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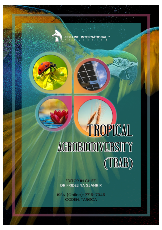

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RESEARCH ARTICLE

INTEGRATED DISEASE MANAGEMENT OF EARLY BLIGHT (*ALTERNARIA SOLANI*) OF POTATO

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ABSTRACT

This review is to reviewed with an objective of reviewing the overall aspect of early blight of potato crop along with its management options. Potato is the most important vegetable crop in terms of quantities produced and consumed worldwide. It is the fast-growing major crop in the world with important economic impact on many resource-poor farming families. However, its production is currently disturbed by a number of biotic and abiotic constraints. Epidemics of early blight caused by Alternaria spp. can cause significant economic damage to potato production if not timely controlled. It is prevalent worldwide wherever potatoes, tomatoes, peppers, and eggplants are grown. The disease can damage both potato foliage and tubers and can causes yield losses of 5-50%. Early blight is a poly cyclic disease that can cause more than one disease epidemics within a single cropping season. It is difficult to control because of its capacity to produce huge amounts of secondary inoculum. Since the disease is very important in causing economic losses of yields on potato crop, developing and using effective and appropriate management options is necessary. Using good cultural practices and applying chemical fungicides are important in reducing as well as managing of early blight disease of potato. Even though there is no well-developed biological control of early blight, it is very important to develop such management strategies. Because biological control measures are specific, efficient and environmentally safe. In order to control early blight in potato, studies were conducted to identify the optimal fungicide strategy and, if possible, to reduce the number of fungicide applications per growing season. Therefore, a disease-threshold-based framework was tested to define the optimal timing of fungicide application. The initiation and subsequent applications of fungicides were based on increases in disease incidence or severity.

KEYWORDS

Potato, pathogen, *Alternaria solani*, management, fungicide

1. INTRODUCTION

Potato (*Solanum tuberosum*) is one of most valuable food crops for mankind FAO and in terms of quantities produced and consumed worldwide (FAO, 2005). The cultivated potato (*Solanum tuberosum* L.) originated in the Andean highlands of South America and was disseminated to other continents by Europeans. It is believed to have been introduced in India towards the beginning of 17th century most probably by the Portuguese traders or by British missionaries (Pushkarnath, 1976). In volume of production it ranks fourth in the world after wheat (*Triticum aestivum L.*), rice (*Oryza sativa* L.), and maize (*Zea mays* L.) (Bowen, 2003). World potato production increases from 30 million tonnes in 1960s to 165 million tons in 2007 (FAO, 2008). An estimated 70% of the country's arable land is potentially suitable for potato cultivation (FAO, 2008). It is used in a wide variety of table, processed; livestock feed and industrial uses (Feustel, 1987; Talburt, 1987). Potato provides nutritious food in a diversity of environments and is an important food for the increasing world population, which has the potential for increased vitamin C, protein content (Pereira and Shock) and serves as a valuable source of cash income for low income farm households (FAO, 2008).

The causal organism of early blight was first described as *Macrosporium solani. Alternaria solani* Sorauer is a major foliar disease of potato caused by early blight (*Solanum tuberosum*) (Ellis and Martin, 1882). Disease symptoms are characteristic dark brown to black lesions with concentric rings, which produce a 'target spot' effect. Symptoms are initially observed on older, senescing leaves (J E et al 2001). Values in the literature for measured crop losses due to early blight vary enormously from 5–78% (Waals et al., 2004; Pasche et al., 2004, 2005). The areas of Kashmir valley affected by early blight disease was surveyed during 2009 and 2010 where overall mean disease incidence and intensity ranged from 24.54 to 28.23% and 13.84 to 15.98%, respectively. The highest disease incidence (39.09%) and intensity (22.54%) was recorded in district Budgam. The lowest level of disease was in district Shopian (14.89 and 8.05%, respectively) (Ganie et al., 2013).

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Figure 1: Early blight of potato

2. SYMPTOMS

Some researchers were the first to describe the symptoms on dying potato leaves. The most susceptible plants that are physiologically old, weak, malnourished and wounded by wind, sand, hail or insects are affected (Ellen and Martin, 1882; Rands 1917a; Heuberger and Dimond 1941). The first symptoms appear on older leaves consisting small, irregular, dark brown to black, dead spots that range from a pinpoint to 1/2 inch in diameter in size. As the spots continues enlarging, concentric rings may form due to irregular growth patterns by the organism in the leaf tissue. This gives the lesion a characteristic "target-spot" or "bull's eye" appearance (Rowe et al.)

Initial lesions on young, fully expanded leaves is often confused with brown spot lesions. These first lesions appear about two to three days after infection, with further sporulation on the surface of these lesions occurring three to five days later. Early blight lesions can be diagnosed in the field easily due to the dark concentric rings alternating with bands of light-tan tissue, giving them a distinctive target spot appearance (Mitchell et. al). Lesions appear as small spots-dry and papery in texture in initial condition and become brownish black and circular as they progress. Older lesions often appear angular in appearance as their margins become limited by leaf veins (Sikora, 2004).

Enlarging lesions are often surrounded by a narrow chlorotic halo due to toxins produced by the pathogen, which move ahead into uninfected epidermal cells (Rands 1917a; Pscheidt 1985). Lesions are usually oval in shape, but under unfavourable conditions may remain small and angular, conforming to the interveinal spaces (Rands 1917a). Lesions enlarge, coalesce and eventually cause death of the leaf (Pscheidt1985). Infected stems is characterized by sunken, elongated spots that may also display the typical concentric rings. Lesions in infected tubers appear as slightly sunken dark irregular spots with raised borders; a dry rot develops internally under the skin (Schultz and French, 2009).

Diseased tissue under lesions is dark brown, firm and 10–12 mm deep.Spores may be seen on older lesions when viewed under a microscope. Lesions can also develop on petioles. (Pscheidt 1985). Internally, the tissue imparts a brown to black corky, dry rot, usually not more than 1/4 to 3/8 inch deep. Deep cracks may form in older lesions. Tuber infection is uncommon under Ohio conditions (Rowe et al.). Reduction in ratio of tuber yield to foliage is associated with a reduction in lesion size and early blight incidence (Rotem and Feldman 1965).

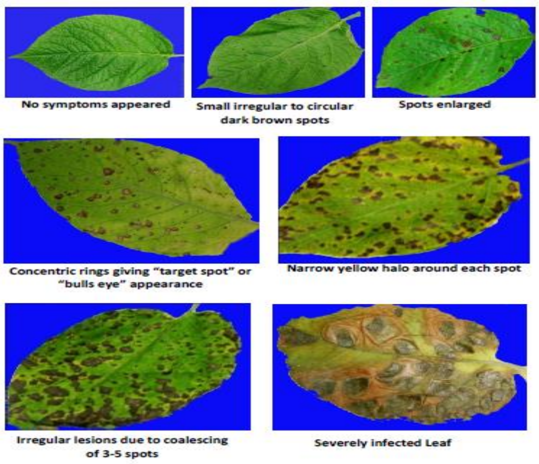

Figure 2: Symptom development in the field.

3. PATHOGEN

A. solani is classified in the domain Eukaryota, kingdom Fungi, phylum Deuteromycota, class Hyphomycetes, order Hyphales, series Porosporae. Colony morphology of *A. solani* varies widely, but is generally effuse, grayish brown to black, with a cotton-felt-or velvet-like texture (Ellis and Gibson 1975). Early blight is caused by the fungus, *Alternaria solani,* which universally survives in infected leaf or stem tissues on or in the soil where they are grown. Spores form on infested plant debris at the soil surface or on active lesions over an alternating wet and dry conditions which are easily carried by air currents, windblown soil, splashing rain, and irrigation water occurring mainly in warm, humid weather with heavy dews or rain. Early blight can develop quite rapidly in mid to late season and is more severe when plants are stressed by poor nutrition, drought, or other pests. Infection of potato tubers occurs through natural openings or injuries in the skin. Tubers may come in contact with spores during harvest and lesions may continue to develop in storage (Schultz and French, 2009).

Cells of *A. solani* are multinucleate, but different organs vary in the number of nuclei. Nuclear division in hyphal cells is followed by multiple septation, which results in the division of elongated tip cells into several multinucleate cells (King and Alexander 1969). The fungus produces dark to black conidia (asexual spores). This fungus has not been found to produce sexual spores. (Schultz and French, 2009). *Alternaria* spp. have dark-colored mycelium, and in older diseased tissue they produce short, simple, erect conidiophores that bear single or branched chains of conidia. Conidia posses large, dark, long, or pear shaped and multicellular, with both transverse and longitudinal cross walls structure which are detached easily and are carried by air currents (Agrios, 2005).

Conidia are usually pale to olivaceous-brown, produced singly or seldom in short chains, straight or slightly flexuous, obclavate to elongate, double walled with 0–8 longitudinal or oblique and 6–19 transverse septa, 75–350 µm in length and 20–30 µm in diameter in the broadest part (Ellis and Martin 1882; Rao 1964, 1969). Beaks are about $1/2^{th}$ to double the length of the conidium, filiform, septate, hyaline to pale brown and 5–9 µm in diameter (Ellis and Martin 1882; Rao 1964, 1969). Because of the variability in spore dimensions, they overlap with dimensions of other large spore *Alternaria* species. In routine work, identification is assisted by leaf symptoms, host range and cultural characteristics. Biochemical or molecular techniques best verify the identity of the fungus. Conidiophores are dark or olivaceous brown, thick-walled, straight to flexuous, septate, arise singly or in small groups, up to 110 µm in length and 6–10µm in diameter (Neergaard, 1945; Ellis and Gibson 1975). Conidiogenesis is tretic (Neergaard 1945; Ellis and Gibson 1975).

Most of the species of *Alternaria* are mostly saprophytic i.e. they cannot infect living plant tissues but grow only on dead or decaying plant tissue generally on senescent or old tissues such as old petals, old leaves, and ripe fruit. So, it is mostly difficult to decide whether an *Alternaria* fungus found on diseased tissue is the cause of the disease or a secondary contaminant. Many species of *Alternaria* produce toxins. (Agrios, 2005).

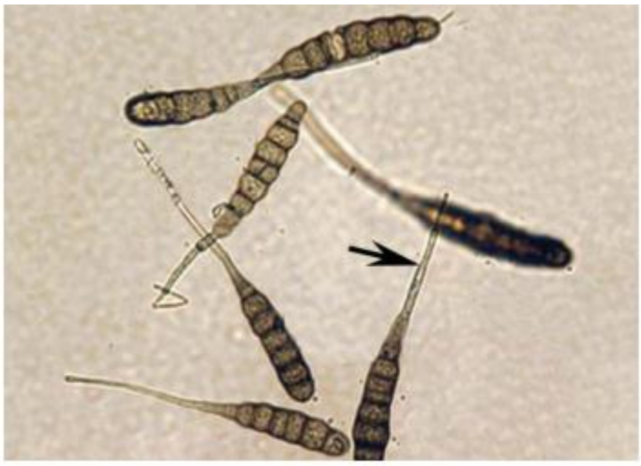

Figure 3: Spores of *Alternaria solani*

4. DISEASE CYCLE

Alternaria solani is a polycyclic pathogen, because of possibility of many cycles of infection during a growing season. The primary inoculum produces conidia in the spring. The pathogen overwinters as mycelium or conidia in plant debris, soil and infected tubers or on other host plants of the same family (van der Waals, 2002). The pathogen survives primarily in soil on infected crop debris for years. Chlamydospores have also been reported as a source of overwintering inoculum for early blight that helps pathogen to survive in cold temperatures. The inoculum remains infective in debris in uncultivated soil for 5 to 8 months. The dark pigmentation of the hyphae increases their resistance to lysis. Spores survive most often in infected debris and seed and best in dry, fallow fields.

If the fungus is carried with the seed, it may attack the seedling, after emergence, and cause damping-off or stem lesions and collar rot. More frequently, however, spores are produced abundantly, especially during heavy dews and frequent rains, and are blown in from infected debris or infected cultivated plants and weeds (Agrios, 2005; Schultz and French, 2009). The new conidia are soon produced from germinating spores penetrating susceptible tissue directly or through wounds that are further spread by wind, splashing rain, etc. With few exceptions, due to some kind of stress Alternaria diseases are more seen in older, senescing tissues, mainly on plants growing poorly (Agrios, 2005). Symptoms usually begin to appear on unprotected plants a week or so after flowering. Symptoms are most severe on plants that are weak due to environmental stress, poor nutrition, or on plants already infected with another disease (such as Verticillium wilt) (Schultz and French, 2009).

Following initial infection, sporulation occurs on lesions, and spores are dislodged under conducive environmental condition. Alternating wet and dry periods or heavy rains are the most favorable for sporulation and dispersal. The spores produced by primary inoculum are responsible for secondary spread of the fungus to health6y tissue, which leads to an exponential increase of foliar infection. Spores landing on leaves of susceptible plants germinate and may penetrate tissues directly through the epidermis, through stomata and or through wounds such as those caused by sand abrasion, mechanical injury or insect feeding. Free moisture (from rain, irrigation, fog or dew) and favorable temperatures (68 - 86°F) are required for spore germination and infection of plant tissues. Lesions begin to form from 2 to 3 days after initial infection (Warton and Kirk, 2012). Spore germination is facilitated by free moisture, but can be induced by relative humidity close to saturation. With a favorable inoculum dose and wetting period, the minimum temperature for infection can be as low as 10°C, the maximum >35°C, and the optimum between 20°C and 30°C. Incubation periods (time from infection to symptom development) vary greatly, depending on age and susceptibility of plants. Epidemics increase in severity after sandstorms, due to increased wounding of the epidermis. The primary infections become necrotic with chlorotic halos. Mycelium from necrotic lesions produces conidia that infect healthy leaves and begin secondary infections. Tubers are infected through wounds, as the conidia are unable to infect directly through intact periderm. Wound healing, by suberisation and the development of wound periderm, reduces infection markedly (van der Waals, 2002).

Tubers become infected as they are lifted through infested soil at harvest. Tuber infection usually occurs through wounds, so immature tubers and tubers of white and red-skinned varieties are more susceptible to the disease. Digging tubers under dry conditions also reduces the risk of infection by the fungus. Tubers harvested under wet conditions should be dried as quickly as possible using force ventilation as soon as they are placed in storage (Sikora, 2004).

On potato plants, sporulation occurs between 3 and 5°C, with the optimum around 20°C. Sporulation of the pathogen is affected by the state of the host and tends to accelerate with an increase in necrotic tissue formation and a decrease in photosynthesis.Sporulation in the field requires at least two days. Conidiophores are produced during a night with wet conditions. Light and dryness the next day induces the production of conidia, which are then formed during the second wet night (van der Waals, 2002). Symptoms appear within a week of infection. Multiple cycles can occur in one crop season under favorable conditions. Susceptibility to *A. solani* increases with the age of the plant tissue and of the plant, particularly after fruit and tuber initiation (Schultz and French, 2009).

Moisture plays a major role in the development of early blight. Studies have shown that free water is critical for disease development and that duration of leaf wetness can account for up to almost 90% of variability in disease development and severity. Increased leaf maturity, heavy fruit load, crowded plants, above average rainfall or dew and shading also enhance early blight development. *Alternaria solani* reacts differently to weather conditions, depending on the circumstances. In certain cases, weather factors may act indirectly by influencing the susceptibility of the host. Cooler temperatures may, for instance, retard the growth of the plant, while short photoperiods are associated with a decrease in sugar content in leaves (van der Waals, 2002).

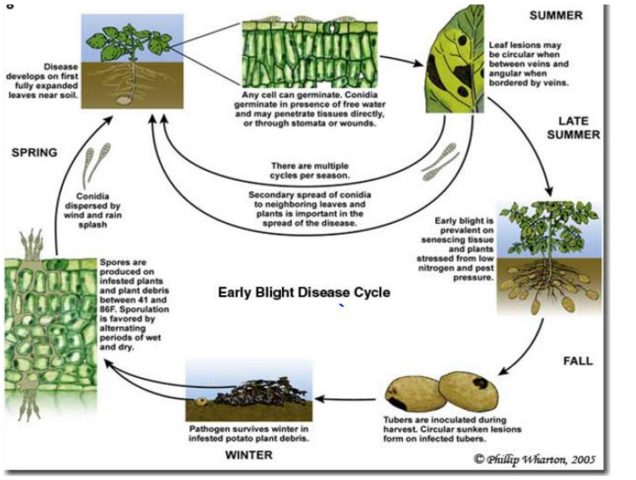

Figure 4: Diseases cycle of the early blight pathogen, *Alternaria solani*. (Warton and Kirk, 2012)

5. Management

Implementation of an Integrated Disease Management (IDM) approach is an effective approach to control this disease through the use of cultural practices, resistant cultivars and foliar fungicides (Warton and Kirk, 2012).

6. Cultural Practices

Early blight can be controlled effectively by cultural practices, such as a 3–5-year crop rotation with non-host crops, site selection, sanitation of fields, providing proper plant nutrition, avoiding water stress, planting disease-free seed, removal and burning of infected plant debris, and eradication of weed hosts helps reduce the inoculum level for subsequent plantings (Madden et al. 1978). *A. solani* persists in plant debris in the field from one growing season to the next so rotation with non-host crops (e.g. small grains, corn or soyabean) can reduce the amount of initial inoculum available for disease initiation (Agrios, 2005; Sikora, 2004; Schultz and French, 2009; Warton and Kirk, 2012). Other cultural control measures may include the following.

a) By using certified, pathogen-free seed and resistant varieties.

b) Waiting for at least 3 or 4 days (preferably 2 weeks) after vine killing before digging potatoes. This practice increases tuber resistance to the early blight fungus.

c) After harvesting, plowing under all plant debris and volunteer potatoes.

d) Storage of lesion-free tubers in a clean, dry, dark, well-ventilated location at 40° F.

e) Handling of tubers carefully to avoid bruising.

f) Selection of well drained and aerated fields, facilitating air circulation, and avoiding dense plant stands and prolonged overhead irrigation.

g) Avoiding irrigation in cool cloudy weather and timely irrigation to allow plants time to dry before nightfall.

h) As *A. solan*i is unable to infect through intact periderm tubers should be stored under conditions that promote rapid suberization.

7. Resistant Cultivar

Planting cultivars which are less susceptible to early blight may also reduce disease severity. However, showed that host resistance has no much effect on the initial appearance of early blight (Shtienberg and Fry, 1990). Cultivars with good field resistance are also available, however no immunity has been found to early blight in commercial potato cultivars or in their wild parents. Highly susceptible cultivars should not be planted in locations where early blight is prevalent and disease pressure is high. Field resistance to foliage infection is associated with plant maturity so, late maturing cultivars are found to be more resistant than early maturing cultivars and therefore, one should not plant early and late cultivars in the same or adjacent fields (Warton and Kirk, 2012).

Table 1: Fungicide resistance level conveyed by mutations in *A. solani* and percentage of isolates collected in a recent survey by Bauske et al. (2018a) possessing each mutation in North Dakota and Minnesota

Mutation	Boscalld	Penthlopyrad	Fluopyram	QoI resistance	% ND Isolates	% MN Isolates
F129L	Sensitive	Sensitive	Sensitive	Moderate	100	100
H278Y	Very high	High	Sensitive	Sensitive	47	33
H278R	Moderate	Moderate	Sensitive	Sensitive	0	0
H134R	Very high	Very high	Sensitive	Sensitive	40	21
H133R	High	Moderate	Sensitive	Sensitive	0	25
D123E	Very high	High	Reduced Sensitive	Sensitive	12	11

8. Chemical Control

The most effective control measure is a protectant type fungicide spray programme used from early in the growing season to vine kill (Jones 1912; Harrison et al. 1965a; Douglas and Groskopp 1974). Application of contact fungicides regularly in the early stages of the disease is recommended to prevent infection. After flowering starts, 3–4 sprays of a systemic or contact fungicide should be applied. If symptoms are seen before flowering, a systemic fungicide should be applied immediately. The most important consideration in the use of fungicides to control early blight is coverage so during aerial application of fungicides one should ensure that the lower, senescing leaves (where most of the early blight lesions occur) receive fungicide to prevent spread of the disease. Proper timing of initial and subsequent fungicide applications reduces the overall frequency of sprays with no significant yield loss (van der Waals, 2002). The application of foliar fungicides is not important in plants at the vegetative stage, when they are comparatively resistant. Spraying should be started at the first sign of disease or immediately after bloom. The number of subsequent sprays can be determined according to the genotype and age-related resistance of the cultivar. Protectant fungicides should be applied initially at relatively long intervals and subsequently at shorter intervals as the crop ages (Warton and Kirk, 2012).

A protectant-type fungicide with the active ingredient chlorothalonil, maneb, or macozeb should be applied on a 7-10 days scheduling from beginning at bloom, or according to a weather-timed spray schedule and continue until the foliage dies. Proper timing and thorough coverage of foliage are essential. Time period between application of fungicide should be shortened in areas where the disease "late blight" is prevalent (Sikora, 2004). Alternating contact and systemic fungicides spray should be done to control the disease and follow a complete spray or dust program (Schultz and French, 2009). If there is risk of more serious late blight, applications should be started when plants are four to six inches tall. Sprays are superior to dusts so apply dusts and sprays in the early morning or evening when the wind is low (less than 5 miles per hour for dusting and 10 mph for spraying) and leaf surfaces are damp with dew. Dusts should contain at least 5-10% fungicide (Anonymous, 1990). Early season applications of fungicides before secondary inoculum is produced have minimal or no effect on the spread of the disease. Thus, early blight can be controlled by relatively few fungicide applications if the initial application is properly timed. Adoption of predictive models to time the first application is used. The first application for early blight control should be adjusted at 200 P days after emergence. Regular inspection of field should be done after plants reach 12 inches in height is recommended in order to detect early infections (Warton and Kirk, 2012).

In Colorado field trials, yields of plots treated with contact fungicides were around 20–40 % higher than in untreated plots, while in Minnesota chemical control of early blight with captafol, triphenyltin hydroxide or maneb-Zn resulted in yield up to 90 % than on unsprayed controls (Teng & Bissonnette 1985; Harrison and Venette 1970).

Table 2: Product name, FRAC[a] resistance management grouping, common name, rate of application and season limit of some currently registered products for control of early blight of potato in Michigan

Product	FRAC[a] group	Common name	Rate of application[c]	Season limit (lb or pt of product)
Quadris	11	Azoxystrobin[d]	6.2 – 15.4 fl. oz/A	3.8 pt/A
Headline	11	Pyraclostrobin[d]	6.0 – 9.0 fl. oz/A	4.5 pt/A
Gem	11	Trifloxystrobin[d]	6.0 – 8.0 oz/A	3.0 lb/A
Tanos	11	Famoxodone[d]	6.0 oz/A	3.3 lb/A
Scala	9	Pyrethamil	7 fl. oz/A	2.2 pt/A
Reason	11	fenamidone[d]	5.5 – 8.2 fl. oz/A	1.5 pt/A
Endura	7	Boscalid	2.5 – 4.5 oz/A	1.3 pt/A
Maneb	M3	Maneb	1.5 – 2 lb/A	11.2 lb/A
Dithane, Manzate, Penncozeb	M3	Mancozeb	0.5 – 2 lb/A	15.0 lb/A
SuperTin	30	Triphenyl tin hydroxide	2.5 – 3.75 oz/A	11.25 oz/A
Bravo, Echo, Equus	M5	Chlorothalonil	1.0 – 2.2 pt/A	15.0 – 22.5 pt/A, depending on product

[a]Fungicide Resistance Action Committee. See (http://www.frac.info) for more information

[b]Product names are provided as a convenience only and mention of them shall not be constructed as an endorsement of the product or sponsorship by or affiliation with the company manufacturing that product. Specific instructions are included on the labels of all the products, and these must be adhered to.

[c]Rates of application are provided as a guide only. Consult specific instructions included on the label for complete details.

[d]Should always be used in combination with a protectant fungicide (i.e. mancozeb, maneb or chlorothalonil)

9. Conclusion

Potato is the most important vegetable crop in terms of quantities produced and consumed worldwide. It is the fast-growing major crop in the world with important economic impact on many resource-poor farming families. However, its production is currently disturbed by a number of biotic and abiotic constraints. Epidemics of early blight caused by Alternaria spp. can cause significant economic damage to potato production if not timely controlled. It is prevalent worldwide wherever potatoes, tomatoes, peppers, and eggplants are grown. The disease can damage both potato foliage and tubers and can causes yield losses of 5-50%. Although the *A. solani* pathosystem on potato has been researched extensively, various aspects remain that need to be investigated. Major gaps in our knowledge of the epidemiology and economic impact of the disease still exists. The identification of *Alternaria* species based only on morphological characters is inadequate and more emphasis should be placed on the development of biochemical, serological and molecular methods. The use of additional molecular markers and larger population sizes should be paramount in any future study to confirm the existence of physiological races of *A. solani*. The biochemical aspects of sporulation still require attention, in order to explain the physiological processes during infection.

Another area of research that requires more extensive studies is the predisposition of the host to infection. Knowledge is also lacking about the physiology of resistance, for example the effects of senescence, stress and susceptibility as well as the role of toxins in pathogenesis. This information can be utilized in developing more effective control and breeding strategies. Although overwintering and transmission of primary inoculum to host plants have been studied, little information concerning the biochemical modes of survival is available. This information can provide a sounder basis for control, focused on eradication of primary inoculum. Although the control of early blight using disease forecasting models has been extensively studied and is currently used in many countries.

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