

## Review Article

# Late blight of potato and its management through the application of different fungicides and organic amendments: a review

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## ABSTRACT

Late the blight of potato is a devastating and one of the economic diseases of potato and other plants belonging to family Solanaceae. Late blight, caused by *Phytophthora infestans*, is one of the most threatening pathogenic diseases which not only results in direct crop losses but also cause farmers to embrace huge monetary expenses for disease control and preventive measure. It was first reported during the Irish Potato Famine, leading to massive starvation in Ireland and other parts of Europe during the middle of 19<sup>th</sup> century. *Phytophthora* harms the foliar portion in the field and also the tuber in the storage that can result in complete crop failure in potato. The pathogen has distinct survival mechanisms and two life cycles infection processes. The development of a sexual spore known as oospore includes two types of pairs, A1 and A2. The spores are introduced to good plants by wind and rain. Different methods for prevention of crops from late blight has been developed and used worldwide. An integrated disease management strategy includes successful control of this disease. Cultural control, chemical management, and advanced disease management are the most effective interventions. Integration of late blight control in tropical regions with abundant fungal inoculants in most months of the year was also seen as one of the best choices in disease management. This paper reviews the significance of late blight of potato and controlling strategies adopted for minimizing yield losses incurred by this disease by the application of synthetic fungicides and different organic amendments.

**Keywords:** Potato, late blight, yield loss, fungicides, organic amendment

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## INTRODUCTION

Potato is one of Nepal's leading crops, ranking fourth in production and harvest following rice, maize, and wheat (ABPSD, 2015). Potato is cultivated in a wide variety of climates from subtropical to temperate Himalayan regions in Nepal (Bajracharya & Sapkota, 2017). Potato, a staple food for lots of households, is consumed as the main crop in Nepal's plains (Terai and the inner Terai). In contrast with neighboring countries, potato productivity is poor (13 mt/ha) relative to China (17 mt/ha) and India (20 mt/ha) (FAO, 2016). The low potato productivity in Nepal is due to many reasons, including poor seed tuber quality, agricultural inputs, and pest control. It is cultivated in a 195,173-hectare area with a production of 2,881,829 tons and productivity of 14,765 kg/ha (MOALD, 2017/18). *Phytophthora infestans* (Mont.) de Bary is one of major disease of potato in Nepal causing a significant yield loss. In hilly and plain areas of Nepal, yield losses from late blight infestations in potatoes grew to up to 75% and 90% respectively (Shrestha, 2000). In mid-hill regions, yield losses in two-season potatoes are much greater. The annual loss of tuber due to late blight has been estimated at around 15 percent, representing around US\$ 100 million in the fiscal year 2009/10 (Sharma *et al.*, 2011).

Potato is a major staple crop and source of income for smallholder farmers in high mountain regions of Nepal (NPRP 2014; Timilsina *et al.*, 2011). The high-altitude seed potato is a traditionally valuable supplier of seeds to farmers in the lower hills and lowlands since they are free of diseases. (Rhoades, 1985). Over one billion people consume potato worldwide, and it is the staple diet of half a billion people. Because of the dry matter, edible energy, and edible protein content, Potato is considered nutritionally a superior vegetable as well as a versatile food item not only in Nepal but also throughout the world (CIP, 2009).

The epidemics of late blight are introduced in the fields, both internal and external, from primary inoculum sources (Mizubuti & Forbes, 2002). Internal reservoirs of inoculum include infected seed tuber, infected volunteer plants, and field culling piles that play important roles in temperate regions in late blight epidemics (Powelson *et al.* 2002). External reservoirs of inoculum include contaminated potato debris that has led to disease epidemics in tropical and subtropical regions since previous years (Lima *et al.*, 2009). Since *P. infestans* also infect tomatoes, the extension of tomato growing areas and year-round subtropical growth also leads to late blight epidemics in Nepal. Growers control the fungus with the planting of resilient crops and spraying fungicides (Forbes *et al.*, 2007). But the sustainability of resistant crops is adversely affected by new breeds. Fungicides are required to reduce the disease epidemics in Nepal (Sharma *et al.*, 2013)

Potato varieties grown in Nepal have low levels of general resistance to late blight. Mostly the commercial potato farmers rely on fungicide applications for control of *Phytophthora infestans*, the causal agent of late blight (Neupane *et al.*, 2018). The late blight directly affect the yield attributing characters like vine mass and tuber yield (Pandit *et al.*, 2020). In Nepal, the potato growers use Mancozeb (dithiocarbamate) and metalaxyl as two common fungicides. Fungicides are typically used by farmers at higher frequencies and quantities than indicated (Sharma & KC, 2004). For example, the farmers of Kathmandu valley apply fungicides to suppress late blight 10–15 times during the season, depending on the circumstances and varieties of the weather (Sharma *et al.*, 2011). The overuse of chemical fungicides not only raises processing prices but has also implications for the climate and public health. Several late blight resistant potato varieties for Nepal's Hills and Plains have been released by the Nepal Agricultural Research Council (NARC). But, as shown in the past, these varieties have evolved in new breeds (Shrestha *et al.*, 1998). Furthermore, producers, researchers, and agricultural extension workers have reported a decline in the effectiveness of widely used fungicides. The

studies in these fields indicate that the possibility has been documented in several other potato-producing countries for fungicide resilient strains in Nepal (Matson *et al.*, 2015). To make appropriate and accurate recommendations for late blight control, this necessitates a periodic review of alternative fungicides.

The potato plant is attacked by many pathogens causing significant losses to potato producers throughout the world. Bacteria, fungi, viruses, nematodes, and phytoplasmas cause serious production constraints. (Kromann *et al.*, 2014). Of the fungal diseases, late blight, caused by *Phytophthora infestans*, stands out from the rest. It is the most widespread throughout the world and causes serious tuber losses globally (Erwin & Ribeiro, 1996; Fry & Goodwin, 1997; Garrett *et al.*, 2001). Worldwide losses due to late blight are estimated to exceed \$5 billion annually and thus the pathogen is regarded as a threat to global food security (Latijnhouwers *et al.*, 2004). This disease is the nightmare of potato producers especially in the coastal wet regions (Fry *et al.*, 2015) and (Runnopaurson *et al.*, 2016). Late blight caused by *Phytophthora infestans* (Mont) de Berry is the major destructive and the most serious fungal disease of potato and affects its leaves, stems, and tubers (Bekele & Hailu, 2001). The late blight develops most rapidly at low temperatures and high humidity (Fry *et al.*, 1998). The pathogen produces water-soaked lesions with chlorotic borders that are small at first expand rapidly under humid conditions, blighting the entire plant in only a few days with subsequent rotting of the developing tubers resulting in heavy yield losses under favorable (Sundaresha *et al.*, 2015).

The average global crop losses of all diseases combined were approximately 12.8% of the potential production but potato alone was subjected to a 21.8% loss (James, 1981). Past studies have revealed that the occurrence of metalaxyl resistance in *P. infestans* populations is associated with severe late blight epidemics, genetic diversity, and pathogen resurgence (Davidse *et al.*, 1981; Goodwin *et al.*, 1992). Due to the current and intensive use of metalaxyl in combination with other fungicides, it is crucial to monitor the pathogen isolates sensitivity to identify the build-up of fungicide resistance and thereby modify fungicide usage strategies. And though, during the rainy season the disease issue is severe, its management studies are not adequate.

**Table 1: Crop losses in due to late blight disease**

Crop loss percent (%)	Country	References
20	Nepal	(Sharma and KC, 2004).
10-75	West Bengal- India	(Dutt, 1979)
50-70	Pakistan	(Lal <i>et al.</i> , 2018)
70	United State of America	(Teng & Bissonnette, 1985)
50	Nigeria	( <i>Phytophthora infestans</i> (Phytophthora Blight), n.d.)
72	Ethiopia	(Selvaraj, 2013)
75	England and Wales	(Large, 1958)
80	Kenya	(Nyankanga <i>et al.</i> , 2004)
50	New York	(Tomato-Potato Late Blight in the Home Garden, n.d.)

### Pathogen of late blight

The late blight pathogen emerged from Central Mexico (Zimnoch-Guzowska *et al.*, 2003). The genus, *Phytophthora*, refers to oomycetes that are not associated with true fungi. This disease, notable for triggering the historical Irish famine in the mid 19<sup>th</sup> century, poses a significant restriction on the production of potatoes in various parts of the world (Fry and Goodwin, 1997;

Elansky *et al.*, 2001). It targets plants, primarily under cool and gloomy conditions and rainy conditions, resulting in 100 percent yield loss in serious attacks on vulnerable species. With effective administration but without spraying on fungicides, yield losses for moderately resistant species may be between 40 and 50% and for most susceptible species between 50 and 70% (Ojiambo *et al.*, 2001; Rahman *et al.*, 2008). It influences field potato foliage and storing tuber, which contributes to yield losses of up to 100% (Tsedaley, 2014). It is the world's major potato disease (Sharma *et al.*, 2013) and is the most well-known, well-researched, and most damaging of all potato diseases (Jones, 1998). Therefore, possible significant disease can cause substantial economic losses for potatoes and tomatoes (Yoshida & Sakai, 1973). Losses attributable to *P. infestans* were estimated at €12 milliards per year, with annual losses estimated at around € 10 billion in developed countries (Haverkort *et al.*, 2009). The pathogen's potential to inflict tremendous loss of returns considers it to be a possible danger to world food protection (Latijnhouwers *et al.*, 2004). The disease also poses a threat to food safety, human health, and the environment, as well as economic losses (Kromann *et al.*, 2009), since it needs multiple fungicide applications in the field (Haverkort *et al.*, 2009). The potato blight, according to (Ghimire *et al.*, 2003), first occurred in Nepal in the mid-1990s between 1883 and 1897. In the summer and the winter in the Katmandu valley, (Shrestha, 1976) reported extreme loss caused by the late blight disease on potatoes. In 1996 there was a late blight national crop failure in Nepal (Dhital and Ghimire, 1996). Host tolerance is an important aspect of integrated control of the disease owing to long-lasting economic advantages for farmers. It also decreases improvements in pathogen population structure, reducing the risk of tolerance to fungicides (Hakiza 1999; Mukalazi *et al.*, 2001). The breeding of the *P. infestans* began in the 19th century and the use of biotechnology tools for their tolerance was slower. Several researchers have shown differences in late blight tolerance between various types of potatoes (Njulaem *et al.*, 2001). Late blight of potato caused by *P. infestans* has received considerable the attention of plant pathologists in the current century since its role in the Irish starvation in 1845s which ended with a million deaths and migration of the Irish people out of Ireland (Nowicki *et al.*, 2012). Since then, late blight epidemics have been frequently observed in Europe (Hannukkala *et al.*, 2007), America (Fry & Goodwin, 1997), Asia (Chunwongse *et al.*, 2002), Africa (McLeod *et al.*, 2001), and many other regions. The pathogen parasitizes diverse hosts in family Solanaceae; however, potato and tomatoes are drastically affected (Flier *et al.*, 2003; Majeed *et al.*, 2017). Typically, late blight symptoms on foliage and stems as green-brown or yellow spots which becomes necrotic regions as the growth of pathogen occurs may appear a few hours after infection with *P. infestans* which generally depend on the environmental conditions and host susceptibility (Fry, 2008; Majeed *et al.*, 2017). Accelerated by the cool temperature and moisture availability, *P. infestans* rapidly propagate its mycelia producing thousands of lemon-shaped sporangia on sporangiophores which serve as dispersal means and asexual infection agents aerially (Nowicki *et al.*, 2012). Sporangia are carried from the infected plants to healthy plant by water and air and when settling on plants leaves and stem, they either directly germinate by germ-tube under temperature the range between 20 and 25°C or indirectly by the release of many zoospores when the temperature is low i.e., range between 10 and 15°C (Fry, 2008). Lesions and disease symptoms appear at this stage and may take 2-3 days for the first necrotic lesion is visible (Fry, 2008). The asexual life cycle may repeat several times a week if environmental conditions allow them to do so (Nowicki *et al.*, 2012). Sporangial survival for next infection is restricted to host tissues and little is known whether they can remain viable in the soil or other dead

matter. However, it is well established that during the growing season when host plants are available, the asexual life cycle of *P. infestans* predominates causing several disease cycles (Drenth *et al.*, 1995). *P. infestation* sex habits heterothallism with two compatible mating types, A1 and A2 and for sexual reproduction, the presence of both mating types are required (Ristaino, 2002; Yuen & Andersson, 2013). Sexual reproduction may proceed both under natural conditions when two opposite thali comes in contacts as well as in artificial inoculation by growing mixtures of both mating types and the result is the formation of oospores (Drenth *et al.*, 1995). However, for sexual reproduction and production of a substantial number of oospores, larger proportions of both mating types should be present nearby (Yuen & Andersson, 2013). Oospores have thick walls and are larger than sporangia with the potential capacity for survival in the soil for long periods unlike sporangia which remain viable only on host tissues (Nowicki *et al.*, 2012). Thus, oospores are a potential source of infection for next season plants as well as a source of genetic variation and development of traits necessary for coping with environmental changes, host resistance and fungicides resistance (Widmark *et al.*, 2011). Oospores germinate to form sporangiophores which bear sporangia that may switch to asexual cycle by releasing zoospores, although germination of oospores is influenced by several environmental factors.

#### **Development, epidemiology and life cycle of late blight**

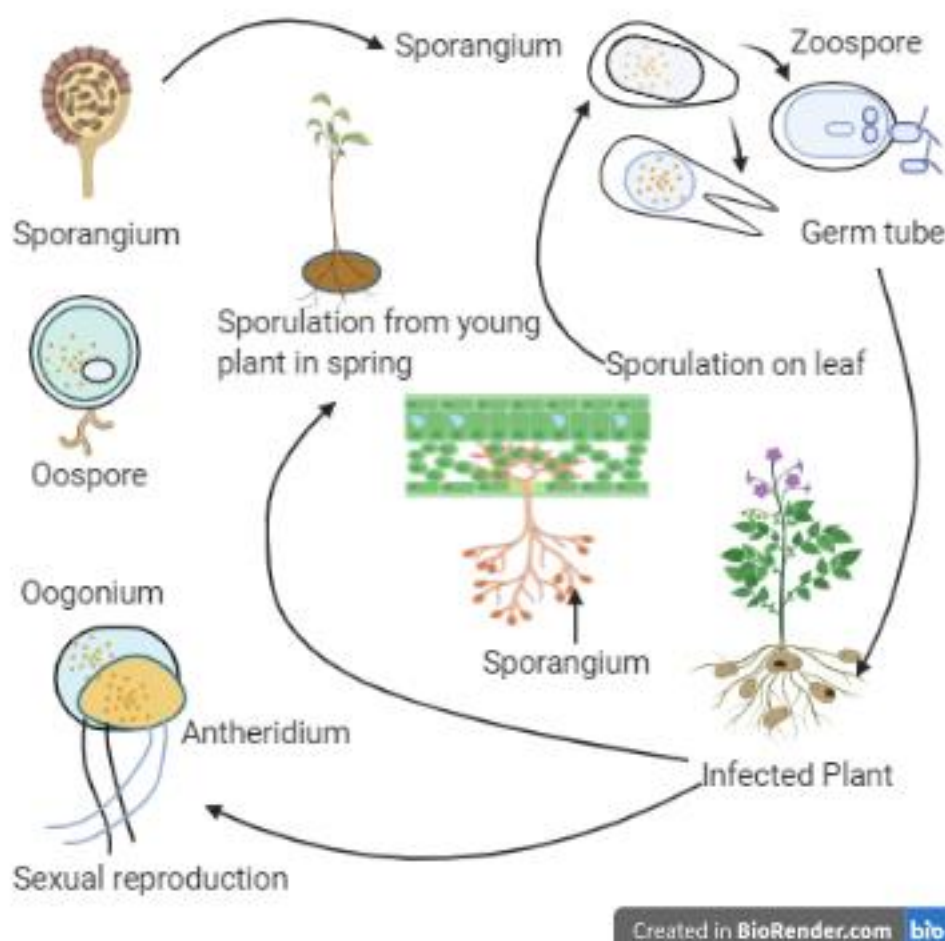
Sporangia germinate with a specific germ tube at temperatures of 13-21°C. Days of 16-13°C with high relative humidity and night-time temperatures followed by light rain, fog, or thick dew, are the optimal conditions for infection and growth of late blight (Kirk 2009; Kirk *et al.* 2013). Temperatures above 30°C delay or stop the fungal growth in the field but do not kill it, and when it gets healthy, the fungus can sporulate again, providing that the relative moisture (near to 100%) is, of course, high enough (Agrios, 2005). The first signs of late blight are small green light-to-dark and odd, water-soaked lesions in the area (Kirk *et al.*, 2013). These usually occur first on the lower leaves where the microclimate has high humidity (Martin *et al.*, 1994). However, they may occur in the upper leaves where weather is conducive and air currents have brought the pathogen into the field (Martin *et al.*, 1994; Kirk *et al.*, 2013). The lesions develop easily in rainy weather and form brown, black areas with infinite boundaries. At the edge of the lesions on the undersides of the leaves is a region of bright, low-yellow, mildew development 3-5 mm width. Both leaves are soon sick, die, and limp (Agrios, 2005). For spore, production conditions shall be kept moist for at least 7-10 hours (Martin *et al.*, 1994). Spores or lesions are more noticeable during wet nights or rainy seasons due to the relationship the edge of the lesion, mostly on the bottom of the leaf, the fungus may be a white, mildew like development. This white growth separates late mildew from many other potato foliar diseases. The spores are transferred to healthy plants by wind and rain where the disease cycle continues. The growth of late blight epidemics depends heavily on the humidity and temperature in the various phases of the fungal life cycle In one season, the fungus can complete several reproductive cycles, taking into consideration the fast increase of the disease after it is found in a field. Under constant conditions, all the tender sections of the plants are damp and grow blight and red, resulting in a common odor. In the span of a few days or even weeks, whole potatoes and plants can be blighted and die. The pathogens' operation is delayed or halted in dry air. Established lesions avoid expanding, turn purple, curl, and wither, and there is no oomycete on the bottom of the leaf. The oomycete returns to moisture and the disease progresses again quickly When the air is damp (Agrios, 2005). Whenever sporangia and tuber

diseases come into contact, tubers may be affected by *P. infestans* from the early stages of tuberisation to storage. Infections occur most frequently as sporangia are washed from injuries to stem and leaves to the surface and then to the tubers via the soil infections arise during the growth or mature stage of the tubers, but the interaction between the tubers and sporangia is more common when the tubers are swollen tubers are most often associated with cold and wet soils (near field capacities) and soil temperatures above 18 ° C tend to eradicate infections. Since sporangia can live in the soil for days or weeks, tubers can get infected for a while after foliage infections are no longer sporadic (Fry 1998). When split open, the tubers in tissue look water-soaked, dark, and somewhat reddish-brown when it is sliced off and stretches 5-15 mm over the pulp. The tubers are at first more or less odd, pure-blue, or brownish-blacks. The affected areas would later become solid and dry and somewhat reduced. Such lesions may be tiny or virtually the whole tuber surface without further spread into the tuber. But after tuber harvesting, rot tends to grow subsequently, sporangiophores or pathogen spores may cover infected tubers or secondary fungal and bacterial infections, causing soft rots and causing disgusting, aggressive, or rotting fume of potatoes (Agrios, 2005). The amount of tubers rotting depends on the culture sensitivity, temperature, and period of the cultivar post-infection (Martin *et al.*, 1994; Kirk *et al.*, 2013).

In living tissues including seed tubers, cull piles, and voluntary potatoes which are spent over the winter in fields (Shinners *et al.*, 2003), other solanaceous and soil, *Phytophthora infestans* can thrive on live host tissue (Kirk *et al.*, 2013). It normally persists every year in tubers that are processed, in piles of cull pumps, or in tubers that are absent during winter harvest (volunteer pumpkin) that are unfrozen. The pathogen may be spread by airborne spores to the potato leaf in the skin from the contaminated tubers in cull piles or by volunteers. Important reservoirs of the disease are also contaminated seed-potatoes. Any of the tubers infected will rot in the ground.

Late blight won't occur until maturity, although not all plants from an infected tuber. *P. infestans* sporangia can spread by wind, splashing rain, mechanical transportation, and animals from infected plants on one field by healthy plants in the ecosystem (Martin *et al.* 1994; Kirk 2009; Kirk *et al.* 2013). Just a few days after the infection the stomata of the leaves are used to form new sporangiospores which cause many of them to spread through the wind and infect new plants. The duration from infection to sporangia formation in favorable weather maybe 4 days; therefore, in the same growing seasons, there can be a large number of asexual generations and new infections. The sporangia, when they are able, are detached and carried away by wind and rain, and germinate and cause infections when landing on damp potato leaves or stems (Agrios, 2005). *P. infestans* sporangia germinate actively or indirectly by releasing the zoospores, either through a germ channel. Germ tubes also can shape secondary sporangia that can enhance the spore's survival (Harrison, 1992). When free water is present on floors and 8-12 motile zoospores per sporangium, sporangia can germinate at temperatures between 7 and 13 ° they are free to swim in water attaché to the leaf and infect the vine. Encyst-borne zoospores infect leaves, by stomata or direct penetration through penetration of the leaf surface with sprouts (Kirk 2009; Kirk *et al.*, 2013). The germ tube is penetrating straight into or touching, stomata, and the mycelium expands abundantly throughout the cells. Older infected cells die as the mycelium expands into fresh tissue. In all cases, as the disease progresses, new legible lesions emerge and sometimes destroy the leaf and reduce the yields of potato tuber

(Agrios, 2005).



**Figure 1: Late blight cycle of potato (Tsedaley, 2014)**

In rainy conditions, when Sporangia has washed off the leaves and transferred into the soil, the second stage of the disease begins. The new zoospores germinate from lenticels or wounds and enter the tubers. In the tuber, the mycelium often develops between the cells and transmits haustorium in the cells. Tubers polluted in the soil or on diseased leaves can also become infected with living sporangia during processing. The majority of blighted tubers however rot in the soil or the storage. The fungus more commonly develops and sporulates at relative humidity close to 100 percent at 15-25 °C (Agrios, 2005).

### **Control methods for late blight**

#### ***Chemical control by applying Fungicides***

Without fungicides application, control of late blight of potato does not seem achievable. Thus fungicides application is an active component of integrated disease control. Chemical controls should be used with caution and under extreme attack only-successful and suggested use was found for items such as Ridomil Gold, Dithane M-45, Filthane M- 45, Stable, Melody Duo (Nyankanga *et al.*, 2004; Rasheed & Khan, 2008; Rahman *et al.*, 2008). Knowledge about the biology of the pathogen, prevailing environmental conditions in potato growing areas, degree of susceptibility of potato cultivars to late blight and mode of action of fungicides can help

farmers to select proper chemicals and to apply them at a suitable time at suitable dosages. Several chemicals are developed to manage various plant diseases by preventing or destroying pathogens causing the disease and their knowledge is important in reducing losses in production (Tiwari *et al.*, 2020). Fungicide security is temporary since it is weathered and broken up over time (Gupta *et al.*, 2018). If applied on schedule, fungicides will sluggish or avoid new symptoms, but the late blight symptoms are no longer healed (Mathews, 2015). Cooke *et al.*, (2011) argued that fungicides could effectively be employed as the active component of integrated disease management if their nature, modes of activity, and their relative influence on foliage, stem, and tuber infection caused by *P. infestans* could be taken into account. Evenhuis *et al.*, (2016) described that standard application rate even lower frequencies of fungicides might be helpful in reducing disease damage if other cultural control measures are addressed. Since the emergence of new strains of *P. infestans* which exhibit fungicides resistance, selection of suitable fungicides, and timing of fungicide spray has become even more crucial for effective control of late blight. In regions where the population of *P. infestans* comprises fungicides resistant isolates, application of more than one type of fungicides and changes in spray, the schedule seems a promising approach along with utilizing integrated control measures such as the cultivation of resistant cultivars of potato.

Late blight of potato is effectively controlled by applying chemical fungicides at suitable rates and intervals depending on the climatic conditions and disease severity (Majeed *et al.*, 2014). Effectively of fungicides in the management of late blight depends on the proper use and time of application. After the great Irish potato famine caused by *P. infestans*, the first effective fungicide used for diminishing late blight atrocities was the Bordeaux mixture, a copper sulfate chemical which has several environmental implications (Haverkort *et al.*, 2008). Progress in synthetic chemistry in the last few decades has resulted in the formulation of advanced chemicals that are relatively less hazardous than has now enabled manufacturers to Bordeaux mixture; however, their excessive use also poses ecological, environmental, and financial problems. The most commonly used fungicides for controlling late blight are cymoxanil + mancozeb, cymoxanil + famoxadone, and fluazinam under different trade names (Hannukkala *et al.*, 2007). The first spray with a Ridomil MZ pace of 63,5% wp with a rate of 2 kg/ha was found to be successful in controlling late blight (Ethiopia Late Blight Profile, 2004), following 2-3 sprays for the required base application of the Dithane M45 with a rate of 3 kg/ha. Every year, substantial quantities of different fungicides and pesticides are used in agriculture for controlling plant pathogens and pests of which more than 30% accounts for late blight fungicides (Naerstad *et al.*, 2007). Though, fungicides application is an effective measure to check late blight at the earliest; however, public health, environmental problems and financial costs associated with it is a major agricultural issue (Majeed *et al.*, 2014; Majeed *et al.*, 2017). Late blight fungicides along with other pesticides are potent sources for the poisoning of farmers, children, and other non-target animals and are one of the leading sources of air, soil, and water pollution. Monetary costs due to late blight fungicides are considered as more than 3 billion dollars per year globally (Haverkort *et al.*, 2008). Moreover, due to several migration events of *P. infestans* and sexual reproduction, new genotypes of the pathogen with more aggressiveness and potentials to overcome fungicides efficacy have been frequently appearing which has further complicated late blight control (Majeed *et al.*, 2014). Although it seems nonfeasible to completely relinquish fungicides application, its use, however, may be significantly reduced by adopting integrated strategies.



**Table 2: Rates of fungicides used to control late blight of potato**

Fungicides	Chemical name	doses	Citation
Mancozeb	Diethane M-45 75% Wp	1.5 kg/ha	(Mekonen & Tadesse, 2018)
Metalaxyl	Ridomil 25% WP	2.5 kg/ha	(Hannukkala <i>et al.</i> , 2007)
Chlorothalonil	Bravo	500,40.4F	(Hannukkala <i>et al.</i> ,2007)
Curzate	Cymoxanil 60% DF	2 kg/ha	(Hardy <i>et al.</i> , 1995)
Oxathiapiprolin	Zorvec	0.15L/ha	(Bekele <i>et al.</i> , 1996)
Bacticide	Copper Hydroxide)	2.5 kg/ ha	(Mekonen & Tadesse, 2018)
Matco	Metalaxyl8%+Mancozeb-64%)	2 kg/ha	(Mekonen & Tadesse, 2018)
Boss 72% WP	Metalaxyl+Mancozeb	2 kg/ha	(Mekonen & Tadesse, 2018)

### ***Cultural control***

The first line of defense against late blight is cultural practice (Arora *et al.*, 2014). The survival of *P. infestans* can be reduced to initiate outbreak by preventing the entry into the field of late blight only by planting disease-free seed tubers, ideally approved seed, killing both culls and potatoes, preventing daily or evening overhead irrigation, and ensuring good coverage (Goutam *et al.*, 2018). Late blight is managed using the appropriate harvesting, storage, and application of fungicides as needed by removing culling piles and volunteer potatoes. The cultural interventions included: the use of disease-free / healthy seed, reduction of voluntary potato plants, soil hilling, and plant nutrient control (Olanya *et al.*, 2009). The pathogenic infestations of farm crops can dramatically be reduced by cultural activities such as field sanitation, weeding, cropping, inter-cropping. (Tripathi *et al.*, 2020)

### ***Integrated late blight management***

Many ways may be used to incorporate adaptive management systems for foliar pathogens of plants. Examples of using host tolerance to reduce or decrease fungicide dependencies include transitioning from vulnerable to moderately resistant maize leaf (*Exserohilum turicum*) to northern maize leaf blight management varieties (*Drechsleratritici repentis*) (Jones *et al.*, 1998; Debela *et al.*, 2017). The successful late blight management technique of *Phytophthora infestans* has shown a decrease in inputs of fungicide on moderately tolerant potato cultivars relative to susceptible cultivars (Fry, 1978; Gans *et al.*, 1995; Naerstad *et al.*, 2007).

Resistant varieties also reduce the risk of fungicide tolerance to changes in *P. infestans* population structure (Tsedaley, 2014; Arora, 2014). Plant breeders are therefore working to produce disease-resistant cultivars to improve tolerance in genes of indigenous species that have been hit hard by non- native invasive plant pathogens (Shah *et al.*, 2020). One of the major compounds for late blight control and in particular in tropical conditions is the use of resistant varieties (Chowdappa, 2015; Pacilly *et al.*, 2016). Resistant varieties are recommended, despite being considered the key technique for the management of fungicides, since resistant varieties postpone onset or decrease their growth rate, meaning that fewer fungicide sprays may be required to achieve a sufficient degree of disease control (Agrios, 2005; Skelsey, 2010).

**Table 3 : Potato varieties and their resistance to late blight disease**

Potato varieties	Resistance categories	Countries	References
Accent	Tuber late blight, black leg, potato cyst nematode	U.K	AHDB, 2020
Sunita	Late blight on tuber and foliage, potato cyst	Netherland	AHDB, 2020
Violet queen	Late blight on tuber and foliage, potato mop top	Canada, france	AHDB, 2020
Gravity	Powdery scab, skin spot, Late blight on tuber and foliage,	Europe	AHDB, 2020
Volare	Late blight on tuber and foliage, potato cyst nematode	European country	AHDB, 2020
Accord	Late blight on tuber and foliage	England	AHDB, 2020
Adora	Late blight on tuber and foliage	Netherland	AHDB, 2020
Kurfi Sinduri	Late blight on tuber and foliage	India	NHB, 2013
Kurfi Jyoti	Late blight on tuber and foliage	India	NHB, 2013
Khumal Seto 1	Late blight on tuber and foliage	Nepal	Krishi diary, 2019
Janak Dev	Late blight on tuber and foliage	Nepal	Krishi diary, 2019
Gourmandine	Late blight on tuber and foliage	Europe, australia	AHDB, 2020
Juliette	Late blight on tuber and foliage, Common scab	France	AHDB, 2020
Manitou	Late blight on tuber and foliage, Potato virus, Dry rot	North africa	AHDB, 2020
Leonata	Late blight on tuber and foliage, bruising , splitting	Europe	AHDB, 2020
Tyson	Late blight on tuber and foliage, potato leafroll virus	Canada	AHDB, 2020
Desiree	Late blight on tuber and foliage	Netherland	NIVAA, 2007

### Use of organic amendments for late blight control

With an annual production of 325.3 million tonnes (FAO, 2010), potato comes ahead of other roots and tubers. These low yields are principally due to fungal disease; especially late blight caused by *Phytophthora infestans* (Mont.) de Bary (CIP, 1987; Fontem, 1995; Njuaem *et al.*, 2001). The use of synthetic fungicides and crop rotation are the recommended means for controlling late blight. Some decades ago, it was reported that the use of compost in crop production not only helps to improve the physicochemical properties and soil fertility but also to control some soil-borne diseases and increase crop yields (Adebayo *et al.*, 2001; Remade 2006; Yadessa *et al.*, 2010). The efficiency of compost in controlling diseases is attributed to its content in antagonistic microorganisms such as bacteria and actinomycetes (Yadessa *et al.*, 2010). These previous research works constitute the motivation of the present study. This study aimed to evaluate the use of organic amendments in association with a synthetic fungicide on the control of late blight.

### ***Sources and types of organic amendments***

The use of organic amendments to improve soil quality and fertility dates back to thousands of years ago. Greeks and Romans applied animal manure and human sewage to the soil. At that time they also knew that wheat took advantages if grown on fields previously cultivated with leguminous plants (Goss *et al.*, 2013). Different materials, such as sea-shells, vegetable waste, farmyard manure, and other waste products were already used to promote crop growth. Ideal use of mineral and organic manures improves the input of plants, crops, and the availability of water use (Pandey *et al.*, 2020). Balanced application of organic fertilizers improves fertilizer performance and increases the soil's physical, chemical, or biological environment, leading to an increase in crop yield (Shrestha *et al.*, 2020). Plant growth and development, therefore, depends fundamentally on fertilizer, compost, water level, i.e. biomass enhancement modifications, increased plant growth, and output. (K.C. *et al.*, 2020)

Nowadays the most common soil organic amendments are compost and animal manure, but also peat moss, wood chips, straw, sewage sludge, sawdust are used. The different materials can be grouped essentially into five categories (Goss *et al.*, 2013).

### ***Animal manure***

Manure is composed of feces, urine, and animal bedding stacked and turned until a certain level of composting. It derives from beef, dairy, pork, poultry, and turkey, and its composition depends on its origin, the time that urine and feces are excreted and mixed and the storage time before being applied to the soil. Manure supplies nutrients for crops but also organic matter thus improving soil fertility (Goss *et al.*, 2013). Indeed, the degradation processes occurring in the surface layers of the manure, under aerobic conditions, produce CO<sub>2</sub> and not easily degradable organic compounds; conversely, when anoxic conditions occur, mainly in the deeper layers of manure if it is not turned, small molecules of volatile organic acids and CH<sub>4</sub> gas form.

### ***Municipal biosolids***

Municipal sludge or biosolids are organic solids subjected to several treatments to stabilize organic matter to reduce unpleasant smell and not attract pests and spreading disease (Goss *et al.*, 2013). As containing nutrients and organic matter, biosolids can be applied to agricultural soils but under regulatory controls that set limits for heavy metals, weeds, human, and plant pathogens.

### ***Green manure and cover crops***

Green manure consists of incorporating into the soil specific forage or crop varieties while green or soon after flowering to improve soil physical and chemical fertility (Goss *et al.*, 2013). Cover crops can be useful in crop rotations also to fill in a short period of non-cultivation to protect soils, prepare the land for a perennial crop or provide animal feed. Cereal crops contribute with straw remained after harvest, whereas legumes, such as soybeans, cowpeas, clover, are frequently preferred as they are able to fix N from the atmosphere working with bacteria at the root level. As green manure legumes are useful to add N besides organic matter that soil gains when whole plants are buried. Even non-legumes plants, such as forage sorghum, millet, annual ryegrass, buckwheat, are used to provide biomass and suppress weeds. The main benefit of green manure and the cover crop is the addition of nutrients and organic matter to

the soil, but also an increase in microbial activity and water retention capability (Shrestha *et al.*, 2020). Independently of its incorporation into the soil, a cover crop is any crop grown to provide soil cover and to prevent erosion by wind and water (Sullivan, 2003). For example, in late summer or autumn, the planting covers the soil to protect it through winter. A summer cover crop will enhance the poor soils or prepare the soil for a perennial crop (Sullivan, 2003).

#### ***Waste from manufacturing processes***

Several organic by-products coming from manufacturing processes such as exhausted seeds, hoof and horn meal, animal feathers and fur, residues from sugar extraction, biochar, distillery waste, biosolids from the paper mill can be applied to soil (Goss *et al.*, 2013). In the latter case, only a small fraction is used for agronomic purposes because not enough information is available about lignin mineralization during composting (Tuomela *et al.*, 2000; Goss *et al.*, 2013).

#### ***Compost***

The decomposition of organic wastes leads to the formation of the most used soil amendment, the compost. The use of compost represents both an interesting agricultural practice and waste recycling management (Pérez-Piqueres *et al.*, 2006). Indeed, it allows reducing the costs of green/urban waste disposal, recycling nutrient elements for crops, and providing for soil organic matter depletion. Multiple benefits derive from the use of compost as fertilizer, for example, an increase in organic C content and microbial activity (Scotti *et al.*, 2015), a greater concentration of plant nutrients like N, P, K, and Mg, and a root reinforcement (Donn *et al.*, 2014). Balanced use of fertilizers increases soil fertility without environmental degradation in a sustainable way (Shrestha *et al.*, 2020). The improvement of soil porosity with a consequent increase of water available for plants (Scotti *et al.*, 2013), cation exchange capacity (CEC), and biological activities can also occur. An important feature of compost is the capability to influence soil microflora by suppressing many soilborne pathogens diseases such as *Pythium*, *Phytophthora*, *Fusarium spp.* (Szczzech & Smolińska, 2001; Borrero *et al.*, 2004). Animal husbandry and their manure have a conveniently reliable and vital role to play in Nepalese agriculture. In the last years, the use of commercial compost in agriculture has been replaced by on-farm compost. On-farm composting could be an efficient, cost-effective, and environmentally safe biological process for the recycling of residual agricultural biomasses (Pane *et al.*, 2015). In this way, the on-farm compost production could contribute to solve the problem of disposing of agricultural biomasses and vegetable feedstock and, at the same time, to provide for farmers a self-supply of quality compost for the improvement of soil quality.

#### **CONCLUSION**

The late scurge is a highly destructive disease in the potato crop with a yield loss of up to 90%. It is essential to know the potato genotypes with tolerance or vulnerability to late blight in the distribution of different cultivars in the right areas. Combined fungicide with a moderately tolerant form of potatoes is an important way of dealing with potato infection of late blight. Potato late blight disease development with a typical decrease in disease index and an enhancement in tuber yield may be reduced by the prescribed treatment pace for fungicides and timeliness. The fungicide analysis decreases contamination from potato-late blight in combination with a moderately resistant variety of potatoes and increases the yield of potato tuber. Late blight prevention was considered one of the best strategies for disease management

in tropical regions with ample fungal inoculants in more months of the year. The late blight is the most damaging of its production restrictions and can result in a complete loss of crops. The selection and execution of its successful management strategy, therefore, involves an understanding of its growth, epidemiology, and life cycle. There are various kinds of potato late blight management options that can help to mitigate the impact. However, owing to the recent emergence of pressure in the world, there is not one successful late potato management method. The most effective, environmentally friendly (both for humans and animals) and low-priced for consumers is thus the integrated disease management (IDM) approach.

### Authors' Contributions

I. Tiwari, K. K. Shah, S. Tripathi, B. Modi, S. Subedi and J. Shrestha wrote this review paper

### Conflicts of Interest

The authors declare that there is no conflict of interest.

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