PHYTOPHTHORA DISEASES OF LEGUMES (A REVIEW)

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B.A. Khasanov
I.T. Asatova
Tashkent State Agrarian University
D.R. Ruzmetov
Institute of Genetics and Experimental Biology of the Academy of Sciences of the Republic of Uzbekistan

Damping-off, root and/or stem blights caused by oomycetes of the Phytophthora genus are one of the most important groups of the most destructive diseases of cultivated plants, in particular legume crops. More than 15 species of this genus can infect species of beans, mungbean, soybean, cowpea and other legumes. No one of these species have been registered on legumes in Uzbekistan, but in our country, there are some other species of the genus that affect other crops (potatoes, tomatoes), so the danger of their accidental introduction into the territory of the republic is not excluded. The information provided in the article will allow specialists to get to know this group of diseases more closely and preliminarily to identify their causal agents if they are met within our country.

Key words: *legumes, Phytophthora spp. and Phytophthora diseases.*

Фитофторозы, вызываемые оомицетами из рода Phytophthora, составлют одну из важнейших групп наиболее опасных болезней возделываемых растений, в частности бобовых культур. Виды фасоли, маш, сою, коровий горох и другие бобовые поражают более 15 видов этого рода. Эти виды на бобовых культурах в Узбекистане не выявлены, однако в нашей стране есть их представители, поражающие другие культуры (картофель, томат), поэтому не исключена опасность их случайной интродукции на территорию республики. Приведённая в статье информация позволит специалистам ознакомиться ближе с этой группой болезней и проводить предварительную идентификацию их возбудителей в случае их нахождения в пределах нашей страны.

Ключевые слова: *бобовые культуры, болезни, фитофтороз, виды рода Phytophthora.*

Introduction.

Phytophthorosis of legume crops is caused by several species of oomycetes in the genus Phytophthora. This genus belongs to the kingdom Chromista, phylum Oomycota, class Oomycetes, order Peronosporales, family Pythiaceae. Oomycetes are also called "pseudofungi" or "fungus-like organisms". Molecularly, they are not close to true fungi,

but to brown and some other algae. In addition to phytopathogenic, the genus also includes saprophytic species [1].

Phytophthoroses are a constant and growing threat to cultivated plants and ecological systems globally. The literal translation of the term "Phytophthora" means "plant destroyer" (from Greek phyton plant, phthoros destroy) [2].

To identify Phytophthora species, morpho-cultural characters (classical method) and DNA characters (molecular method) are studied; identification of phytopathogenic representatives of the genus also requires determination of pathogenicity of isolates in experiments with artificial infection of host plants (i.e., fulfillment of Koch's postulates).

The classical method determines the species and organs of the affected host plant; the sex sign of the mycelium (homothallicity or heterothallicity); the method of antheridium attachment to the oogony (amphiginous or paraginous); and the presence or absence of a papilla on the zoosporangium apex (conidia). Using these two methods, scientists until 2012 identified 116 valid species in the genus Phytophthora, classified into 10 clades [2]. The main biological characters of the genus species affecting leguminous crops are given in the table below

According to literature reports, legumes are affected by more than 16 species of the genus Phytophthora from 9 clades, including chickpea (Cicer arietinum L.) parasitized by 6, bean species (Phaseolus spp.) 5, mung bean species (Vigna spp.) 2, cowpea (Vigna unguiculata [L.] Walp.) 4, lentil (Lens culinaris Medic.) 1, on pigeon pea (Cajanus cajan [L.] Millsp.) 1, on soybean (Glycine max [L.] Merr.) 4, on pea (Pisum sativum L.) 3, on species of lupins (Lupinus spp.) 2, on other species of genera Vicia and Vigna one each, on alfalfa (Medicago sativa L.) 2 and on clover species (Trifolium spp.) 3 species (see table).

Seven species of the 16 listed in the table are polyphagous, which, in addition to legumes, affect many plant species from other families.

In Uzbekistan, none of these species is registered on legume crops, but there is a risk of their introduction with seeds or other plant parts.

Legumes can be affected by Phytophthora species in all phases of their growth and development. Their seeds may rot without germination, seedlings may die while still in the soil or after reaching the soil surface, and crops may become very thin. On older plants, phytophthora appears as root and/or stem rot. Brown spots and rot also develop on root necks, leaves, leaf petioles, and beans.

Phytophthora usually appears in low areas of the field where moisture remains long. Root necks of infested seedlings show moisture-soaked spots, they become lodged, wither, and die. Affected older plants develop root rot that spreads upward several internodes high.

Species of the genus Phytophthora overwinter mainly in the soil by oospores and on plant debris by mycelium, and some species also by chlamydospores. Their oospores are very resistant to drying out, cold and other adverse factors; in the

absence of host plants, they remain viable in soil for several years. During germination, they form germinal sporangia and zoospores. The latter emerge from the sporangium and infect the root hairs of plants. Under weather conditions favorable for pathogens, phytophthorosis develops rapidly and kills the plant within a few days after the first symptoms appear.

Kinds of genus *Phytophthora*, affecting leguminous crops, and some of their important traits

Kinds of genus *Phytophthora*	Treasure	Paul	C	Xc	AO	Specialty	PO	T, °C
P. cactorum	1a	Го	●	±	P	Polyphage	K/L	~25
P. cajani	7b	Го	■	?	A	Pigeon peas	Ct	30
P. capsici	2b	Ге	●	+	A	Polyphage	K/L/Pl	24-33
P. citrophthora	2a	Го	●	–(+)	A	Polyphage	L/Pl/K/ Ksh	24-28
P. clandestina	1b	Го	●	–	P	Polyphage	K	25
P. cryptogea	8a	Ге	■	–	A	Polyphage	L/Ksh	25
P. drechsleri	8a	Ге	■	–	A	Polyphage	K	27-28
P. macrochlamydospora	9	?	○	+	?	Soybean	K,Ct	25-30
P. medicaginis	8a	Го	■	+	PA	Alfalfa, chickpeas	K	25-26
P. megasperma	6b	Го/Ге	■	±	A	Polyphage	K	20-25
P. nicotianae	1	Ге	●	+	A	Polyphage	K/L/Ksh	30-32
P. phaseoli	1c	Го	○	–	A	Lima beans	Л/Пl	15-20
P. sansomeana	8a	Го	■	?	P	Soybean	K	25
P. sojae	7b	Го	■	±	P	Soybean	K/Ct	15
P. trifolii	8a	Го	■	–	P	Clover	K	22,5
P. vignae	7b	Го	■	+ (P)	A	Cow peas, adzuki	K/Ct	28-30

Notes: The literature sources used are given in the text. Mycelium sex sign: Go, homothallic; Ge, heterothallic; ? - unknown. "C" - presence/absence of a papilla on the zoosporangium apex: ● - present; ○ - present, but the papilla is small, flat; ■ - absent. "Xs" - presence of chlamydospores: + - present; + (P) rare; - absent, ± - form isolates or rarely, not always; (+) - usually absent, ? - unknown. "AO" - location of the antheridium in relation to the oogonium: A - amphiginous; P - paraginous; PA - paraginous and amphiginous; ? - unknown. "PO" - plant organs affected: K - roots; Ksh - root neck; L - leaves; St - stems; Pl - fruit (beans and/or seeds). "T" - optimal temperature for fungus growth and development, oC.

The roots and stems of diseased plants turn brown, soften, become saturated with moisture, and die off. Leaves can first become infected and rot, from which the infection spreads to the leaf petioles and then to the stems. Numerous new sporangia form on the diseased tissues. They are spread by irrigation water or within raindrops by the wind. When sporangia germinate, they form a sprout tube or develop zoospores inside them that infect plant roots. Sporangia of the next generation develop on the affected tissues, and the pathogen development continues [2-9].

Below is a summary of the species of the genus Phytophthora that cause disease on legume crops.

Phytophthora medicaginis E.M. Hansen & D.P. Maxwell. This species, previously included in the Phytophthora megasperma s.l. species complex, was later isolated as an independent species (see below for information). P. medicaginis is highly specialized and affects only chickpea and alfalfa crops. It causes rot of seeds, seedlings, and roots. Phytophthora root rot is included in the main diseases of chickpea and alfalfa. There are reports that the pathogen affects other alfalfa species as well as sainfoin [8].

P. medicaginis occurs in India, Pakistan, Japan, Turkey, Hungary, Greece, Ireland, Norway, Russia, Sicily (Italy), Croatia, South Africa, USA, Canada, Mexico and

Argentina. Na chickpea is a minor pathogen in India and an important ("major") pathogen in Australia [5].

Symptoms. Seedlings are severely infected (rotting), and the density of standing plants is greatly reduced. On young plants, infection from roots can spread to stem up to 1 cm in height.

In the field, the disease usually appears on chickpea plants after flowering, more often in cool, wet weather or with long standing water after abundant watering. Dark brown to black sores appear on the roots of the plants. They ring and kill the tap roots and lateral roots, which rot. Sick plants cannot get water and nutrients from the soil, their leaves turn yellow, their height decreases, they wither and die. Foci of dead plants are formed in the field [5, 8, 9]. In Australia, a complete infestation of all plants in fields was recorded.

Development. P. medicaginis is a homothallic species and overwinters in oospores, which can persist in soil for up to 3.5 years, and in Australia for at least 10 years [5]. The pathogen can also persist by chlamydospores. In early spring, in the presence of moisture and exudates excreted from the roots of chickpea seedlings, oospores germinate and form lemon-shaped zoospores. Zoospores that have emerged from them attack plant roots. New sporangia appear throughout the season, and plants are repeatedly infected with zoospores. The degree of disease development on chickpea plants depends on plant condition, variety resistance, air temperature, soil humidity, and degree of virulence of the pathogen races. At the end of the season, oogoniums and anteridia are formed inside the affected tissues, and after the sexual process, oospores of the pathogen are formed. After destruction of plant tissues, the oospores enter the soil.

Harmfulness. The disease is most widespread and harmful in chickpea fields in Australia. In this country, yield losses of susceptible chickpea varieties are 50-70% annually [8, 10]; the monetary equivalent of the yield lost due to the disease is 8.2 million Australian dollars annually [11].

Phytophthora vignae Purss is also highly specialized and affects only two species of the Vigna genus, cowpea and adzuki (red mungbean, V. angularis [Willd.] Ohwi & H. Ohashi), on which it rots germinating seeds, seedlings, roots and stems. Stem rot is the main form of the disease. P. vignae occurs in India, Sri Lanka, China, Japan, South Korea and Tanzania. The species was recently introduced into Australia with the remains of cowpea plants, where it has spread widely [12]. Epiphytoties caused by P. vignae on cowpea have been recorded in Australia and on adzuki in Japan.

This oomycete has two specialized forms: P. vignae f. sp. vignae, common in the tropics and subtropics, affecting only cowpea (V. unguiculata ssp. unguiculata) and asparagus bean (V. unguiculata ssp. sesquipedalis), and P. vignae f. sp. adzukicola, widely distributed in temperate regions, affecting only adzuki [4, 5, 12].

In Japan, P. vignae (form not specified) was also reported to affect rice beans [12]. In greenhouse experiments, P. vignae did not affect common mung bean (Vigna radiata

[L.] R. Wilczek), common bean (Phaseolus vulgaris[L.] Sav.), soybean, pea, and some other plant species [12].

On cowpea and adzuki, the pathogen causes rot of germinating seeds, seedlings, and adult plants. Under wet conditions, the disease first appears in foci, then spreads rapidly and the foci become large. As dry weather sets in, the plants wilt. The plants first have rotting roots, and eventually the rot spreads to the stems. Stems of susceptible varieties shrivel and turn yellow. Reddish-light brown spots appear on stems of resistant varieties.

Disease severity depends on pathogen race, variety genotype, and weather conditions. Under conditions favorable for the pathogen, the yield of non-tolerant varieties is lost completely, in partially resistant varieties 20-80% of the yield is lost. In Australia, phytophthora in Queensland causes great losses of cowpea crops. In the mountainous regions of Japan, the disease causes a 61% reduction in rice bean weight [4, 12].

Phytophthora sojae Kaufm. & Gerd are among the major pathogens of soybeans in the United States, Canada, some regions of Australia and China([3, 13-17]. The center of origin of this species is believed to be Korea and China [7]. The main host plant of P. sojae is soybean, but in North America it also affects beans, peas, lupine species, clover and tomato [3, 7, 13].

Symptoms Soybean is affected by Phytophthora from seedlings to maturity, but the disease is more common before the seed ripening phase. Seeds may rot in the soil during germination, seedlings before and after emergence on the soil surface. Moisture-soaked sores develop on their root necks. Most seedlings may die and crops may become severely thin. In dry weather before sowing, the occurrence of the disease decreases sharply.

The disease begins with root rot in seedlings and more mature plants, then spreads to the stems. Mature plants gradually die or become severely weakened. The disease usually causes groups of plants to die, resulting in empty spaces in the field. Sick plants are easily yanked out of the soil because their lateral rotted roots disappear and the taproots become very short. The infection rises from the roots to the stem up to a height of 10-20 cm. The pathogen then penetrates the conductive tissues, resulting in brown rot of leaves and shoots. Leaves wither and remain hanging on the branches. Susceptible varieties die quickly, tolerant and resistant varieties weaken, but do not die quickly [3, 7, 13-15].

Development. P. sojae is a homothallic oomycete that overwinters on plant debris and in the soil and persists primarily by oospores. In spring, at optimal temperature (15-16°C), the oospores germinate either by mycelium (if near soybean root hairs) or by zoospores (if far away). Mycelium or zoospores spread by irrigation water, tools, rain drops in the wind, and infect soybean sprouts. The mycelium that grows from them grows inside soybean roots, moving to the stems, disrupting the flow of water in them. As a result, the plants suddenly wither and die, the tissues collapse and

disintegrate. Under humid conditions, a large number of P. sojae zoosporangia develop on the remains of seedlings, roots, and stems. The optimum temperature for this is 20 (25)oC, and the minimum is 5oC. Zoospores do not form in sporangia at 14°C, and they germinate, forming hyphae (growth tubes). Soybean roots are most affected at 15°C; infection does not occur at 35°C.

Soybean leaves become infected more easily and quickly than roots. They become infected by soil particles trapped by raindrops. Only young leaves are affected, and especially after rain, they rot and hang down. The pathogen passes through their petioles to the stems.

On soybean plants growing in heavy, wet soil, with a crust on the surface, phytophthora is observed more often. Plant infestation by the gall nematode Meloidogyne hapla, species of the genera Fusarium and Pythium, and Rhizoctonia solani increases the development of phytophthora rot.

New oospores are formed on the plants killed by phytophthora, and they enter the soil [3, 7, 13].

Harmfulness. The amount of soybean yield lost to phytophthora depends on soil type, amount and frequency of rainfall, tillage system, and cultivar [13]. In its range, P. sojae can kill many soybean plants in fields and destroy more than 50% of the yield of susceptible varieties. In Ohio, USA, the pathogen is known to have killed all soybean plants in 121,200 ha during one season [7].

Phytophthorosis of soybean has been a big problem in the province of Ontario, Canada, since the 1950s, in fields with clayey soil heavily infested with the pathogen. Introduction of resistant and tolerant soybean varieties reduced plant mortality to <1%, but under unfavorable conditions in some fields plant losses still exceeded 25% [3].

Phytophthora megasperma Drechs. s. l. This species is reported to be polyphagous and affects beans, seedlings, roots, branches and leaves of legumes and many other plant species [2]. Chickpeas are also affected, where the pathogen causes root rot; this disease in Australia is very severe on chickpea crops in fields where water stagnates for long periods of time [11]. Infestation of soybean plants by P. megasperma was recorded in England, Italy and Ireland, Canada and Russia (Amur Region), as well as in 2015 in Kazakhstan, where it is an object of external quarantine [18].

The species P. megasperma was created by the American scientist C. Drechsler in 1931 based on an isolate isolated from Althea [cited from 19]. It was later found as a pathogen on more than 60 plant species, including chickpeas, alfalfa, clover, vegetable crops, fruit trees, and berries [19]. A number of changes then occurred in the taxonomy of this oomycete. For example, based on the size of the oogonium, Waterhouse (Waterhouse, 1963; [quoted from 19]) distinguished subspecies P. megasperma var. sojae and P. megasperma var. megasperma, and Kuan and Erwin

(1980 [quoted from 19]) distinguished specialized forms P. megasperma f. sp. glycinea and P. megasperma f. sp. medicaginis.

Subsequently, it was revealed that this species is not a single taxon but a complex species, and it is currently divided into the following independent species: Phytophthora sojae (affects soybean), P. medicaginis (affects chickpea and alfalfa), P. trifolii (affects clover), P. rosacearum (affects fruit trees) and P. sansomeana (affects soybean and fruit trees) [19]. Given this information, the taxonomic position of the species found on soybean in Kazakhstan [18] became unknown.

Phytophthora phaseoli Thaxter. According to the information we collected, this oomycete occurs in the United States and affects only lima beans [2, 20-22]. It is widespread in Delaware, Maryland, and New Jersey, and has been considered a new and serious threat to lima bean crops since the 1977s [22]. Reports that P. phaseoli also affects other bean species [23, 24] were not confirmed in further studies.

On lima beans, the pathogen causes leaf rot, bean rot, and leaf spotting on branches, flowers, and leaf veins; no information is available on root damage. Mainly white patches appear on infected leaves, less often on beans; dark-red spots appear on stems, flowers, and leaf veins; pods shrivel up and die off. The pathogen persists on sick seeds and plant debris, on which spore organs appear in damp weather. Its spores are spread by the wind inside raindrops. Affected plants of susceptible varieties die within a few days [20].

Phytophthora cactorum (Lebert & Cohn) J. Schröt. is cosmopolitan and polyphagous, affecting herbaceous plants from 160 genera and 200+ tree species [25]. It has been reported in Europe, South and North America, New Zealand, and Russia, including as a pathogen of legumes, such as beans, soybean, pea, alfalfa, vetch, vigna, etc. In Kazakhstan, it is found in strawberry, strawberry, and vetch. In Kazakhstan, it was found on strawberries [24]. The pathogen in the United States causes red stem cancer of cowpea; this disease is a minor disease of this crop in South Asia [4].

Phytophthora capsici Leonian is also cosmopolitan and polyphagous, affecting 50+ species of cultivated and wild plants from 15+ families, most often Fabaceae, Cucurbitaceae, and Solanaceae; including common bean and lima beans, which cause rot of seedlings, roots, leaves, stems, beans, and seeds [2, 6]. It is also indicated as a pathogen of soybean.

Of the other species, Phytophthora cajani K.S. Amin, Baldev & F.J. Williams affects pigeon pea stems, P. citrophthora (R.E. Sm. & E.H. Sm.) Leonian - chickpea roots, P. cryptogea Pethybr. & Lafferty and P. drechsleri Tucker - roots of chickpea [26] and cowpea [4], P. clandestina Taylor, Pascoe & Greenhalgh and P. trifolii E.M. Hansen & D. P. Maxwell - clover roots, P. macrochlamydospora J.A.G. Irwin and P. sansomeana E.M. Hansen - soybean roots and stems, [2], P. nicotiana Breda de Haan var. parasitica (Dastur) G.M. Waterhouse causes bean and leaf rot of bean species [23], and unidentified species of the genus Phytophthora cause seed rot, seedling rot, and root rot of adult chickpea and lentil plants [5, 27].

Control measures against phytophthoroses of legume crops. An integrated control system is required against phytophthoroses of legumes, primarily by cultivating resistant and/or tolerant varieties, as well as by carefully observing sanitary and hygienic requirements, ensuring high agronomic practices in crop care, and, if necessary, using chemical and/or biological methods of disease control.

Cultivation of resistant varieties is the main way to control phytophthora of soybean, cowpea, beans and other legumes [22]. In soybean, 14 resistance genes have been identified and mapped [7]. More than 20 physiological races have been identified in P. sojae. There are soybean varieties resistant to all (Sinclair, 1982) or some [3, 15] of these races. There are resistant varieties of cowpea in India and Australia [4], and adzuki in Japan [12]. P. vignae is not conserved in the seeds of these crops.

In breeding for resistance to phytophthora, indent selection, a method of selecting individual resistant plants against a strong natural or artificial background of infection, is used. In Australia, this method showed high efficiency against chickpea root rot caused by P. medicaginis [10].

Among agrotechnical methods against Phytophthora soybean blight, it is recommended to improve drainage conditions in the field, not to allow long moisture retention in the soil and crust formation on its surface; sowing seeds in warm (18o C or higher), fertile soil; using crop rotation with inclusion of corn and wheat [3, 13].

Oospores and sporangia of Phytophthora species, except for water droplets, are spread by machinery, workers' shoes and tools, so they must be disinfected regularly. Pathogens must not be allowed to enter pathogen-free fields with contaminated soil particles, irrigation water, and plant materials; after completing work in one field, all working tools must be thoroughly disinfected before starting work in another field.

Before and after sowing the seeds, the soil should be sufficiently dry and the crops should not be over-watered. Considering that pathogen oospores can persist in the soil for a long time, crop rotation schemes should provide for the legume crop to return to the same field every 3 or 4 years. Infected fields should not be adjacent to fields with healthy crops.

Chemical control of phytophthora of legume crops includes pre-sowing seed dressing or application of fungicides to the soil, and spraying of crops with fungicides during the growing season.

Seed dressing with methylaxyl-based preparations protects seedlings of legume crops for five weeks. During vegetation, weekly spraying of plants with a mixture of dimethomorph (Acrobat 50% s.p., 448 g/ha) and copper sulfate (e.g. Kuprofix Dispress, 2.25 kg/ha) is effective. To protect soybean seedlings from Phytophthora rot, pre-sowing seed dressing with Metalaxyl (it is especially effective in tolerant varieties), or introduce Metalaxyl into the soil (which provides higher and longer protection against the disease than seed dressing) [7]. Spraying lima bean crops against P. phaseoli with copper hydroxide and Ridomil fungicides was found to reduce grain yield losses [22].

Seed dressing and plant spraying significantly reduced yield losses. However, it should be remembered that pathogen strains resistant to mephenoxam and methylaxyl appear in nature, so it is recommended to check the populations on specific fields for resistance to pathogens [8, 9].

It was experimentally found that some fungicides did not directly suppress phytophthora pathogens of legume crops, but had a protective effect by activation of plant defense mechanisms. For example, treatment with phosphite formed during decomposition of Fosetil-Al fungicide in susceptible to Phytophthora cryptogea plants of cowpea induced synthesis of several phytoalexins, including kieviton (one of the enzyme lyases) and significant amounts of phaseolidin, which stopped P. cryptogea growth [4].

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