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Late Blight of Potato Caused by *Phytophthora infestans* and its Integrated Management: A Review

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ABSTRACT

Potato (*Solanum tuberosum* L.), a crucial global food source, is significantly threatened by late blight, a disease caused by *Phytophthora infestans*. This historically devastating pathogen leads to severe crop losses and economic damage worldwide. Late blight manifests as water-soaked lesions on potato leaves, stems and tubers, resulting in extensive tissue damage and crop failure. The pathogen's ability to reproduce both asexually and sexually enhances its adaptability and persistence. Effective management of late blight requires a comprehensive approach, integrating cultural practices, chemical control, biological controls and genetic resistance. Key cultural methods include crop rotation, field sanitation and the use of disease-free seed potatoes. While chemical controls are useful, their effectiveness is challenged by the growing resistance to fungicides, particularly metalaxyl. Biological control offers a promising alternative, with several microorganisms showing effectiveness in combating *P. infestans*. Breeding efforts focus on developing resistant potato varieties, with biotechnology advancements like CRISPR/Cas9 providing new opportunities to enhance resistance. Recent advancements in epidemiological modeling, such as the JHULSACAST system, assist in predicting late blight outbreaks and optimizing management strategies. Sustainable management emphasizes reducing chemical fungicide use and promoting eco-friendly practices. Continued research and collaboration among scientists, farmers and policymakers are crucial for mitigating late blight's impact and ensuring the long-term sustainability of potato production.

Key words: Epidemiology, Management, Pathogen, *Phytophthora infestans,* Potato.

The potato (*Solanum tuberosum* L.), a member of the Solanaceae family, is a crucial global crop due to its nutritional content, economic significance and adaptability to diverse agricultural environments. It ranks as the fourth-largest food crop worldwide, following maize, wheat and rice and plays a significant role in food security by providing calories and essential nutrients. China leads global potato production, followed by Russia and India. In India, potato cultivation spans 2.32 million hectares, yielding 56.17 million tonnes. Uttar Pradesh ranks highest in production, with 19.17 million tonnes, followed by West Bengal, Bihar, Gujarat and Madhya Pradesh (Ram *et al.,* 2024). Potatoes are high in carbohydrates, primarily as starch and contain important nutrients like vitamin C, potassium and dietary fiber (Camire *et al.,* 2009). As a staple, potatoes are widely consumed, with adults averaging 300-800 grams daily (De Haan *et al.,* 2019). The crop's adaptability to different climates and soils supports its global cultivation, with thousands of genetically diverse varieties suited to specific environments and culinary uses.

Late blight, caused by the oomycete *Phytophthora infestans* (Mont.) de Bary, is a major disease affecting potatoes and tomatoes worldwide (Son *et al.,* 2008). This pathogen significantly threatens potato production, causing severe yield losses and economic damage (Table 1), particularly in regions like Northern Europe, including Ireland, where it triggered the Irish Potato Famine (1843-1845), resulting in mass starvation and emigration (Elansky *et al.,* 2001). Recognized as the most damaging disease for potatoes (Agrios, 2005), late blight continues to impact production systems globally (Madden, 1983).

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Regional losses due to late blight are particularly severe in Sub-Saharan Africa (44%), followed by Latin America (36%), the Caribbean (36%), Southeast Asia (35%), Southwest Asia (19%) and the Middle East and North Africa (9%) (Erwin *et al.,* 1983; Singh and Shekhawat, 1999; Singh and Bhat, 2003; Fry, 2008; Lozoya-Saldana, 2011). The disease affects yield-related traits such as tuber yield and can lead to total crop loss in severe cases (Mercure, 1998; Pandit *et al.,* 2020).

In India, late blight results in an average potato yield loss of 10-15% (Lal *et al.,* 2016). In Karnataka, regions such as Hassan and Belur experience disease severity levels ranging from 3% to 100%, with an average severity of 54.8%. For instance, Belur recorded a 70% severity rate in 2013. Punjab has also faced significant yield reductions due to late blight. Similarly, high humidity in Uttar Pradesh exacerbates the disease, adversely affecting both yield and quality. In Maharashtra, late blight is a major production challenge, with reports suggesting considerable yield losses. Overall, productivity and yield decline from late blight vary between 25% and 85%, depending on the susceptibility of potato cultivars (Kumar *et al.,* 2003).

Despite advancements in agricultural practices, late blight continues to cause substantial economic losses through reduced yields and higher production costs related to disease management. Breeding programs aim to enhance yield, disease resistance and nutritional quality, with biotechnology aiding the development of potato varieties with improved traits. This genetic diversity is crucial for building crop resilience against pests, diseases and changing climates. Successful potato cultivation requires suitable soil preparation, planting, irrigation, pest and disease management and harvesting. Potatoes thrive in loose, well-drained soils rich in organic matter. Crop rotation and certified, disease-free seed potatoes are vital in preventing soil-borne diseases (Tiwari *et al.,* 2021). Integrated disease management (IDM), incorporating cultural, biological and chemical control measures, along with resistant varieties, offers effective and environmentally safe disease control (Tsedaley, 2014). This review intends to provide an in-depth look at late blight, examining pathogen biology, disease dynamics and contemporary management approaches.

Symptomatology

Late blight of potato, caused by *Phytophthora infestans*, manifests through distinct symptoms on leaves, stems and tubers showed in Fig 1 to 3. Symptoms include pale green to dark brown water-soaked lesions, primarily near the tips and margins of leaves, which quickly expand into large, brown to purplish-black necrotic spots. These lesions are often the first visible signs of infection (Fry, 2008). Under favorable conditions, the disease spreads rapidly; leading to extensive blighting where entire leaves and even plants can collapse and die, resembling frost damage (Grunwald and Flier, 2005). In humid environments, a white, downy growth appears on the underside of infected leaves, especially at the edges of necrotic lesions, indicating sporulation (Fry and Goodwin, 1997). Infected stems develop dark brown to black elongated lesions, leading to girdling and plant death in severe cases (Haverkort *et al.,* 2009). Lesions on stems are less common than on leaves but are a serious indicator of disease spread. Infected tubers show irregular, sunken lesions that are brown to purple (Fry, 2008). Cutting open an infected tuber reveals reddish-brown to dark brown granular rot extending inward from the skin (Grunwald and Flier, 2005). These infected tubers are usually hard, dry and discolored, contrasting sharply with healthy tissue and may be further attacked by bacteria causing soft rot, leading to rotting in the field and storage.

Host range

P. infestans is well known for causing severe damage to a variety of crops, particularly within the Solanaceae family. Its host range is relatively narrow, with a primary focus on potatoes (*Solanum tuberosum*) and tomatoes (*Solanum lycopersicum*), where it is the primary causal agent of late blight (Fry and Goodwin, 1997; Nowicki *et al.,* 2012). However, under certain environmental conditions, *P. infestans* can also infect other Solanaceous plants, including brinjal (eggplant) and chili peppers, leading to additional crop losses.

Etiology and biology of *phytophthora infestans*

P. infestans, the pathogen responsible for late blight, originates from Central Mexico (Zimnoch-Guzowska *et al.,* 2003). The mycelium of *P. infestans* is endophytic, consisting of hyaline, highly branched coenocytic hyphae that are intercellular, with single or double club-shaped haustoria or haustoroid hyphae. The sporangiophores are thick-walled, with cross partitions and the side branches show bulbous enlargements at intervals, indicating where sporangia are attached. The sporangia are multinucleate,

Table 1: Losses of potato due to late blight disease.

Name of country	Crop losses (%)	References
India	10-75	Dutt,1979
Pakistan	50-70	Lal *et al.,* 2018
Nepal	20	Sharma and KC, 2004
U.S.A.	70	Teng and Bissonnette, 1985
Ethopia	72	Selvaraj, 2013
Kenya	80	Nyankanga *et al.,* 2004
England and Wales	75	Large, 1958

thin-walled, hyaline, oval, pear, or lemon-shaped, with a distinct papilla at the apex. Zoospores are biflagellate, motile spores released directly from the sporangium through the papilla. Low temperatures favor zoospore formation, while higher temperatures favor germination of the sporangium by germ tubes. The pathogen's frequent emergence of new pathogenic types due to its variability creates challenges in the field, as does the sectoring of fungal colonies often observed in laboratory settings. Early studies by Giddings and Berg (1919) and Berg (1926) were instrumental in detecting variations in *P. infestans* populations.

Taxonomy and life cycle

Phytophthora infestans belongs to the class Oomycetes, a group of fungus-like organisms known for their complex life cycles (Fig 4), which include both asexual and sexual reproduction (Judelson, 1997). Asexual reproduction in *P. infestans* involves the production of sporangia, which release motile zoospores under favorable conditions. These zoospores are capable of swimming, encysting and subsequently germinating to infect host tissue. Under suitable environmental conditions, the asexual life cycle can be repeated multiple times within a week, leading to rapid disease proliferation (Nowicki *et al.,* 2012). The survival of sporangia for subsequent infections is primarily confined to host tissues, with limited knowledge regarding their *vi*ability in soil or other dead organic matters. The predominance of the asexual life cycle results in multiple disease cycles within a single growing season (Drenth *et al.,* 1995). Sexual reproduction occurs when opposite mating types (A1 and A2) come into contact, leading to the formation of oospores. These oospores can survive in soil and plant debris for extended periods, serving as a primary inoculum source in subsequent growing seasons (Judelson, 1997).

Disease cycle and epidemiology

The infection process of *P. infestans* begins when sporangia or zoospores land on the surface of potato foliage or tubers.

Fig 1: Late blight infection on potato leaf.

Fig 2: Late blight infection underside of leaf.

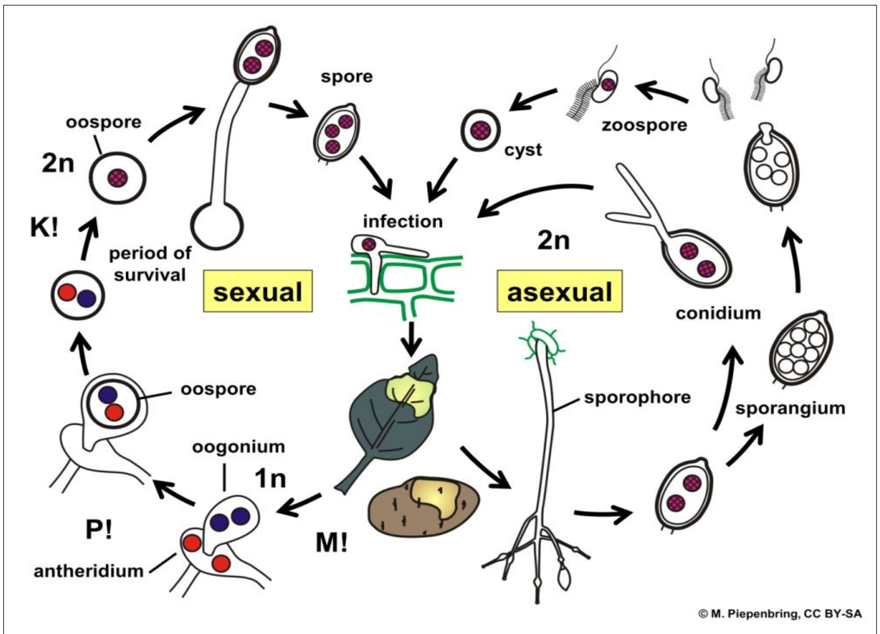
Fig 3: Aerial view of late blight infected field.

Under favorable environmental conditions, these spores germinate and penetrate the host tissue through stomata or wounds. Once inside the plant, the pathogen colonizes the intercellular spaces and produces haustoria, specialized structures that extract nutrients from host cells. This leads to tissue necrosis and the characteristic symptoms of late blight, including water-soaked lesions on leaves, stems and tubers (Birch and Whisson, 2001).

In regions where field soil temperatures remain below 30°C, *P. infestans* can persist as dormant mycelium in tubers left in the field. In areas where seed tubers are stored at low temperatures, the mycelium in these tubers acts as the primary inoculum source for the next growing season. The pathogen thrives on live host tissue, including seed tubers, cull piles, volunteer potatoes and other Solanaceous plants, as well as in soil (Shinners *et al.,* 2003; Kirk *et al.,* 2013). *P. infestans* demonstrates high adaptability and can spread rapidly under favorable environmental conditions. Primary dissemination occurs through wind-borne sporangia, rain splash and human activities, such as the transport of infected plant material (Fry, 2008). Secondary infection cycles are initiated when sporangia from infected plants spread to healthy plants, perpetuating the epidemic. The development of late blight is heavily influenced by environmental factors. High humidity (above 90% RH), rainfall and temperatures between 15-25°C create optimal conditions for sporangia production and zoospore release. Prolonged leaf wetness is crucial for infection, as it allows zoospores to swim and encyst on leaf surfaces (Harrison, 1992). The level of tuber infection is closely related to rainfall during the fungus's sporulation on foliage. Heavy and frequent rains, particularly when 50% of the foliage is infected, result in maximum infection of underground tubers (Arora *et al.,* 1987).

Host-pathogen interactions

Potato plants are susceptible to late blight throughout their growth stages, with the highest risk occurring during the tuber bulking period. Symptoms include water-soaked lesions that rapidly expand, leading to extensive tissue decay. Infected tubers display a characteristic brown, granular rot that can penetrate deep into the tissue, rendering them unmarketable (Crosier, 1934). The interaction between *P. infestans* and its host involves a complex exchange of molecular signals. The pathogen secretes various effectors that manipulate host cellular processes, facilitating infection and suppressing immune responses (Bos *et al.,* 2009). These effectors are delivered into host cells *via* specialized infection structures known as haustoria. In response, the host plant has evolved a range of defense mechanisms to detect and counteract pathogen invasion. These defenses include pathogen recognition receptors (PRRs) that detect conserved microbial patterns, triggering the activation of basal defense responses (Kamoun *et al.,* 1999). Additionally, the host may possess resistance (R) genes that recognize specific pathogen effectors, leading to a more robust defense response known as effector-triggered immunity (ETI) (Jones and Dangl, 2006). However, the high genetic variability of *P. infestans* allows it to quickly adapt, overcoming host resistance and leading to the emergence of new, more virulent strains.



(**Source:** https://en.wikipedia.org/wiki/Phytophthora_infestans#/media/File:07_08_life_cycle, Phytophthora_infestans_on_potato,_Peronosporales,_Oomycota_(M._Piepenbring).png).

Fig 4: Life cycle of *Phytophthora infestans* on potato.

Monitoring and management strategies

Machine learning tools for early prediction of potato late blight

Early prediction of potato late blight plays a critical role in supporting precision agriculture. Weather forecasting and warning systems leverage meteorological parameters, such as relative humidity, temperature, wind direction and wind speed, to predict disease onset. By analyzing these variables, the system can effectively forecast late blight in potatoes. Machine learning models, incorporating algorithms like logistic regression and neural networks, have been developed to predict this disease (Mohammad, 2021). The system compares the performance of these algorithms on the same dataset to identify the most accurate and suitable model.

Convolutional neural network (CNN)

Continuous monitoring of plant diseases, particularly identifying infected leaves, poses a challenge. Convolutional Neural Networks (CNNs) address this by classifying potato diseases more efficiently through image-based phenotyping, which reduces the computational time required for processing learnable parameters. To further enhance the CNN model, a meta-heuristic algorithm known as the Whale Optimization Algorithm (WOA) is used to optimize its hyperparameters (Pandiri *et al.,* 2022). The optimized CNN, named POT-Net, classifies potato diseases with high accuracy. Its performance is evaluated using metrics such as precision, recall, F1-score and accuracy. POT-Net achieves a 99.12% accuracy rate, outperforming pre-trained deep learning models and other optimized algorithms, thus surpassing state-of-the-art models.

Cultural practices

Cultural methods are essential for managing late blight, with key strategies including crop rotation, the elimination of volunteer plants and maintaining good field sanitation to reduce the primary sources of infection. To minimize leaf wetness and lower the risk of infection, it is advisable to avoid overhead or nighttime irrigation and ensure adequate air circulation (Draper *et al.,* 1994). Additionally, using disease-free seed potatoes and maintaining proper plant spacing can help prevent the spread of the disease (Stevenson *et al.,* 2007). Effective management also involves removing cull piles and volunteer potatoes, employing proper harvesting and storage techniques and applying fungicides when necessary (Davis *et al.,* 2009). The researchers Bodker *et al.* 2006 and Hannukkala *et al.* 2007 demonstrate that crop rotations of three or more years between potato crops significantly reduce the risk of soil-borne infections by *Phytophthora infestans*.

Chemical control

Fungicides play a crucial role in managing late blight, commonly used protectant fungicides include chlorothalonil and mancozeb, while systemic fungicides such as metalaxyl are also frequently applied (Table 2). However, the overuse of metalaxyl-based fungicides has led to the development of resistance globally, including in India (Arora *et al.,* 2014). This resistance has necessitated the adoption of integrated pest management (IPM) strategies, which involve rotating fungicides with different modes of action and combining chemical treatments with other methods to reduce the risk of resistance development (Gisi *et al.,* 2011).

Biological control

Biological control offers a promising alternative to chemical fungicides. Various antagonistic microorganisms, such as *Trichoderma* spp. and *Bacillus* spp., have shown potential in suppressing *P. infestans*. These biological agents can inhibit the pathogen through competition, antibiosis and induction of host resistance. For instance, *Bacillus subtilis* B5 has been tested using the dual culture method and found effective in inhibiting the growth of *P. infestans* (Ajay and Sunaina, 2005). Other bioagents, including *Pseudomonas fluorescens*, *Pseudomonas* sp., *Aspergillus flavus*, *A. niger*, *Penicillium* sp., *Trichoderma virens* and *T. harzianum*, have also been reported to inhibit *P. infestans* (Lal *et al.,* 2013). Ongoing research aims to develop effective biocontrol formulations that can be integrated into existing management programs (Whipps, 2001).

Genetic resistance

Breeding for resistance is a sustainable approach to managing late blight. Several potato varieties, such as Kufri Anand, K. Arun, K. Badshah, K. Pukhraj, K. Satluj, K. Sadabahar, K. Jawahar, K. Chipsona-I, K. Chipsona-II, K. Girdhari and K. Kiran, have demonstrated moderate to high resistance against late blight, as developed by the Central Potato Research Institute (CPRI) in Shimla, India. The incorporation of R genes from wild potato relatives has led to the development of resistant cultivars. However, the

Table 2: Doses of fungicides used to control late blight disease in potato crop.

Trade name	Common name	Doses	Reference
Dithane M-45, Indofil	Mancozeb 75% WP	2.0 Kg/ha	Mekonen and Tadesse, 2018)
Ridomil	Metalaxyl 25%WP	2.5 Kg/ha	(Hannukkala *et al.,* 2007)
Bravo/Kvach	Chlorothaonil 75%WP	1.5 Kg/ha	(Hannukkala *et al.,*2007
Curzate	Cymoxanil 60% WP	2.0 Kg/ha	Hardy *et al.,* 1995
Motco/Ridomil gold	Metalaxyl 8% +Mancozeb 64%	2.0 Kg/ha	Mekonen and Tadesse, 2018
Curzate M8	Cymoxanil 8% +Mancozeb64% WP	2.0 Kg/ha	Lal *et al.,* 2018

rapid evolution of *P. infestans* often overcomes these resistances, necessitating continuous breeding efforts to introduce new R genes and combine multiple genes to achieve durable resistance (Bradshaw and Bonierbale, 2010). Researchers have documented variations in resistance among different potato varieties (Njualem *et al.,* 2001). Additionally, biotechnology is being utilized to develop late blight resistance, although genetically modified plants for disease resistance are not acceptable for organic production (Shapiro *et al.,* 1998).

Current research and future directions

Genomics and biotechnology

Advances in genomics and biotechnology are enhancing our understanding of *P. infestans* and its interactions with potato hosts. The whole genome sequencing of *P. infestans* has provided insights into its genetic diversity and pathogenicity mechanisms (Haas *et al.,* 2009). Techniques like CRISPR/Cas9 are being explored to develop resistant potato varieties by precisely editing R genes and studying pathogen virulence factors (Vleeshouwers and Oliver, 2014).

Epidemiological modeling

Improved epidemiological models are aiding in the prediction of late blight outbreaks and informing timely management interventions. A disease forecasting model anticipates the occurrence or variations in the severity of one or more diseases by analyzing data related to weather, crops, pathogens, or a combination of these factors. Over time, several forecasting models have been designed and applied worldwide to predict late blight in potatoes (Singh *et al.,* 2013). These models incorporate weather data, pathogen biology and host resistance information to provide accurate risk assessments. Decision support systems based on these models can help farmers optimize fungicide applications and reduce unnecessary treatments (Skelsey *et al.,* 2009). Singh *et al.* (2000) developed the computerized forecasting model 'JHULSA CAST' for western Uttar Pradesh, which has been validated and can accurately predict late blight in the region. This model is like the BLITECAST model developed by Krause *et al.* 1975 but is designed for forecasting the initial appearance of late blight. JHULSACAST has also been calibrated for other regions in India, including the Tarai region of Uttarakhand and the plains of West Bengal (Pundhir *et al.,* 2014; Chakraborty *et al.,* 2014). Based on JHULSACAST, a Decision Support System (DSS) has been developed, which includes three components: (i) prediction of the first appearance of the disease, (ii) decision rules for need-based fungicide application and (iii) a yield loss assessment model.

Sustainable practices

Sustainable late blight management requires an integrated approach that combines cultural, biological and chemical controls. Emphasizing reduced reliance on chemical fungicides and promoting environmentally friendly practices is crucial for long-term disease control. Developing resilient agricultural systems and fostering collaboration among researchers, extension services and farmers will be essential to achieving sustainable management of late blight (Kirk *et al.,* 2013).

CONCLUSION

Late blight, caused by *Phytophthora infestans*, continues to pose significant challenges to potato production worldwide. Advances in understanding the pathogen, improving resistant cultivars and implementing integrated management strategies are essential for effective disease control. The use of biocontrol agents is particularly promising as they are eco-friendly and can minimize the need for pesticides. As new information emerges, it is vital to develop disease management strategies that are accessible and practical for farmers. Ongoing research and collaboration among scientists, farmers and policymakers will be crucial in mitigating the impact of late blight and ensuring sustainable potato production.

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article

REFERENCES

Agrios, G.N. (2005). Plant Pathology. 5th Edition. Academic Press, London, New York. pp. 922.

Ajay, S. and Sunaina, V. (2005). Direct inhibition of *Phytophthora infestans*, the causal organism of late blight of potato by *Bacillus* antagonist. *Potato J.* **32:** 179-80.

Arora, D.K., Upadhyay, R.S. and Singh, C.S. (1987). Biological control of plant pathogens using antagonistic fungi. *Indian Phytopathology.* **40(3):** 334-341.

Arora, R.K., Sharma, S., Singh, B.P. (2014). Late blight disease of potato and its management. *Potato J.* **41(1):** 16-40.

Berg, A. (1926). Tomato late blight and its relation to late blight of potato. West Virgiana Agric. *Exp. Stn. Tech. Bull.* **205:** 1-31.

Birch, P.R.J. and Whisson, S.C. (2001). *Phytophthora infestans* enters the genomics era. *Mol. Plant Pathol.* **2(5):** 257-263.

Bodker, L., Pedersen, H., Kristensen, K., Moller, L., Lehtinen, A., Hannukkala, A. (2006). Influence of Crop History of Potato on Early Occurrence and Disease Severity of Potato Late Blight Caused by *Phytophthora infestans*. In: Proc. [Westerdijk, C.E. and Schepers, H.T.A.M. (Eds.)], 9th Workshop of an European Network for Development of an Integrated Control Strategy of Potato Late Blight. *PPO Special Report. No.* **11:** 53-56.

Bos, J.I.B., Armstrong, M.R., Gilroy, E.M., Boevink, P.C., Hein, I., Taylor, R.M., Tian, Z., Engelhardt, S., Vetukuri, R.R. and Birch, P.R.J. (2009). *Phytophthora infestans* effector AVR3a is essential for virulence and manipulates plant immunity by stabilizing host E3 ligase CMPG1. *Proceedings of the National Academy of Sciences.* **107(21):** 9909-9914.

Bradshaw, J.E. and Bonierbale, M. (2010). Potatoes. In: Handbook of Plant Breeding. [Carena, M.J. (Ed.)]. Springer. **7:** 11-56.

Camire, M.E., Kubow, S. and Donnelly, D.J. (2009). Potatoes and human health. *Crit. Rev. Food Sci. Nutr.* **49:** 823-840.

Chakraborty, A., Singh, B.P., Ahmad, I. and Sharma, S. (2014). Forecasting late blight of potato in the plains of West Bengal using JHULSACAST model. *Potato J.* **41: (in press).**

Crosier, W. (1934). Studies in the biology of *Phytophthora infestans* (Mont.) de Bary. *Cornell Univ. Agric. Exp. Stn. Memoir.* **155:** 1-40.

Davis, R.M., Nunez, J. and Aegerter, B.J. (2009). Potato Late Blight. Statewide IPM Program, Agriculture and Natural Resources, University of California.

De Haan, S., Burgos, G., Liria, R., Rodriguez, F., Creed-Kanashiro, H. and Bonierbale, M. (2019). The nutritional contribution of potato varietal diversity in andean food systems: A case study. *Am. J. Potato Res.* **96:** 151. doi: https://doi.org/10.1007/s12230-018-09707-2.

Draper, M.A., Secor, G.A., Gudmestad, N.C., Lamey, H.A. and Preston, D. (1994). Leaf blight diseases of potato. late blight. North Dakota State University Agriculture and University Extension. pp. 1084.

Drenth, A., Janssen, E.M. and Govers, F. (1995). Formation and survival of oospores of *Phytophthora infestans* under natural conditions. *Plant Pathol.* **44(1):** 86-94.

Dutt, B.L. (1979). Bacterial and fungal disease of potato. ICAR, New Delhi.

Elansky, S.N., Smirnov, A.N., Dyakov, Y., Dolgova, A., Filippov, A., Kozlovsky, B., Kozlovskaya, I., Russo, P., Smart, C. and Fry, W.E. (2001). Genotypic analysis of Russian isolates of *Phytophthora infestans* from the Moscow region, Siberia and Far East. *J. Phytopathol.* **149:** 605-611.

Erwin, D.C.S., Bartnicki-Garcia, S. and Psao, P.H. (1983). *Phytophthora* its biology, taxonomy and pathology. The American Phytopathological Society, St. Paul, Minnesota.

Fry, W.E. and Goodwin, S.B. (1997). Re-emergence of potato and tomato late blight in the United States. *Plant Disease.* **81(12):** 1349-1357.

Fry, W.E. (2008). Phytophthora infestans: The plant (and R gene) destroyer. *Mol. Plant Pathol.* **9(3):** 385-402.

Fry, W.E. and Goodwin, S.B. (1997). Resurgence of the Irish Potato Famine Fungus. *BioScience.* **47(6):** 363-371.

Giddings, N.J. and Berg, A. (1919). A comparison of the late blight of tomato and potato. A preliminary report. *Phytopathology.* **9:** 209-210.

Gisi, U., Cohen, Y. and Silue, D. (2011). Fungicide Resistance in *Phytophthora infestans*: Problems and perspectives. In: Oomycete Genetics and Genomics: Diversity, Interactions and Research Tools. [Lamour, K., Kamoun, S. (Eds.)], Wiley-Blackwell. pp. 243-258.

Grünwald, N.J. and Flier, W.G. (2005). The biology of *Phytophthora infestans* at its center of origin. *Annu. Rev. Phytopathol.* **43:** 171-190.

Haas, B.J., Kamoun, S., Zody, M.C., Jiang, R.H.Y., Handsaker, R.E., Cano, L.M. and Nusbaum, C. (2009). Genome sequence and analysis of the Irish potato famine pathogen *Phytophthora infestans*. *Nature.* **461(7262):** 393-398.

Hannukkala, A.O., Kaukoranta, T., Lehtinen, A. and Rahkonen, A. (2007). Late blight epidemics on potato in Finland 1933-2002; increased and earlier occurrence of epidemics associated with climate change and lack of rotation. *Plant Pathol.* **56:** 167-176.

Hardy, B.B., Trognit, Z. and Forbes, G.A. (1995). Late blight breeding at CIP. *Circular (Lima-Peru)*. **21:** 2-5.

Harrison, J.G. (1992). Effects of the Environment on Late Blight of Potatoes. In: *Advances in Plant Pathology.* [Ingram, D.S., Williams, P.H. (editors)]. Academic Press. **8:** 101-134.

Haverkort, A.J., Struik, P.C., Visser, R.G.F. and Jacobsen, E. (2009). Applied biotechnology to combat late blight in potato caused by Phytophthora infestans. *Potato Res.* **52:** 249-264.

Jones, J.D.G. and Dangl, J.L. (2006). The plant immune system. *Nature.* **444:** 323-329.

Judelson, H.S. (1997). The genetics and biology of Phytophthora infestans: Modern approaches to a historical challenge. *Fungal Genet. Biol.* **22(2):** 65-76.

Kamoun, S., Huitema, E. and Vleeshouwers, V.G.A.A. (1999). Resistance to oomycetes: A general role for the hyper-sensitive response? *Trends in Plant Science.* **4(5):** 196-200.

Kirk, W., Wharton, P., Hammerschmidt, R., Abu-el Samen, F. and Douches, D. (2013). Late blight. michigan state university extension bulletin E-2945. East Lansing, MI. Available on: http://www.potatodiseases.org/lateblight.html.

Krause, R.A., Massie, I.B. and Hyre, R.A. (1975). BLITECAST: A computerized forecast of potato blight. *Plant Dis. Reptr.* **59:** 95-98.

Kumar, S., Singh, P.H., Garg, I.D. and Paul, S.M.P. (2003). Integrated management of potato diseases. *Indian Horticulture*. **48:** 25-27.

Lal, M., Arora, R.K., Maheswari Uma, Rawal, S. and Yadav, S. (2016). Impact of late blight occurrence on potato productivity during 2013-14. *Int. J. Agricult. Statistcal Science.* **28:** 67-70.

Lal, M., Sharma, S., Yadav, S. and Kumar, S. (2018). Management of Late Blight of Potato. Potato from Incas to All Over the World. doi: https://doi.org/10.5772/intechopen.72472.

Lal, M., Singh, A.P., Tomar, S., Hussain, T., Sharma, S., Kaushik, S.K. and Singh, B.P. (2013). Antagonistic effect of bioagents against three potato fungal diseases and their fungicidal sensitivity. *Vegetos.* **26:** 362-367.

Large, E.C. (1958). Losses caused by potato blight in England and Wales. *Plant Pathol.* **7(2):** 39-48. doi: https://doi.org/10.1111/j.1365-3059.1958.tb00820.x.

Lozoya-Saldana, H. (2011). Evolution of vertical and horizontal resistance and its application in breeding resistance to potato late blight. *Potato J.* **38(1):** 1-8.

Madden, L.V. (1983). Measuring and modeling crop losses at the field level. *Phytopathology.* **73(11):** 1591-1596.

Mekonen, S. and Tadesse, T. (2018). Effect of varieties and fungicides on potato late blight (Phytophthora infestans, (Mont.) de Bary) management. *Agrotechnology.* **07(02).** doi: https://doi.org/10.4172/2168-9881.1000182.

Mercure, P. (1998). Early Blight and Late Blight of Potato. University of Connecticut, Integrated Pest Management. 2p. Available on: www.hort.uconn.edu/IPM/VEG/HTMS/BLTPOT.HTM.

Mohammad, S.I. (2021). Smart proactive warningsystem for early prediction of potato pate Blight *Via* Machine Learning. *Geintec.* **11(4):** 2177-2193.

Njualem, D.K., Demo, P., Mendoza, H.A., Koi, J.T. and Nana, S.F. (2001). Reaction of some potato genotypes to late blight in Cameroon. *African Crop Science Journal.* **1(1):** 209-213.

Nowicki, M., Foolad, M.R., Nowakowska, M. and Kozik, E.U. (2012). Potato and tomato late blight caused by *Phytophthora infestans*: An overview of pathology and resistance breeding. *Plant Disease*. **96(1):** 4-17.

Nyankanga, R.O., Wien, H.C., Olanya, O.M. and Ojiambo, P.S. (2004). Farmers' cultural practices and management of potato late blight in Kenya Highlands: Implications for development of integrated disease management. *Int. J. Pest. Manage*. **50(2):** 135-144. doi: https://doi.org/10.1080/09670870410001691812.

Pandiri, K., Murgan, D.N., Goel, R., Sharma, T., Singh, N., Sen, A.K. and Burah, T. (2022). POT-Net: *Solanum tuberosum* (Potato) leaves disease classification using an optimized deep convolutional neural network. *The Image Science Journal.* **70(6):** 387-403.

Pandit, R., Bhatta, R., Bhusal, P., Acharya, B., Subedi, S. and Shrestha, J. (2020). Response of local potato cultivars to late blight disease (*Phytophthora infestans* (Mont.) de Bary) under field conditions. *Agro Bali*: *Agricultural Journal.* **3(1):** 28-37.

Pundhir, V.S., Singh, B.P., Ahmad, I., Sharma, S., Kushwaha, H.S., Singh, V.K. and Joshi, V. (2014). Forecasting late blight of potato in Tarai region of Uttarakhand using JHULSACAST model. *Potato J.* **41:** (in press).

Ram, C.N., Dalal, P.K., Maurya, M.K., Singh, S., Uppadhayay, D.K., Jha, A., Kumar, A., Singh, A.K., Yadav, L. and Tiwari, C.P. (2024). Advance Production Technology of potato. Book Abhiram Prkashan. pp. 2.

Selvaraj, T. (2013). Field evaluation of new fungicide, Victory 72 WP for management of potato and tomato late blight [*Phytophthora infestans* (Mont) de Bary] in West Shewa Highland, Oromia, Ethiopia. *J. Plant Pathol. Microbiol.* **04(08).** doi: https://doi.org/10.4172/2157-7471.1000192.

Shapiro, L., Hager, M., Springen, K. and Hayden, T. (1998). Is organic better? *Newsweek*. **1:** 54-57.

Sharma, H.B. and KC, H.B. (2004). Participatory IDM research on potato late blight through farmer's field school. In: Proc. Fourth National Workshop on Horticulture 2004. Kathmandu, Nepal: Horticulture Research Division, Nepal Agric. Res. Council, Khumaltar, Lalitpur, Nepal.

Shinners, C.T., Bains, P., McLaren, D. and Thomson, J. (2003). Commercial potato production-disease management. Guide to Commercial Potato Production Prairies. Western Potato Council.Retrievedfromhttp://www.gov.mb.ca/agriculture/crops/potatoes/bda04s07.

Singh, V.K., Shailbala and Pundhir V.S. (2013). Forecasting models for potato late blight management-A review. *Agricultural Reviews.* **34(2):** 87-96.

Singh, B.P., Ahmad, I., Sharma, V.C. and Shekhawat, G.S. (2000). JHULSACAST: A computerized forecast of potato late blight in western Uttar Pradesh. *Potato J.* **27:** 25-34.

Singh, B.P. and Bhat, N.M. (2003). Emerging trends in the epidemiology of late blight of potato. *Annu. Rev. Plant Pathol.* **2:** 43-83.

Singh, B.P. and Shekhawat, G.S. (1999). Potato Late Blight in India. Technical Bulletin No. *Central Potato Res. Inst. Shimla*. **22:** 85.

Skelsey, P., Rossing, W.A.H., Kessel, G.J.T. and van der Werf, W. (2009). Scenario studies of the effects of host resistance and climate change on late blight epidemics in potato. *Agricultural Systems.* **99(2-3):** 37-48.

Son, S.W., Kim, H.Y., Choi, G.J., Lim, H.K., Jang, K.S., Lee, S.O., Sung, N.D. and Kim, J.C. (2008). Bikaverin and fusaric acid from Fusarium oxysporum show antioomycete activity against P. infestans. *Journal of Applied Microbiology.* **104:** 692-698.

Stevenson, W.R., Loria, R., Franc, G.D. and Weingartner, D.P. (2007). Compendium of Potato Diseases (2nd ed.). The American Phytopathological Society.

Tiwari, I., Shah, K.K., Tripathi, S., Modi, B., Subedi, S. and Shrestha, J. (2021). Late blight of potato and its management through the application of different fungicides and organic amendments: A review. *Journal of Agriculture and Natural Resources*. **4(1):** 301-320. doi: https://doi.org/10.3126/janr.v4i1.33374.

Tsedaley, B. (2014). Late blight of potato (*Phytophthora infestans*) biology, economic importance and its management approaches. *Journal of Biology, Agriculture and Healthcare.* **4(25):** 215-225.

Vleeshouwers, V.G.A.A. and Oliver, R.P. (2014). Effectors as tools in disease resistance breeding against biotrophic, hemibiotrophic and necrotrophic plant pathogens. *Molecular Plant-Microbe Interactions*. **27(3):** 196-206.

Whipps, J.M. (2001). Microbial interactions and biological control of plant diseases. *Journal of Experimental Botany.* **52(Supplement_1):** 487-511.

Zimnoch-Guzowska, E., Lebecka, R., Kryszczuk, A., Maciejewska, U., Szczerbakowa, A. and Wielgat, B. (2003). Resistance to *Phytophthora infestans* in somatic hybrids of *Solanum nigrum* L. and diploid potato. *Theoretical and Applied Genetics.* **107(1):** 43-48.