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Review Article

Revolutionizing Potato Farming: Dynamic Innovations Reshaping Late Blight Control in Pakistan

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ABSTRACT

Potato *(Solanum tuberosum L.)* is one of the most extensively cultivated crops around the world, and Pakistan's weather favor production and cultivation. Despite the ease of cultivating potatoes and the nominal labor supplies, Pakistan's output of potatoes has not yet achieved a promising level when compared to nearby nations like India and Bangladesh. The crop's low production in Pakistan is caused by several biotic and abiotic stresses that instigated several pathogenic diseases such as early blight, bacterial wilt, viral infections, nematode infestations and late blight. Late blight disease is one of the most dreaded diseases of potatoes globally. It is caused by the fungus *Phytophthora infestans* which is highly adaptive to fungicides. Several fungicides have been in use against this disease for a long time, however, it has developed a high degree of resistant strains to these fungicides due to their unselective use over time and ultimately may cause colossal losses to the crop. In response, scientists have developed different potato varieties like Setanta, Nicola, Cara and Acoustic that are highly resistant to late blight. Similarly, cultural methods are also employed to combat late blight disease. This article provides an overview of the implications of late blight disease in potato cultivation and explores various strategies to reduce yield losses brought on by this disease via the application of synthetic fungicides.

INTRODUCTION

The potato is a starchy tuber of the *Solanum tuberosum* and an annual crop. Its genome consists of 12 chromosomes [1]. Globally, there are over 5000 potato types, chiefly found in South America. Today, potatoes are a common staple food and a crucial component of the global food supply. Its constituents include 205 solid substances, about 80% water, 85% starch, and 15% protein. In addition to being easily digestible, potatoes are a good source of carbs, vitamin C, niacin, and thiam [2]. Depending on the variety and method of production, potatoes' nutritional value can change. In terms of planting area and production, the potato has recently surpassed all other food crops in Africa. It is becoming a significant crop in countries like China with 21.8% and India with 14.3% of the global production. Pakistan is now the world's 19th-largest producer of potatoes. Potato has overtaken wheat and rice as

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Pakistan's fourth-most significant food crop with a total production of roughly 4.00 million tons and chiefly cultivated in KPK. Typically, three potato crops—spring, summer, and autumn—are farmed in Pakistan's various agro-ecological regions, which range from plains to hilly terrain[3].

Table 1: Production of Crops in Pakistan by Season

Crop	Planting Season	Harvesting Season	Production Share (%)	Planting Start Date	Planting End Date	Harvesting Start Date	Harvesting End Date	Share Range	Primary Region
Spring	Jan-Feb	April-May	7-10	Jan 15	Feb 28	Apr 5	May 20	7-10	Punjab
Summer	March-May	Aug-Oct	15-20	Mar 5	May 10	Aug 15	Oct 10	15-20	Sindh
Autumn	Sep-Oct	Jan-Feb	70-75	Sep 10	Sep 30	Jan 10	Feb 28	70-75	KPK

Pakistan is cultivating and producing potatoes from many years; however, its yield is low and mostly lost due to several abiotic and biotic stresses as well as poor facilities of storage. The most harmful abiotic factors include high or low temperatures, drought, salinity stress or metal toxicity that bring about large-scale losses in the agriculture sector [4]. These factors inhibit the tuberization phase during potato life cycle and ultimately reduce potato yield and productivity. In addition, overall, each year, the potato crop is reduced by 20–24% because of biotic stresses, resulting in an annual loss of roughly 63–66 million tons of potatoes [5]. Biotic stresses include living organisms specifically viruses, fungi, nematodes, bacteria, weeds and insects that cause chlorosis, stunting, rotting, late blight, early blight, bacterial wilt etc. Among these, late blight is one of the most dreaded potato diseases in the world. Late blight is caused by *P. infestans that* is a diploid, mycelial plant pathogen with huge genome of 240 MB through an extraordinary organization *P. infestans* can infect many solanaceous plants, such as petunias, tomatoes, and hairy nightshade, although potatoes are its main host is potato [6]. It has drastic effects on potato development, production, and productivity overall, especially in moist-temperate environments [7]. It affects tubers, stems, and leaves. Pale green, erratic dots can be seen on the leaves as a result. Small, light-to-dark green, circular to irregularly shaped, water-soaked lesions are the first signs of late blight in the field [8]. In addition, an initial tuber infection causes a superficial, reddish-brown dry rot that diffuses unevenly through the flesh from the surface like a brown stain. Petioles and stems turn brown when they are infected [9]. Furthermore, the pathogen causes water-soaked lesions with chlorotic borders that are small at first but quickly spread under humid conditions, blighting the entire plant in only a few days. When mycelium starts its growth in the host results in the damaging of the host cells with the appearance of yellowish or greenish-brown spots, which turn into black with the progress of disease [10]. Consequently, the pathogen causes developing tubers to rot, which leads to heavy yield losses under favorable conditions each year and a reduction in global production of about 15%. In past, one million people had died of starvation caused by late blight in Ireland in the 1840s. *P. infestans* continues to cause tremendous economic harm, estimated at $5 billion annually worldwide [11]. While the disease in Ethiopia resulted in a 100% crop loss during the early days of its breakout. In Pakistan, *P. infestans* was initially discovered in the District of Swat, and later it spread in the plains of Punjab, NWFP, Baluchistan and Northern area of Pakistan where the environmental conditions remained suitable during the growing season of potatoes [12]. Resultantly, late blight disease causes colossal damage to potato crops leading to huge economic losses globally. Various measures for disease management are employed, but the disease-causing pathogen is continuously developing resistance against the fungicides and challenging the control options [13]. Therefore, this review provided the relevant literature to assess the prevalence of late blight and analyze the mechanism of action of *P. infestans*. It also evaluates the selectively available information and proposes an effective plan to control the spread of the disease.

Mechanism of Disease

Potato late blight is one of the devastating diseases of potato caused by *P. infestans*. It is reducing potato production not only in Pakistan but also in the world, so the mechanism of the disease should be analyzed to control and prevent this disease. *P. infestans* reproduces both asexually and sexually to cause this disease [14].

Asexual Reproduction

P. infestans have asexual propagation structures e.g., sporangia and zoospores, they are spread by rain and wind for further infection, while oospores, the product of sexual reproduction, may resist the pathogen for extended periods of time [15]. Within 4-5 days of spore germination, indications of colonization and infection appear on leaves, stems, or tubers, and additional spores are produced.

Sexual Reproduction

P. infestans sexual oospores were initially discovered in Mexico in the 1950s [16], and the existence of two mating types that are A1 and A2, was established. Meiosis takes place in the gametangia, after which the antheridium's nucleus enters the oogonium. A diploid oospore is created after the fusion of two nuclei (known as karyogamy) takes

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place in the oogonium [17]. However, zoosporangia help the pathogen to enter and infects potato plants in the field, which spread via water, soil and wind. At lower temperatures, sporangia indirectly germinate by the generation of zoospores. The sporangia immediately germinates when the temperature is higher by forming a germ tube. Infected tubers in volunteer or cull piles may release airborne spores in the spring that infect potato leaves. When the pathogen challenges the host tissues, its mycelium begins to grow [11]. Specialized spherical structures called haustoria are then created, forming an intercellular link with the host tissues by rupturing the host cell wall for nutrient absorption.

Management of Late Blight in Potato

Many management strategies for late blight have been created and put into practice. Implementing an integrated disease management strategy is necessary for the disease's effective control [18]. The most important measures are cultural, chemical and biological controls.

Management of Late Blight Through Chemicals

Fungicides are formulation of different organic and inorganic chemicals available in two for forms i.e., systematics and protectants, which have potentials for the inhibition of growth, killing of zoospores of the causative pathogen [9]. Late blight may be well managed when application of fungicides is applied before infection because most fungicides have protective properties and can destroy or block the pathogen's propagation mechanisms before they can get established, although they lose efficiency once *P. infestans* has establish itself in plant tissues. In Pakistan, mostly farmers apply chemical fungicides e.g., Metalaxyl, Mancozeb, Fostyl A-1 Fentin-acetate phosphate, Captafol and Chlorotalonyl to control *P. infestans* and suppress the late blight disease [8]. At the Vegetable Research Area of the Institute of Horticultural Sciences, University of Agriculture, Faisalabad, Pakistan, field tests were carried out in 2008 to assess the efficacy of three fungicides, namely Application of Kocide (Copper cxychloride), Flint Max (Trifloxystrobin), and Tazoline (Mancozeb + Metalaxy) on eight potato varieties [19]. Tazoline was applied to the cultivar SH-103 at intervals of 7,14,21, and 28 days, with Kocide coming in second and Flint Max coming in last for disease control [20]. Furthermore, Protective fungicide sprays are often applied to potato foliage four weeks after planting, with subsequent applications occurring at intervals of seven to ten days. However, 5–7day intervals of spraying produce good results in wet and cool conditions. Foliar late blight infection in potatoes was significantly decreased by the regular use of protective fungicides [4]. Fungicides can stop zoospore encasement, cause them to burst, and stop the *P. infestans* pathogen's protoplast from regenerating [21]. The indiscriminate use of these chemicals develops resistant strains of the fungus that ultimately may cause colossal losses to the crop. In the past several years, it has been noted that new strains of *P. infestans* have been discovered that exhibit resistance to fungicides that include metalaxyl. Instead of using chemicals scientists are developing other methods to control the disease [22].

Table 2: Management of Late Blight Through Chemicals

Fungicide	Application Frequency (days)	Effectiveness (%)	Cost (in PKR per acre)	Application Method	Resistance Risk
Metalaxyl	7	85	800	Foliar Spray	Low
Mancozeb	10	80	600	Foliar Spray	Moderate
Chlorothalonil	14	70	500	Foliar Spray	High
Azoxystrobin	7	90	750	Foliar Spray	Low
Cymoxanil	12	75	700	Foliar Spray	Moderate

Management of Late Blight Disease through Biological Control

Researchers are interested in developing biological methods, to avoid the use of chemicals that have ultimately adverse impression on the atmosphere, for disease control. The use of resistant potato- with inherent resistance to late blight- crop cultivars is one method of biological control for potato late blight disease. This method offers a sustainable and environmentally friendly approach to disease management [23].

Table 3: Management of Late Blight Disease Through Biological Control

Biological Control Agent	Method	Effectiveness (%)	Cost (in PKR per acre)	Application Frequency	Resistance Risk
Trichoderma spp.	Soil Application	70	400	Single application	Low
Pseudomonas fluorescens	Foliar Spray	60	500	Weekly	Low
Bacillus subtilis	Soil Drench	75	600	Bi-weekly	Low
Mycorrhizal Fungi	Soil Inoculation	80	800	Single application	Low
Bacterial Antagonists	Foliar Spray	65	550	Weekly	Low

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Resistant Cultivars and R-Genes

Researchers primarily working the use of microorganisms to develop resistant cultivars. Through map-based cloning, a significant late blight resistance gene known as RB was previously discovered in the wild potato species *Solanum bulbocastanum* [24]. By using *Agrobacterium*-mediated transformation approach, this resistance gene has been integrated into potato crop. In greenhouse tests, *P. infestans* was exposed to RB-containing transgenic plants under the ideal late blight circumstances. Transgenic lines having RB gene exhibited foliar resistance. But RB containing tubers showed no resistance against late blight. In addition, Lorkh formulated biological preparations of both Riyoplan (*Pseudomonas putida*) and Bectofit (*Bacillussubtilis*) under laboratory conditions in Russia that reduced the formation of zoospores in vitro when administered on the sensitive potato variety [25]. Lastly According to Chulow SA, the microorganism on the surface of Cara and Bintje tubers boosted their resistance to *P. infestans* while *Aspergillus terreus* and *Penicillium oxalicum* could prevent *P. infestans* from growing in potato [26, 27].

Table 4: Resistant Cultivars and R-Genes for Managing Potato Late Blight

Cultivar/R-Gene	Resistance Level	Effective Against	Released Year	Popular Region
Kufri Jyoti	High	US-8	2016	Punjab
Sante	Moderate	US-6, US-11	2018	Sindh
Lady Rosetta	Low	US-1, US-5	2017	KPK
Diamant	High	US-8, US-13	2019	Punjab
Desiree	Moderate	US-6, US-12	2020	Sindh
R-gene Rpi-blb1	High	Multiple strains	-	Global
R-gene Rpi-blb2	High	Multiple strains	-	Global
R-gene Rpi-blb3	High	Multiple strains	-	Global
R-gene Rpi-blb4	High	Multiple strains	-	Global

Management of Late Blight through Cultural Control

Several chemical and biological methods are being used by researchers and farmers to control late blight disease but it's better to control disease before its occurrence, so different cultural methods are used by researchers to achieve this goal [28]. For late blight disease management, various cultural strategies might be used. The primary line of protection against late blight is cultural practices. By lowering the pathogen's reproduction, survival rate, and penetration, cultural techniques are used to lower its population [29]. Avoiding introducing late blight into a field by using only disease-free seed tubers, preferably certified seed, eliminating all cull and volunteer potatoes, avoiding frequent or nighttime overhead irrigation, and ensuring good soil coverage can minimize the survival of *P. infestans* to establish epidemics. To avoid the introducing late blight on seed especially. new strains of the disease, seed sources should be carefully chosen [30]. Managed irrigation and field selection procedures can help limit the length of times when disease growth is favorable, even while weather circumstances are beyond many controls. Late blight can be decreased with generally resistant potato genotypes and enhanced cultural techniques. It's better to use resistant crop varieties along with regular application of fungicides to completely eradicate late blight disease in potatoes [31].

Table 5: Management of Late Blight Through Cultural Control

Cultural Control Method	Effectiveness (%)	Cost (in PKR per acre)	Popular Region
Crop Rotation	75	500	Punjab
Early Planting	70	400	Sindh
Hilling-Up	65	350	KPK
Sanitation Practices	80	600	Balochistan
Residue Removal	75	500	Gilgit-Baltistan
Field Hygiene	70	400	AJK

Future Prospective

The causative pathogen itself, as well as growers, researchers, plant breeders, product developers, and other stakeholders, have a significant impact on the future. The pathogen has demonstrated the ability to evolve so that it can defeat resistance strains and fungicides. If both mating types of the pathogen become established together in the growing area, Late blight could spread like Early blight and become a widespread disease. If this happens to potato crops it could have a bad impact on the production of potatoes, especially for organic growers and gardeners. Instead of using fungicides scientists need to work

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on environmentally friendly treatment methods. There are three types of management strategies in use: cultural, biological, and chemical management. If precise forecasts are made and end users are informed as soon as possible, forecasting is the superior option for managing late blight, as infected potato tubers cause the primary sources of infection in next season. In Pakistan, farmers have lack of awareness to manage the potato crop if it gets infected, there should be workshops to aware the growers so they could control the disease at initial stages of disease.

CONCLUSIONS

Since potatoes are recommended as a crop for food security both globally and in Pakistan. It is crucial to identify the main production limitation. The most damaging disease limiting production is late blight, which can completely wipe out a crop of potatoes. Therefore, choosing an appropriate management approach requires a thorough grasp of the disease's progression and mechanism. Potato late blight can be managed in a variety of ways that can help to lessen its impact. However, because of the introduction of new strains, there is no one management method for potato late blight that is successful worldwide. Therefore, strategies like resistant cultivars, cultural controls and appropriate application of fungicides are more effective methods to control late blight disease in Pakistan.

Authors Contribution

Conceptualization: SU
Methodology: OA
Formal analysis: SK
Writing, review and editing: SU, OA, SK

All authors have read and agreed to the published version of the manuscript

Conflicts of Interest

The authors declare no conflict of interest.

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