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# Investigation of *Phytophthora Infestans* Causing Potato Late Blight Disease: A Review

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**ABSTRACT**

*Phytophthora infestans* (Mont.) cause potato late blight disease and can infect of roots, tubers, and shoots of the plant. The majority of significant factors in determining the spread of the potato late blight is the cultivation of infected potato tubers and their presence as agricultural plant debris in the agricultural field. Mycelium, zoospores, Oospores, and sporangia, all these structures can make infection, also Oospores with their thick wall can survive for 3 to 4 years under low temperatures. *P. infestans* responsible to yield losses may arrive at 100% in optimum condition. There are two types of mating patterns for A1 and A2, and this depends on the spread of each type in different environments. This fungus also contains several genetic patterns that have been identified through molecular analysis. The different genotypes in this fungus led to new challenges to make an unstable guideline for the study of virulence and aggressiveness. Different strategies or methods were used to prevent or control late blight disease, included of chemicals, crop rotation, bio-agents, and resistant plants. There are many advantages or disadvantages to each strategy, but several studies mention that using resistant plants and fungicide together on conditions in suitable times and strategies led to perfect effect. This paper investigated in important factors in the spread of late blight disease, and some challenges in this fungus.

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## 1. Introduction

The Fungus of *Phytophthora* sp includes more than 60–80 species they are all infected by plants (Lilja et al., 2006; Meirinho et al., 2010). *Phytophthora infestans* infect potatoes and tomatoes primarily, the infection included tubers, stems, leaves, and fruits (Karki & Halterman, 2021). This fungus was caused by the Irish famine (in the 1840s) because it infected potatoes (Ristaino & Records, 2020). When this fungus entered Europe in the nineteenth century, caused die a bout million people and more than two million people to migrate to other parts of the world, and since then the disease become established in all countries where potatoes are grown (Corbière et al., 2010).

Late blight losses are varies by countries, depending on the environmental condition, plant protection strategies, and cultivars employed, several studies document the late blight yield losses, which recorded about 50–70% (Rasheed & Khan, 2008), also 85% (Thomas-Sharma et al., 2016), and may arrive to 100% under an environment in favorable condition (Ahmed et al., 2015).

Primary sources of inoculum have included infected seed tubers, volunteer potatoes, and cull piles (Johnson et al., 2003). Infection of tubers occurs during the growing period or harvest or handling, besides the pathogen can survive from cold season to make a second infection (Arneson, 2001). *P. infestans* reproduction modes included sexual, asexual, and parasexual reproduction, so this led to higher evolutionary potential (Gu & Ko, 2000). There are two types of mating in this fungus, which included A1, and A2, mating led to zygote forming (Tzelepis et al., 2020). In addition, the different genotypes detected can make a fungus have different abilities in resistance to fungicides (Saville et al., 2015). Migration of the *P. infestans* population and reported the possibility that sexual reproduction led to high aggressiveness levels (Flier et al., 2002).

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Several strategies were used to manage and control the late blight disease on potato, each method have advantage and disadvantage effect, most method used included chemical management by using different fungicides, eco-friendly agent as a biological control, host resistance, cultural practices, and many others strategies (Lal, et al., 2018), but using of resistance plants and fungicides in correct strategies considers most effective control methods for farmers (Namanda et al., 2004).

## 2. Sources of Inoculation of *P. infestans*

Initial sources of *Phytophthora infestans* inoculum are responsible for the early potato late blight infection and the outbreaks, infected tubers (including cull volunteer potatoes and piles), also seed tubers with latently infected and oospores consider important sources of primary inoculum (Evenhuis et al., 2008). Next season's plant may infect by this fungus during planting, cutting, and handling of the seed-tuber or occur in the field (Johnson, 2010).

Secondary infection during handling and cutting requires the pathogen to survive in intact tubers over the winter, sporulation, spread, and make others infect the tubers or the plants (Zellner, 2004). Sporangia produce by *P. infestans* on tubers, and after nineteen hours occur of sporulation, the infected tubers develop at high soil humidity following rainfall (Adler, 2000; Bäßler et al., 2002; Bäßler et al., 2004). Sporangia were easily transmitted directly between seed pieces or infected tubers and non-infected seed pieces (Turkensteen et al., 2000).

## 3. *P. infestans* Life Cycle and Stage of Infection

*P. infestans* considers as hemibiotrophic pathogen, and this means the pathogen has biotrophic and necrotrophic features (Zuluaga et al., 2016). In biotrophs the fungus shows higher specificity to the host, also, healthy plants are required, and the fungus produces haustoria for absorption of nutrients (Lee & Rose, 2010). While, nectrotrophs cause necrosis tissue in the plants which led to killing its host (Arévalo-Marín et al., 2021). *P. infestans* can infect different parts of the host, including tubers, leaves, and stems of potatoes, tomatoes, and other plants of the solanaceae family (Becktell et al., 2006; Hardham et al., 2007).

Through the asexual cycle of *P. infestans* the seedlings emerge infected by the fungus conceders the beginning of the life cycle, exist of high humidity or free water led to the release of the sporangiophores (through the openings stomata) from the fungus Mycelium which exists inside of the plant (Fry, 2008; Johnson, 2010). Sporangia will appear on the sporangiophores tip which contains zoospores (3-8 zoospores), depending on the environment condition up to temperature 12-15°C the zoospores release from the sporangia and make infection, while in temperatures 20-25 C the sporangia infect the plant directly during penetration the host by released germ tubes (Stanghellini & Tomlinson, 1987; Sujkowski, 1987).

Zoospores swarm for a few times about 60 min. before encysting, the Zoospores Encysted led to direct germination by producing germ tube which infects host tissue (stem or leaf) after two days appear visible symptoms as necrosis areas, in higher humidity or exist free water each lesion will contain about 300 000 sporangia which spread and make another infections (VanderMolen, 1971; Fry, 2008). Asexual stage of *P. infestans* may survive from season to another season like mycelium in resting mode inside the tubers of potato.

While, the sexual stage of *P. infestans* led to heterotallic pathogen, which means required compatible two mating types (A1and A2) (Retes-Manjarrez et al., 2022). Result of the sexual stage formed of Oospores during the oogamy when each mating type is able to form antheridium (male structure) and oogonium (female structure) (Drenth, Janssen & Govers, (1995). Meet both mating types led to the production of the sexual structures, a female hypha when grows through to the male structure (antheridium), the oogonium forming above the antheridium, the fertilization takes place and led to producing fertilized oogonium which develops to oospore with a thick-walled (Cohen et al., 1997). Germ tubes produce from the Oospores which form sporangia, and contain the zoospores which can infect the host tissue in the same method as in the asexual stage (Erwin & McCormick, 1971). Oospores have a hard structure, and can survive in hard environments for a long time in the soil, at low temperatures may survive three to four years (Agrios, 2005).

## 4. *P. infestans* Mating Style

*Phytophthora infestans* have three modes of reproduction (sexual, asexual, and parasexual), and also can be divided into A1 and A2 mating types, due to their capacity for mating and oospore production, isolates frequently develop in cultures close to one another (Tzelepis et al., 2020). Because importation of infected potatoes from Mexico (in 1976) led to a change A1 mating type (the old known genotype, US-1 genotype) by more genotypic variability also co-occurrence the both A1 and A2 mating types (Goodwin & Drenth, 1997).

In Colombia and Antioquia through the period 1994-2000 used the A1 pairing type as the standard isolate for *P infestans*, because none of the isolates produced oospores, it was determined that all isolates belonged to the mating type A1(Ramelli et al., 2009). The pairing test was conducted to determine the pairing pattern in several regions of the world. In northern Nicaragua, it was found that all the communities of *P. infestans* belonged to the mate-pair type A2 (Blandón-Díaz, 2011). A2 isolates were those that produced oospores with isolates that had the A1 mating phenotype in the primary potato-producing areas of France, regarding the isolates that produced oocytes in conjunction with the isolate, the isolates with the A2 and A1 mating patterns (Montarry et al., 2010). The isolates encompassing the majority of India between the years 1997 and 2006, for A1 mating patterns and A2 mating patterns were detected, with 30% mating pattern A1 and 40% mating pattern A2 (Chimote et al., 2010).

## 5. Genotypes of *P. infestans*

The DNA fingerprint test was used to find out the repetitive sequence of nitrogenous bases in the chromosomes of the strains of *P. infestans*, and to compare it with other strains (Shimelash & Dessie, 2020). Several genotypes of *P. infestans* appeared such as could be divided into four distinct clonal lineages include, KR-1-A1, KR-2-A2, and US-11. KR-1-A1 and SIB-1 (Choi et al., 2020). First characterized in the 1970s by the genotype US-1 (genotypes of *P. infestans*) in Wisconsin (Gevens & Seidl, 2013). At the beginning of the eighties, both BR-1 and US-1 genotype was

found in Brazil, where isolates of the BR-1 genotype were considered to A2 mating pattern and associated with the potato plants (Maziero et al., 2009; Gevens & Seidl, 2013). While, US -1 genotype isolates consider to A1 mating pattern and associated with tomato crops (Reis et al., 2002; Reis et al., 2003).

In the 1990s, US-8 as a new genotype was detected in Canada, with mating type A2 which has higher aggression toward potatoes (Goodwin et al., 1996). The infection in late blight increased in Canada in 2009 and at the same time several genotypes as new appearances such as US-24, US-23, US-22, and US-11, including A1 and A2 mating types (Kalischuk et al., 2012; Gagnon et al., 2016). *P. infestans* have different levels of resistance or are sensitive to fungicide, depending on the genotypes (Cohen et al., 2021).

## 6. Virulence and Aggressiveness of the Disease

First, we must be differential between both terms, virulence term means a compatible reaction and this means the ability of the pathogen to make the infection to the host, whereas aggressiveness means differences in the quantity of disease caused by pathogen strains on the host (Pariaud et al., 2009). *P. infestans* have different systems of reproduction including asexual and sexual (Yuen & Andersson, 2013), also have a high level of genotype migration, and are most likely to overcome significant resistance genes (Guo et al., 2010). In the 1980s small-scale for tests, of virulence were made by a combination of five different laboratories in European, depending on three common isolates of *P. infestans* , but there are report were so brief and don't contain protocols as a guideline for use (Scho ̈ber, 1990). *P. infestans* of virulence testis started immediately after R-genes from *Solanum demissum* were introduction, However, the differences in R-gene expression, the susceptibility of the phenotypic to both physiological and environmental conditions, and the variety of experimental techniques make comparing data from different research difficult (Andrivon et al., 2011).

The term aggressiveness refers to epidemic parameters (Pariaud et al., 2009), which is able to be measured in several different ways, such as whole plants, tubers, field trials, and climate chambers (Cooke et al., 2006). It prefers to use different cultivars when aggressiveness tests were performed and may be adapted to certain cultivars prevalent in the production area under studied (Young et al., 2018). Aggressiveness of *P. infestans* isolates with new genotypes responsible to changes of the population, because the mechanisms of the genotypes processing not understood and this led to difficult in control of the disease (Njoroge et al., 2019). The aggressiveness studies for the isolates of *P. infestans* have been difficult due to the difficulties of standardizing experimental conditions, which can lead to significant variations in results among laboratories, also the important reasons included present R-genes in the cultivars, and challenges the explanation of aggressiveness research because data on their incidence is frequently insufficient (Lehtinen et al., 2009).

## 7. Some of the Methods for Management of the Disease

Several methods were used alone or as a combination for the management of late blight on potatoes, there included, fungicide, biocontrol, resistance cultivars, crop rotation, resistance breeding, resistance cultivars, and others, such as forecast systems which help in taking precautions. In this paper, we will focus on some of these methods.

Usually, the fungicide application before the plant infection for the protective effect, because, it has become useless when fungus establish in the tissue. Bordeaux mixture considers the first chemical application (in 1885) against the fungal disease, was used to treat late blight on potatoes and tomato worldwide. After that, several fungicides were used such as Metalaxyl, which was so effective against in control of late blight disease but after 3 years were appeared resistance isolates (Gisi & Cohen, 1996). There are several fungicides that become useless because release the resistance isolates (Namanda et al., 2004). Many researchers used the biocontrol and recorded high effects against *P. infestans,* included of fungi (Oubaha, Ezzanad & Bolívar-Anillo, 2021), bacteria (De Vrieze et al., 2019), actinomycetes (Bermejo et al., 2020), and plant extract (Stephan et al., 2005). Application of the biocontrol agent required deep studies, the bio-agent may have a good effect against the target pathogens but also, may have a side effect on non-target organisms, leading to a high risk to the biodiversity and the soil processes (Lagerlöf et al., 2015).

Resistance cultivars consider the eco-friendly and important method in management of the late blight disease. The first use of the resistant genotypes was in India, when made field germplasm screening, such as cv. Kufri Jyoti which have R-genes that arise from *S. demissum,* but these varieties become sensitive to the late bright and infected because of the development of the pathogen's virulence. Kufri Shailja, Kufri Himalini, Kufri Giriraj, and Kufri Jyoti as examples of varieties used in India which have different abilities in resistance to late bright (Joseph et al., 2007). When the same varieties grow every year in the same area may lead to the development of new isolates have more aggressive which breakdown of varieties' resistance, These plants cannot be available for every disease also currently there are no suitable resistant variants available (Ghorbani, 2007). The use of resistant cultivars is the most viable management strategy among the several methods of control, but the absence of acceptable seed materials for resistant cultivars pushes farmers to cultivate susceptible cultivars with correct fungicide scheduling (Mhatre et al., 2021).

## 8. Conclusion

*P. infestans* isolates have several infection structures that can infect different parts of the potato plant and can survive for a long period. Fungus are able to reproduction as sexually and asexually, and also have A1 and A2 mating patterns and different genotypes. All these features led to appear several challenges in the study of virulence also aggressiveness. The second and most important challenge includes, how can we choose the best method to control the disease (late blight), because appear isolates can resist different fungicides, also appear isolates can infect the resistant plants, and many reasons make this challenge more important.

**Competing Interests**

The authors have declared that no competing interests exist.

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