on V8 juice agar for 7 days in the dark. Based on the previous result, that all isolates were transferred to V8 juice agar previously amended with metalaxyl at 1 µg ml⁻¹ and showed a very small amount of growth after 7 days, agar disks (5 mm in diameter) were removed from actively growing margins of the cultures and transferred to V8 juice agar previously amended with metalaxyl at 0, 0.01, 0.05, 0.1, 0.5, and 1 µg ml⁻¹. Three replicate petri dishes were tested for each isolate. Isolate growth was determined by measuring colony diameters in two perpendicular directions after 7 days of incubation in the dark at 25°C. Measurements were averaged, the diameter of the mycelial plug was subtracted, and relative growth reduction for each rate of fungicide was calculated as follows: [100 – (growth with fungicide/growth in control plate) × 100] (19,20). The half maximal effective concentration (EC₅₀) value was estimated by plotting the percent inhibition against the log-scale of fungicide concentration. Two independent trials were conducted to determine EC₅₀ values for each sensitivity test. The isolates were considered to be sensitive to metalaxyl if EC₅₀ values were less than 1.0 µg ml⁻¹, resistant if EC₅₀ values were more than 100 µg ml⁻¹, and intermediate if EC₅₀ values ranged from 1.0 to 100 µg ml⁻¹ (19,20).

RESULTS

Distribution of *P. sojae*. *P. sojae* was recovered from 75 of 258 fields, and 75 isolates were obtained. All 75 isolates matched the features of *P. sojae*. Each of the 75 isolates came from a different field. In all, 57 isolates were isolated from 39% of soil samples in Heilongjiang Province while 18 isolates were isolated from 16% of soil samples in Fujian Province. These 75 fields were located in 33 of the 84 counties sampled (Fig. 1); of these, 31 counties were in Heilongjiang Province and 2 counties (Longhai and Xiamen) were in Fujian Province. The results indicated that *P. sojae* was distributed widely in Heilongjiang Province compared with the narrow distribution in Fujian Province.

Pathotype evaluation. All 75 isolates were characterized for pathotype on 13 differential cultivars. In total, 35 pathotypes were identified, which included 30 pathotypes from Heilongjiang Province and 7 pathotypes from Fujian Province; however, all pathotypes were not characterized to any race based on published race definitions (Table 1). Two virulence pathotypes (2,3a,3b,3c,4,5,6,7 and 2,3a,3c,4,5,6,7) were recovered from both provinces. In Heilongjiang Province, each pathotype composed less than 11% of the isolates tested. In Fujian Province, the three common pathotypes identified, which composed 67% of the isolates tested, were the pathotypes with virulence phenotype 1b,2,4,5 (28%), 2,3a,3c,4,5,6,7 (22%), and 2,3a,4,5,6,7 (17%).

Virulence frequency to 13 soybean differentials were different in the two provinces. In Heilongjiang Province, only 2, 4, 4, and 2% of the isolates were virulent to cultivars with single *Rps* genes 1a, 1b, 1c, and 1k, respectively, whereas 93 and 91% of the isolates were virulent to cultivars with single *Rps* genes 2 and 3c, respectively (Fig. 2). In Fujian Province, no isolates were able to overcome *Rps* genes 1a, 1c, 1d, and 1k, whereas all isolates were able to overcome *Rps* genes 4 and 5 (Fig. 2).

Metalaxyl sensitivity testing. EC₅₀ values of all 75 isolates ranged from 0.04 to 0.22 µg ml⁻¹, and the mean EC₅₀ value was 0.1 µg ml⁻¹. EC₅₀ values of more than 80% of all isolates ranged from 0.06 to 0.15 µg ml⁻¹ (Fig. 3). Therefore, all isolates were sensitive to metalaxyl. However, resistance of the population in Heilongjiang Province to metalaxyl was higher than that of the population in Fujian Province. The mean EC₅₀ values of the population in Heilongjiang and Fujian Provinces were 0.11 and 0.08 µg ml⁻¹, respectively.

DISCUSSION

The populations of *P. sojae* from Heilongjiang and Fujian Provinces in China were studied in detail, and three important results were provided. First, *P.*

Fig. 1. Distribution of *Phytophthora sojae* in A, Heilongjiang and B, Fujian provinces. Circles represent counties sampled. Black circles represent counties where *P. sojae* was detected.

sojae was distributed widely in Heilongjiang Province compared with the narrow distribution in Fujian Province. Second, less than 5% of the isolates were able to overcome *Rps* genes 1a, 1c, and 1k in both provinces. Third, all isolates from the two provinces were sensitive to metalaxyl. The combination of these results may provide theoretical guidance for the control of Phytophthora stem and root rot in the two provinces.

Because *P. sojae* was first isolated in northeast China in 1989, it has also been found in more than 20 counties in Heilongjiang Province (12,25,26). In this study, the pathogen was isolated from 31 counties in Heilongjiang Province. Nine counties (Huma, Wuchang, Kedong, Keshan, Baiquan, Fuyu, Xunke, Wudalianchi, and Jidong) were first reported from which this pathogen was isolated. These results show that *P. sojae* was already widely distributed in Heilongjiang Province. Also, *P. sojae* was reportedly found in Longhai and Xiamen in Fujian Province several years ago (2). In this study, though we collected soil samples from many regions in Fujian Province and examined these samples carefully, *P. sojae* was still only isolated from samples in Longhai and Xiamen. It is evident that *P. sojae* was still limited to these areas and has not spread in the past several years. Strict quarantine measures were applied by local governments to prevent it from spreading to other areas but quarantine measures for this pathogen should further be strengthened in the areas.

It was previously reported that 10 known races (races 1, 3, 8, 9, 11, 13, 15, 17, 21, and 24) and some new pathotypes were identified in Heilongjiang Province using eight soybean differentials, whereas there are no reports about pathotype of *P. sojae* in Fujian Province (12,25). In previous studies, race 1 was the dominant race in Heilongjiang Province. Although 35 pathotypes were identified in this study, they were not different from those of previous studies. We hypothesize that two main causes are responsible for the difference. First, the number of differential cultivars was increased from 8 to 13. In our study, we could find four known races (races 1, 13, 15, and 17) that were identified in previous studies if five extra differential cultivars were removed. Second, *P. sojae* was isolated from diseased soybean plants in previous studies. *P. sojae* with more pathotypes was not isolated because of the role of host selective pressure. Furthermore, few pathotypes were in accordance with those that were reported in foreign studies (3,5,7,13,14). Two possible causes exist. First, after *P. sojae* was introduced into China, it has varied and new pathotypes have appeared under selective pressure of native soybean cultivars. Second, *P. sojae* was not introduced into China but was native in China.

Significantly, less than 5% of the collected isolates from both provinces could overcome *Rps* genes 1a, 1c, and 1k, indicating that soybean cultivars with *Rps* genes 1a, 1c, or 1k can be more widely grown in the two provinces to control Phytophthora stem and root rot. In the United States, *Rps* genes 1c and 1k were deployed in soybean cultivars in the 1990s. Not long after that, however, reports on the increasing percentage of isolates with virulence to

soybeans containing *Rps*1c and 1k began to surface (3,13,15). This is because *P. sojae* is highly diverse in virulence and can adapt to changing deployment of *Rps* genes. Hence, we must monitor the virulence structure of the *P. sojae* population continuously and deploy appropriate *Rps* genes to control Phytophthora stem and root rot.

In 1993, 17 isolates of *P. sojae* from China were tested for sensitivity to

Table 1. Pathotypes of *Phytophthora sojae* baited from soybean field soils collected in Heilongjiang and Fujian provinces in 2007

Number	Virulence pathotype ^a	Race ^b	No. of isolates ^c	Province ^d
1	1a,2,4,5,6	UD	1	Heilongjiang
2	1b,1d,2,3a,6	UD	1	Heilongjiang
3	1b,1d,2,3a,3b,3c,4,5,6,7	UD	1	Heilongjiang
4	1b,2,4,5	UD	5	Fujian
5	1b,4,5	UD	2	Fujian
6	1c,2,3a,3c,4,5,6,7	UD	1	Heilongjiang
7	1c,2,3b,3c,5,6	UD	1	Heilongjiang
8	1d,2,3c	UD	1	Heilongjiang
9	1d,2,3c,4,5,6	UD	1	Heilongjiang
10	1d,2,3c,4,5,6,7	UD	1	Heilongjiang
11	1d,4,5	UD	1	Heilongjiang
12	1k,2,3b,3c,4,5,6	UD	1	Heilongjiang
13	2,3a,3b,3c,4,5,6,7	UD	3	Combined
14	2,3a,3c,4,5	UD	2	Heilongjiang
15	2,3a,3c,4,5,6	UD	4	Heilongjiang
16	2,3a,3c,4,5,6,7	UD	6	Combined
17	2,3a,4,5,6,7	UD	3	Fujian
18	2,3b,3c,4,5,6	UD	1	Heilongjiang
19	2,3b,3c,4,5,6,7	UD	3	Heilongjiang
20	2,3b,3c,4,5,7	UD	1	Heilongjiang
21	2,3c	UD	4	Heilongjiang
22	2,3c,4	UD	1	Heilongjiang
23	2,3c,4,5	UD	6	Heilongjiang
24	2,3c,4,5,6	UD	5	Heilongjiang
25	2,3c,4,5,6,7	UD	6	Heilongjiang
26	2,3c,4,6	UD	1	Heilongjiang
27	2,3c,5	UD	2	Heilongjiang
28	2,3c,5,6	UD	2	Heilongjiang
29	2,4,5	UD	2	Fujian
30	2,5	UD	1	Heilongjiang
31	2,6	UD	1	Heilongjiang
32	3a,3c	UD	1	Heilongjiang
33	3b,3c	UD	1	Heilongjiang
34	3b,3c,4,5	UD	1	Heilongjiang
35	4,5,7	UD	1	Fujian

^a Virulence pathotype, which is a list of ineffective *Rps* genes among 13 soybean *Rps* gene differentials (1a, 1b, 1c, 1d, 1k, 2, 3a, 3b, 3c, 4, 5, 6, and 7).

^b Race as reported by Dorance et al. (3) and Grau et al. (5). UD = undefined races of *P. sojae*.

^c In total, 75 isolates were evaluated.

^d Province in which *P. sojae* was baited and isolated.

Fig. 2. Frequency of virulence of *Phytophthora sojae* isolates on individual *Rps* genes.

Fig. 3. Distribution of half maximal effective concentration (EC₅₀) values of *Phytophthora sojae* isolates for metalaxyl.

metalaxyl (11). At that time, the mean EC₅₀ value of the population was 0.01 μg ml⁻¹ and all isolates were sensitive to metalaxyl. In our study presented here, the mean EC₅₀ value of the *P. sojae* population was 0.1 μg ml⁻¹. The results show that the resistance of the Chinese population to metalaxyl has increased in the last more than 10 years but also that the Chinese population of *P. sojae* remains sensitive to metalaxyl. Therefore, *Phytophthora* stem and root rot can be controlled effectively in China by metalaxyl and other compounds with the same modes of action. Metalaxyl resistance has been frequently detected in other *Phytophthora* spp. (4,6,21) but the *P. sojae* population from China is still sensitive to metalaxyl, because local farmers have not realized the destructiveness of this disease and seldom use fungicides to control it. In the United States, *Phytophthora* stem and root rot is one of the most important soybean diseases and metalaxyl has been used to manage it since the mid-1980s. However, reports of metalaxyl-resistant isolates detected in soybean fields have not yet been published (13,14). Resistance to metalaxyl in *P. sojae* has been difficult to produce, likely because only minor selection pressure was exerted on *P. sojae* by these compounds when they were used as seed treatments (14).

ACKNOWLEDGMENTS

We thank B. M. Tyler for supplying seed of differentials and *P. sojae* isolates. Funding was provided by the National Special Research Programs (Agriculture) for Non-Profit Trades (No. 3-20).

LITERATURE CITED

- Burnham, K. D., Dorrance, A. E., Francis, D. M., Fioritto, R. J., and St-Martin, S. K. 2003. *Rps8*, a new locus in soybean for resistance to *Phytophthora sojae*. *Crop Sci.* 43:101-105.
- Chen, Q. H., Weng, Q. Y., Wang, Y. C., and Zheng, X. B. 2004. Identification and sequencing of ribosomal DNA-ITS of *Phytophthora sojae* in Fujian. *Acta Phytopathol. Sin.* 34:112-116.
- Dorrance, A. E., McClure, S. A., and deSilva, A. 2003. Pathogenic diversity of *Phytophthora sojae* in Ohio soybean fields. *Plant Dis.* 87:139-146.
- Gisi, U., and Cohen, Y. 1996. Resistance to phenylamide fungicides: a case study with *Phytophthora infestans* involving mating type and race structure. *Annu. Rev. Phytopathol.* 34:549-572.
- Grau, C. R., Dorrance, A. E., Russin, J., and Bond, J. 2004. Fungal diseases. Chapter 14 in: *Soybeans: Improvement, Production, and Uses*, third ed. no. 43. American Society of Agronomy, Madison, WI.
- Hwang, J., and Benson, D. M. 2005. Identification, mefenoxam sensitivity, and compatibility type of *Phytophthora* spp. attacking floriculture crops in North Carolina. *Plant Dis.* 89:185-190.
- Jackson, T. A., Kirkpatrick, T. L., and Rupe, J. C. 2004. Races of *Phytophthora sojae* in Arkansas soybean fields and their effects on commonly grown soybean cultivars. *Plant Dis.* 88:345-351.
- Kaitany, R. C., Hart, L. P., and Safir, G. R. 2001. Virulence composition of *Phytophthora sojae* in Michigan. *Plant Dis.* 85:1103-1106.
- Kauffmann, M. J., and Gerdemann, J. W. 1958. Root and stem rot of soybean caused by *Phytophthora sojae* n. sp. *Phytopathology* 48:201-208.
- Laviolette, F. A., and Athow, K. L. 1981. Physiologic races of *Phytophthora megasperma* f. sp. *glycinea* in Indiana, 1973-1979. *Plant Dis.* 65:884-885.
- Li, B. D., Peng, Y. F., and Shen, C. Y. 1993. Sensitivity and variability of *Phytophthora megasperma* f. sp. *glycinea* to metalaxyl. *Acta Phytopathol. Sin.* 25: 23-27.
- Ma, S. M., Ding, J. J., Zheng, T. Q., and Gu, X. 2005. The identification of physiological races of *Phytophthora megasperma*. *Soybean Sci.* 24:260-262.
- Malvick, D. K., and Grunden, E. 2004. Traits of soybean-infecting *Phytophthora* populations from Illinois agricultural fields. *Plant Dis.* 88:1139-1145.
- Nelson, B. D., Mallik, I., McEwen, D., and Christianson, T. 2008. Pathotypes, distribution, and metalaxyl sensitivity of *Phytophthora sojae* from North Dakota. *Plant Dis.* 92:1062-1066.
- Niu, X. F., Yang, X. B., Lundeen, P., Uphoff, M. D., and Cianzio, S. R. 2003. Changes in *Phytophthora sojae* races in Iowa soybean fields. (Abstr.) *Phytopathology* 93:S66.
- Schmitthenner, A. F. 1999. *Phytophthora* rot. In: *Compendium of Soybean Diseases*. G. L. Hartman, J. B. Sinclair, and J. C. Rupe, eds. American Phytopathological Society Press, St. Paul, MN.
- Schmitthenner, A. F., Hobe, M., and Bhat, R. G. 1994. *Phytophthora sojae* races in Ohio over a 10-year interval. *Plant Dis.* 78:269-276.
- Shen, C. Y., and Su, Y. C. 1991. Discovery and preliminary studies of *Phytophthora megasperma* on soybean in china. *Acta Phytopathol. Sin.* 21:298.
- Taylor, R. J., Pasche, J. S., and Gudmestad, N. C. 2006. Biological significance of mefenoxam resistance in *Phytophthora erythroseptica* and its implications for the management of pink rot of potato. *Plant Dis.* 90:927-934.
- Taylor, R. J., Salas, B., Secor, G. A., Rivera, V., and Gudmestad, N. C. 2002. Sensitivity of North American isolates of *Phytophthora erythroseptica* and *Pythium ultimum* to mefenoxam (metalaxyl). *Plant Dis.* 86:797-802.
- Timmer, L. W., Graham, J. H., and Zitko, S. E. 1998. Metalaxyl-resistant isolates of *Phytophthora nicotianae*: occurrence, sensitivity, and competitive parasitic ability on citrus. *Plant Dis.* 82:254-261.
- Tyler, B. M. 2007. *Phytophthora sojae*: root rot pathogen of soybean and model oomycete. *Mol. Plant Pathol.* 8:1-8.
- Wang, Z. Y., Wang, Y. C., Zhang, Z. G., and Zheng, X. B. 2006. Genetic relationships among Chinese and American isolates of *Phytophthora sojae* assessed by RAPD markers. *Chin. Sci. Bull.* 51:2095-2102.
- Wrather, J.A., and Koenning, S.R. 2006. Estimates of disease effects on soybean yields in the United States 2003 to 2005. *J. Nematol.* 38:173-180.
- Zhang, S. Z., Wu, J. J., Xu, P. F., and Li, W. B. 2008. Identification of virulence *Phytophthora sojae* in Heilongjiang province and the first report on race 15 in China. *Chin. J. Oil Crop Sci.* 30:229-234.
- Zhu, Z. D., Wang, H. B., Wang, X. M., Chang, R. Z., and Wu, X. F. 2004. Distribution and virulence diversity of *Phytophthora sojae* in China. *Agric. Sci. China* 3:116-123.