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Nilesh Vikas Dhangar
Department of Plant Pathology, Lovely Professional University, Phagwara, Punjab, India

Dr. Debjani Choudhury
Department of Plant Pathology, Lovely Professional University, Phagwara, Punjab, India

Correspondence Author;
Nilesh Vikas Dhangar
Department of Plant Pathology, Lovely Professional University, Phagwara, Punjab, India

Septoria leaf spot cause by *Septoria lycopersici* on tomato: A review

Nilesh Vikas Dhangar and Dr. Debjani Choudhury

Abstract
In humid climates, Septoria leaf spot (*Septoria lycopersici Speg*.) is one of the most destructive foliar diseases, especially during periods of heavy rainfall, frequent dew, or overhead irrigation as stated by Andrus *et al*. in 1945 and Delahaut, Stevenson in 2004. Under ideal conditions for disease growth, it may cause total defoliation, resulting in considerable crop loss. *S. lycopersici* causes leaf spots on the elder leaves of tomatoes (Ramakrishnan and Sundaram, 1954): The disease begins with water-soaked spots on older leaves closer to the ground, followed by progressive drying and shriveling of the leaves. The dots are round in shape and have a grey center. Throughout the dots, tiny black pycnidia may be detected. The dots are tiny and numerous at first, but eventually, consolidate to cover a greater leaf surface. The primary infection takes place with the help of debris. Pycnidiospores generated in pycnidia developed in leaf patches induce secondary infection (Stoin Elizibeta, 1968). In 1966 as per Rizinski's observation. The illness caused a yield reduction of 12 to 16 percent. Our efforts are just a drop of water from the sea of knowledge.

Keywords: Septoria leaf spot, Pycnidiospores generated

Introduction
Tomatoes are called “Poor man’s apple” which are being exported in the form of whole fruits, paste and in canned form. Septoria leaf spot produces round to elliptical lesions with grey centres and dark brown borders surrounded by yellow halo seen on infected older leaves (Zhang *et al*., 2018) [52], is one of the most damaging foliar diseases dreasing crop production, and market value (Gul *et al*., 2016) [18].

The fungus developed a white to greyish black mycelium with hyaline, septate, and branching hyphae that eventually became brownish and were fairly thick walled. The pycnidia generated were globose to subglobose in shape, thick walled, ostiolated, and dark brown to black in colour with a diameter of 75-224 µm. Pycnidiospores were hyaline, filiform, straight or slightly curved with pointy or rounded ends, 2-9 septate, and measured between 68.40 µm and 117.09 × 2.28-3.74 µm.

Broad-spectrum fungicides such as carbendazim (bavistin), difolatan (captafol), dithane M-45 (mancozeb), and dithane Z-78 (zineb) have already been used in the field for successful control of *Septoria lycopersici* (Rajagopal and Vidyasekharan, 1982) [34]. As a result, it was considered that it would be useful to evaluate the efficacy of novel compounds such as azoxystrobin, tebuconazole, carbendazim+mancozeb, and others against the pathogen and illness in the current research. Our efforts have resulted in a drop of water, i.e. information on the disease, from the sea of knowledge.

Symptomatology
The disease can begin any part of the tomato leaf, which generally starts on the lower leaves and spreads to the upper leaves, the stem, and eventually, all of the leaves, except for a tiny tuft at the apex, are infected. The illness starts as little dark brown patches approximately the size of a pinhead. The patches progressively grow in size and change colour from brown to grey. Dark coloured borders surround light coloured cores in old places. They have a diameter of two to three millimetres. Frequently, the surrounding region dries up, the tissue shrinks, and various types of deformation result. The fungus produces little, black pycnidia on the infected region. Pycnidia are produced beneath the epidermis, but they emerge on the leaf's top surface later. On a single location, one to many pycnidia might be formed. Defoliation occurs from the bottom to the top, leaving just a few healthy new leaves. The illness manifests as tiny, infested, black sunken patches on the stem.

These marks aren't as distinct as the ones on the leaves. The damage to the stem is not as severe as the damage to the leaves (Endrinal and Celino, 1940) [13]. The calyx and flower pedicel show symptoms as well. Fruits do not have spots (Stoin Elizebeta, 1968) [42].

Causal organism

Saccardo (1884) published the first description of the fungus *S. lycopersici* in "*Sylloge Fungorum* was also described by Harris (1935) [19]

According to Harris (1935) [19], there are two kinds of *S. lycopersici* mycelium: hyaline and brown. The immature and actively developing hyphae, as well as the sporogenous tissue inside the pycnidium, have hyaline mycelium. The walls of hyphals are thin, hyaline, and usually septate. Closed septum is a rare occurrence. The protoplasmic contents are granular and vacuolated, with many tiny oil globules. The diameter of hyaline mycelium varies from 1.2 to 5.8 mm

Young and elderly hyphae are typically septate, hyaline to light brown, thin walled, varied in size, and vacuolated, according to Endrinal and Celino (1940) [13]. According to Sohi and Sokhi (1973), the mycelium possesses tight septation and branching is uncommon. The thickness of the brown hypha1 wall is about twice that of the hyaline mycelium.

The pycnidia appear on damaged tomato leaves and stems. They are abundantly generated on sterilised plant substrates and culture medium. A hollow globose body with no discernible ostiole makes up the pycnidium. Pycnidiaspores are released when the pycnidia wall breaks readily under the cover glass. The pycnidia have a diameter of 300 to 750 micrometres. Pycnidia generated on the host are usually much smaller, ranging in size from 30 to 175 m. Inside the pycnidium, a large number of pycnidiospores are generated. The pycnidial wall breaks down during maturity, allowing pycnidiospres to be released (Endrinal and Celino, 1940) [13].

The filiform, zero to nine septate, hyaline pycnidiospores with granular contents. They range in length from 28.00 to 119.00 metres and in breadth from 2.10 to 3.80 metres; the average size of 250 pycnidiospores is 67.00 metres (Endrinal and Celino, 1940) [13]. The pycnidiospores are filiform, hyaline, and septate, with a pointy or blunt end measuring 34.00 - 69.00 mm, according to Sohi & Sokhi (1973).

In order to determine the pathogenicity of *S. lycopersici*, two inoculation techniques were used. The first technique involves pricking tomato leaves with a sterilised pin and then spreading the fungus on the punctured area. The second approach is spraying the infected plants with a suspension of pycnidiospores in sterile water (Endrinal and Celino, 1940) [13]. Using mycelial pieces of *S. lycopersici* as inoculum, Andrus *et al*. (1945) [5] proved pathogenicity on tomato. For puncture inoculation, Locke (1949) [24] utilised mixed *S. lycopersici* mycelial pieces. Brock (1950) [9] and Henning and Alexander (1959) [1] inoculated the leaves of field and greenhouse grown plants with *S. lycopersici* mycelial pieces suspended in water. Marcinkowska (1977b) [27] utilised a suspension of at least two pycnidiospores per drop of water. When the inoculum concentration was raised to 2000-10,000 spores per drop, the pathogen developed quicker and infection was more severe. Brush inoculation of leaves is more precise than dipping or spraying in inoculating *S. lycopersici* to tomato leaves. A camel's hair brush was used to apply an inoculum concentration of 106 spores per ml (or greater) on both sides of the leaf (Tu and Poysa, 1990) [44].

Cultural studies

Potato dextrose agar grew *Septoria lycopersici* the best, whereas water agar grew the least. On both oatmeal agar and tomato-decoction agar, reasonable growth was achieved. Sweet potato cubes, carrot cubes, Kentucky beans, eggplant fruit cubes, sliced tomato fruit, and sliced pepper fruit were among the better sterilised plant substrates, while tomato leaf was among the worst (Endrinal and Celina 1940) [13]. Several studies have shown that potato dextrose agar is an effective medium for *S. lycopersici* growth and sporulation (Bonde, 1942; Neergard, 1945 and Rotem, 1966) [8]. On potato dextrose agar, the fungus grew and sporulated well. On oatmeal agar, Coon's agar, and Richard's agar, it produced good sporulation but poor mycelial growth. Both mycelial development and sporulation were scarce in Czapeck's solution (Sohi and Sokhi, 1973). On tomato leaf extract agar, potato dextrose agar, and carrot agar, the fungus grew most linearly (Marcinkowska, 1977a) [27]. Septoria tritici grew well on potato dextrose agar, according to Weber (1982) [47]. Mycelial growth was profuse on Czapek's Dox agar and potato dextrose agar, according to Rawal and Sohi (1983). For growth and sporulation of *Septoria lycopersici* Wolcan, potato dextrose agar medium was the best and V -8 juice agar was the worst of the four artificial media employed (1988). According to Govardhan (2001) [16], potato dextrose broth had the highest dry mycelial weight, followed by Sabouraud's dextrose broth, Czepek's broth, and Richard's medium.

Sporulation

Conidia of *S. lycopersici* did not germinate above 31 °C, according to McNeil (1950) [26], with maximal germination occurring between 21 °C and 29 °C. According to Sohi and Sokhi (1973), the optimal temperature for conidial germination was 25 °C, with no growth or germination occurring at 30 °C or above. Pycnidiospores germinated in a temperature range of 5° to 27.5 °C, with 20° to 22.5 °C being optimal, according to Sheridan (1968) [37] working with *Septoria apicola Speg*. *Septoria digitalis* Pass. germinated best at 23° to 25 °C, according to Kowalsky (1968) [22]. The germination of *Septoria tritici Rot.* pycnidiospores was reported by Gheorghiest (1972). Ex. Deson. had a temperature range of 10° to 30 °C, with a maximum of 37 °C and a low of 2 °C. According to Almeida, the most spores germinated equally at 22°, 25°, and 28° after 24 hours, and after 48 hours, 83 percent of the spores germinated evenly at 22°, 25°, and 28°. (1978). Sporulation was excellent at temperatures ranging from 6° to 24 °C.

Physiological studies

Fungi growth and sporulation were impacted by the initial pH of the media, according to Lockwood (1937). Endrinal and Celino (1940) [13] discovered that the fungus grows best on agar with a pH range of 5.6 to 8.4. According to Sohi & Sokhi (1973), the fungus may thrive in a pH range of 4.0 to 8.5, with a pH of 6.0 providing the best growth and sporulation. Septoria humulii thrived well at temperatures ranging from 5 to 25 degrees Celsius, however spores were only produced at temperatures between 20 and 25 degrees

Celsius (Munjal and Gautam, 1978) [28].
The fungus grew best at temperatures between 1.6°C and 34.4 °C, according to Pritchard and Parte (1924) [31]. The fungus thrived effectively at temperatures ranging from 15° to 28 °C, with 25 °C being the optimum temperature for growth and pycnidial generation, according to Sohi & Sokhi (1973). The growth temperature ranged from 28 to 30 degrees Celsius. Below 15 °C, the pathogen did not generate conidia. According to Marcinkowska, fungal growth occurs at a minimum temperature of 3 °C, an optimum temperature of 22-25 °C, and a maximum temperature of 30 °C (1977a). Pycnidia matures between 17 and 29 °C, while pycnidiospores germinate between 22 and 25 °C. *lycopersici* may grow at a minimum temperature of 4 °C and a maximum temperature of 30 °C, with the ideal range being 20 – 24 °C (Weber, 1982) [47]. Fungus flourished from 12 – 36 °C, with the optimal temperature being 24-1 °C and pycnidia forming at 16° - 28°C, according to Rawal and Sohi (1983). Fungus thrived at temperatures ranging from 10 to 25 degrees Celsius. According to Wolcan (1988) [50], the temperature range of 21-27 °C is optimum for fungal growth and development.
The conidia of the fungus were typically produced after 6 hours in the dark, according to Lukens (1963). Prasad and Dutt (1971) discovered that when a six-day-old culture was exposed to sunshine for six minutes for 24 hours, sporulation was higher than when the culture was subjected to incandescent electric light or infrared light. In contrast to continuous light and continuous darkness, alternate light and darkness for 12 hours each resulted in more mycelia development (Kurozawa and Balmer, 1975) [23].

Varietal reaction

Alexander (1942) [1] looked at the *Lycopersicon genus* for resistance to the most common illnesses. He was able to develop resistance to the leaf spot disease in 67 different cultivars. He accepted four kinds that had acceptable characteristics. *Lycopersicon peruvianum (L.) Mill.*, *L. glandulosa*, *L. hirsutum Humb* and *Bonpl*., and *L. pimpinellifolium Mill*. all showed resistance. Some *Lycopersicon hirsutum* and *Lycopersicon perurvianum* lines showed resistance to *Septoria lycopersici* (Locke, 1949) [24]. According to Gupta (1960) [17], the Pusa red plum cultivar has a higher disease resistance than other varieties. Only 8 tomato varieties, tomato Kt -4 a natural cross, EC 2750, EC 4555, EC 6993, EC 7785, EC 7293, and HP2453, were found to be resistant to this disease out of 154 types examined by Sohi and Sokhi (1969) [41]. According to Marcinkowska (1977) [27], *S. lycopersici* infected all 27 types tested in the field, 3 were somewhat sensitive, 17 were moderately susceptible, and 7 were very susceptible. The tomato PI 422297 exhibits a high level of resistance to *S. lycopersici* leaf spot (Barksdale and Stoner, 1978). In 1987, 58 genotypes from India, the United States, Taiwan, and the Netherlands were evaluated under epiphytotic conditions, and 25 exhibited field resistance to *Stemphylium solani*, 23 cultivars to *Alternaria solani*, and 12 to *Septoria lycopersici*.
All three illnesses were shown to be vulnerable in Pusa Ruby (Madalgeri *et al*., 1988). Only Rossol and EC 1085 demonstrated resistance or moderate resistance to disease, according to Bedi *et al*. (1990), who examined 279 lines generated at research institutes in Taiwan, France, the United States, and Japan in a field utilised for tomato harvests for ten yearsOnly two tomato cultivars (one from the United States, the other from Denmark) and one tomato variety (*L. esculentum var. cerasiforme*) showed resistance to *S. lycopersici* in a study by Sotirova and Rodeva (1991). Although *Solanum sisymbrifolium* was resistant, it could not be crossed with tomato cultivars. Pandey & Pandey (2002) [29] tested 132 tomato germplasm for *Septoria lycopersici*, *Alternaria solani*, and *Xanthomonas campestris pv. vasicatoria*, among other diseases. Only one germplasm line, LE-415, was discovered to be disease resistant among the tested lines for the multiple disease complex of tomato. Six of the lines were somewhat resistant, 29 were moderately susceptible, 48 were susceptible, and the remaining 48 were very vulnerable. Raina and Razan (2010) [33] screened forty-one tomato cultivars against *Septoria lycopersici* in the field in Jammu and found 11 varieties to be susceptible, 14 to be moderately susceptible, and 10 to be moderately resistant, with four varieties ranging from moderately susceptible to susceptible and only two varieties, SH-12 and S-2, to be resistant.

Chemical control

***In vitro* efficacy of fungicide**

The poisoned food method was used to test the effectiveness of fungicides against *S. lycopersici* in the laboratory at doses of 250, 500, 1000, and 2000 ppm with three replications each. Mancozeb, captafol, bavistin, benomyl, and zineb were among the fungicides studied. As a consequence of the study's findings, all of the fungicides were determined to be effective (Falck, 1967). Against *Septoria tritici*, a combination of thiophanate methyl + colloidal s 80 + mancozeb provided a good control (Baicu *et al*., 1977) [7]. S. nodorum infection was decreased by one treatment of thiophanate methyl + maneb and chlorothalonil in Switzerland (Jaggi, 1979) [20]. Carbazim, maneb, and tridemorph fungicides were shown to be efficacious by Lartaud and Lipatoff (1980). When sprayed 4 to 5 times at a 14-day interval, thiophanate methyl + maneb produced marketable yields (Vulsteke and Meeus, 1983) [45]. Ahamad and Ahmad (2000) examined five fungicides (carbendazim, thiophanate-methyl, captan, blue copper, and mancozeb + thiophanate-methyl) for their capacity to suppress tomato leaf spot caused by *Septoria lycopersici* in a pot experiment. The disease was controlled by all of the fungicides, but captan was the most effective, followed by carbendazim, blue copper, and mancozeb + thiophanate-methyl.

Bio control of *Septoria lycopersici*

Many soil-borne plant diseases have been found to be hostile against *Trichoderma spp.* Wright (1956) found that *Trichoderma spp*. generated numerous hazardous metabolites *in vitro*, and there is some indication that similar compounds were formed in soil pieces of dynamic matter. *T. viride* inhibited *S. lycopersici* to the tune of 30-40%. (Kashyap and Leukina, 1977) [21]. *T. harzianum* has been found to be an efficient *Rhizoctonia solani* suppressant (Chet and Baker, 1980) [10]. *T. viride* has been used to control soil-borne plant pathogens including *Sclerotium rolfsii* that cause root rot in a variety of crops (Elad *et al*., 1980) [12]. By adding conidia of *T. harzianum* to the soil, Sivan and Chet (1989) [40] noticed a substantial reduction in the chlamydospore germination rate of *Fusarium oxysporium f. sp. vasinfectum* and *F. oxysporium f. sp. melonis*. In Auburn, Alabama, Blum (1996) [6] tested a

biocontrol agent. Field plants were used to isolate the pathogen and one antagonist. Six yeast isolates and one bacterial strain were examined in a series of seven tests in the greenhouse. With four to eight treatments and six replications, the studies were done in a totally randomised manner. The antagonists were injected 48 hours before the pathogen was inoculated, with occasional misting. In most trials, the yeast strain Y236 (*Cryptococcus laurentii*) and the bacterial isolate BTL (*Pseudomonas putida*) dramatically decreased the disease's incidence or severity.

Field management

Disease control in the field Temple (1920) identified blue stone liquid spray with or without resin oil soup as the most promising fungicide for controlling *S. lycopersici* tomato leaf spot disease. Several employees from all over the world have stated that the Bordeaux combination is the most efficient fungicide in treating this disease from time to time. Pritchard and Parte (1924) [31] achieved good results with a Bordeaux mixture of 4:4:50 and copper soap dust. To control this illness, Whetzel (1922) [49] advised a Bordeaux combination that improved yield by up to 20% when fresh soap was used. According to Frome (1922) [14], spraying the Bordeaux combination with soap resulted in a yield increase of up to 20%. Pool (1922) [30] found that spraying 2 to 7 times with a Bordeaux mixture with a 4:4:50 ratio improved control. Walker *et al*. (1937) [46] suggested soil sanitation, Bordeaux mixture spraying, and keeping the plots weed-free. Singh (1966) recommended a 0.3 percent copper fungicide spray solution, as well as other cultural techniques. Folpet, captan, mancozeb, benomyl, and metirammethyle were shown to be extremely efficient against *S. lycopersici* by Alexandri and Iosifer (1973) [2]. Although it was mildly phytotoxic, benomyl at 0.1 percent provided effective control (Sarasoca and Rocca, 1971) [36]. In the field, bavistin (0.1%) and benomyl (0.05-0.1%) were found to be effective against *S. lycopersici* on tomato plants (Abelentsev *et al*., 1978). Quinn and Johustone (1979) [32] discovered that a 3 kg/ha captafol spray was efficient against *S. lycopersici* and *Alternaria solani* on tomato plants.

S. lycopersici was sensitive to copper oxychloride 50, dithane M-45 (mancozeb), and benlate 50 WP (benomyl). Only mancozeb, according to Alexandri *et al*. (1980) [3], was effective against the fungus. Both mancozeb and captafol successfully controlled *S. lycopersici* and *A. solani*, reducing defoliation and increasing fruit yield, according to Rajgopal and Vidhyasekaran (1983) [34]. Tedla (1985) [43] discovered that captafol 80 percent WP (metalaxyl) at 0.3 percent and ridomil MZ 63.5 percent WP (metalaxyl) at 63.5 percent WP (metalaxyl) were effective against *S. lycopersici* and *A. solani*. The most effective treatments against *Septoria lycopersici*, *Phytophthora infestans*, which causes tomato leaf spot and late blight, were zineb, pyrocalectol, hydro quinone, and kasumin (Dorozhkin and Ivonyuk, 1982) [11]. In Bangalore, Govardhan (2001) [16] tested fungicides against *Septoria lycopersici* in the field. Spray treatments in the field included fungicides such as iprodion, mancozeb, blitox, capton, bavistin, kavach, zineb, and baynate. At a 10-day interval, three sprays of the different fungicides were administered. The disease surveillance was done at 10-day intervals up to the 95th day after planting. Mancozeb and bavistin were shown to be very effective and significant among the fungicides. Anand *et al*. (2010) [4] tested azoxystrobin against the tomato diseases early leaf blight and septoria leaf spot in a field trial. Spraying azoxystrobin at different doses, such as 31.25, 62.50, and 125 g a.i. per ha (500 ml per ha), revealed that the 125 g a.i. per ha (500 ml per ha) recorded only 3.90 and 4.86 percent disease index (PDI) of leaf blight and 0.00 and 2.42 percent PDI of leaf spot, and the same treatment also produced higher yields of 27.60 and Even at four times the allowed dosage of 125 g a.iper hectare, no phytotoxic impact of azoxystrobin was detected in both field experiments of tomato.

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