Breeding for late blight disease resistance varieties in Potato: A strategic approach for food security and sustainability.

ABSTRACT

Potato (*Solanum tuberosum* L.) is one the most important stable foods that helps to resolve the global food crisis. However, its production has been limited due to various biotic and abiotic factors. Late blight disease caused by *Phytophthora infestans* is one of the destructive pathogenic diseases that not only results in potato yield losses but also increase the cost of production due to huge monetary expenses the growers inquire for disease control and preventive measures. The pathogen could result in a 20-100% yield reduction depending on the susceptibility of the variety, prevailing climatic variables, preventive and control measures taken, and the pathogen load in the area. The losses in the yield resulted in hunger and starvation. Annually, the losses due to *Phytophthora infestans* have been estimated to be $ 12 billion globally. The use of chemicals to control the disease seems to be the most effective measure, the method is no more economically and environmentally sustainable. The development and deployment of resistant varieties remain the most sustainable approach to managing and controlling diseases to ensure food security. This review examines the significance of the late blight disease of potatoes, its control measure, and the need for disease-resistant varieties.

KEYWORDS: Chemical control, Food security, Late blight, *Phytophthora infestan*, Potato, Resistant.

Introduction

Food insecurity and sustainability is a global issue that needs urgent intervention. The world population was estimated by the United Nations [1] to reach 9.4 billion by 2050. Presently, there is a wide gap in global food supply and demand. Feeding the continuously growing population has been one of the greatest challenges encountered by international organizations, government bodies, and individuals. The level of food security in a geographical or political region is estimated by the quantity of food available, accessible, and affordable by the people. Unfortunately, a greater percentage of the human population doesn't have access to sufficient, safe, and quality daily dietary needs [2]. In Africa, the number of hungry and undernourished people are increasing rapidly in the past 10 years [3].

Overcoming the problem of food insecurity and malnutrition in the growing population requires active food production to bridge the gap between the global food supply and demand [4]. Active food production involves the use of good farm inputs, increasing the area of farmland to be cultivated, involvement of more people in farming activities, and adoption of new farming techniques. While adopting these strategies, biotic and abiotic factors limiting crop production should also be guided against.

Potato (*Solanium tuberosum* L) is an annual herbaceous crop that produces edible tubers. After rice, wheat, and maize, potato is the fourth most consumed crop globally [5]. The average yield of potato tuber in Nigeria is about 4.3 t/ha compared to the global tuber yield average of about 21.4 t/ha [6]. Potato is rich in carbohydrates, protein, vitamins, minerals, and fibres [7]. Potato production, processing, and marketing have contributed significantly to the livelihoods of those who are involved and enhanced food availability and sustainability. Despite the economic and nutritional importance of the crop, it is still challenged by different biotic and abiotic adversities. Among the various biotic factors affecting the crop, late blight disease is the most devastating one causing the greatest economic losses [8].The disease could cause more than 50% of tuber losses in potatoes [9]. 100 % tuber yield loss was reported by Ahmed *et al*. [10] under epidemic conditions. However, the extent of losses recorded in the disease-infected farms varied as per their plant protection measures taken and the degree of susceptibility of the cultivar grown, and the prevailing environmental conditions in the area. Global potato losses due to late blight disease were estimated to exceed US $12 billion yearly [11], thus the pathogen responsible for the manifestation of the disease is a great threat to food security and sustainability [12].

Late blight disease of potatoes is caused by *Phytophthora infestans* (Mont.) de Bary*.* It is a fungal disease caused by *Phytophthora infestans* (P. *infestans*) in class *Oomycetes.* The pathogen *Phytophthora infestans* is the most popular and most researched species of *Phytophthora*. However, it is the most destructive of all potato diseases [13]. Managing the disease has been a major farmer’s challenge. Management of the disease using different approaches has increased the cost of crop production, thereby reducing the grower’s income. The use of chemicals seems to be the most effective control measure, however, agrochemicals lead to environmental problems [14]. The objectives of this review were to (i) know more about the pathogen “*Phytophthora infestans* (Mont.) de Bary” causing potato late blight; (ii) understand various management approaches for potato blast disease and (iii) have reasons for developing late blight disease tolerant varieties.

Epidemiology

The major source of infection in potato late blight is through infected tubers. The pathogen, *Phytophthora infestans can* survive on numerous solanaceous plants, weeds, and in the soil which serve as a source of infection in the next growing season [15-16]. The fungus can also survive on the living tissue of unharvested or volunteer potatoes abandoned on the field or elsewhere[16]. Wind, splashed rain, materials transportation, humans, and animals are responsible for the spread of the pathogen from one location to another[16]. Within a short time of infection, new sporangiophores will emerge from the leaves' stomata and thereby multiply depending on the prevailing environmental variables in the area. Bhattacharyya *et al*. [17]

reported that 0.01 % to 3.0 % of the infected tuber is sufficient to initiate a late blight epidemic in the subsequent growing seasons.

Symptomatology

The late blight disease affects all the underground and aboveground parts of the plant. The first symptoms of late blight disease in the field appear on the lower leaves with a small, light-to-dark green, and circular-to irregularly-shaped. The lower leaves show water-soaked lesions which may not be easily noticed[16]. It is sometimes surrounded by a pale yellowish border. When the variety grown are susceptible and the environmental variables are favourable for the pathogen, the symptoms spread to the upper leaves rapidly [18]. The light to dark green water-soaked lesions turn brown to black spots, destroying the whole leaf. A white fluffy fungal appears at the underside part of the infected leaves. The visible white fluffy fungal is the distinguishing feature of leaf blight[18]. On the stem and the petioles, light brown lesions are developed in an elongated or encircled manner that weakens and breaks them, thus killing the plant [19]. Rusty brown discoloration, and dry, hard, and granular lesions on the potato tuber flesh is a typical symptoms of the disease [20]. A severely infected potato late blight field looks like a field burnt partially by fire [21] and emits a rotten odour.

Management Approaches of Late Blight Management Potato

An integrated disease management approach is an effective method of controlling late-blast disease. This involves the use of biological, cultural, and chemical measures and resistant varieties [22]. In developing and under-developed nations, the use of resistant crop varieties is considered the best option for farmers in managing this problem [23].

Cultural method

The first line of action to ensure a late blight-free potato field and tubers is cultural practices. This method reduces the pathogen load by reducing their survivability, inhibiting their reproduction, and reducing the rate of their dispersal and the pathogen penetration. The initiation of the disease can be reduced through avoidance by planting disease-free tubers and eliminating all potato plants and tubers abandoned on the field in the previous year. The low dosage of nitrogenous fertilizer usage is often recommended as a cultural practice to inhibit the growth and development of late blight [24] while the high dosage of phosphorus and potassium fertilizer is recommended [25]. The selection of well-aerated fields and early planting and early weeding should be adopted as a preventive measure[18].

Biological control

Biological control is an eco-friendly disease management approach. This approach is a difficult task especially when the extent of the disease pressure is high and the prevailing environmental conditions are favourable to the pathogen[18]. The use of botanicals and microorganisms has been used in the management of late blight of potatoes. The leaf extracts from onions and garlic inhibit the mycelial growth of *P. infestans.* The effectiveness of some antifungal properties was reported to inhibit late blight from botanicals [26]. Some microorganisms have been used to inhibit the mycelial growth of late blight. *Bacillus subtilis and Purpureocillium lilacinum* was found to be good antagonist of *P. infestans* [28]. O' Herlihy *et al*., [29] reported the use of some endophytic organisms in controlling the late blight of potatoes.

Chemical Control

The use of fungicides has been the major approach adopted to prevent late blight disease of potatoes. However, the use of fungicides is temporary as they are subject to breakdown over time [30]. Thus, multiple application of fungicide at certain intervals is required [31]. The fungicides can stop or slow down the development of new symptoms if applied at a specific interval, however, the use of fungicides will not cure potato plants with existing late blight symptoms [32].

Forecasting Systems

The use of computer programming models to forecast disease outbreaks helps to estimate the likelihood and severity of the outbreak and this will help to prepare for the approaches to be adopted[23].

Integrated Management of Blight Disease

Integrated management involves the use of various disease control methods for efficient management. This method should be adopted by both commercial and small-scale farmers. An Integrated Management approach saves the environment from degradation and increases grower profit margin. Chemical control seems to be the most effective measure against late blight disease of potatoes but it should be the last option to be adopted by the grower.

The need for genetic improvement for resistant varieties

The use of improved varieties that are resistant to blast disease offers an excellent control strategy without any negative effects on the ecosystem. The method is less expensive, eco-friendly, and not laborious, unlike other control measures. Thereby reducing the farmer's cost of production and increasing their livelihood.

Developing disease-resistant varieties involves a proper understanding of the disease and the plant biology by the plant breeder. Although, this may be tasking because the pathogen can evolve or mutate to overcome resistance genes [33]. Screening of potato accessions and wild-related species for genes that are resistant to late blight is the first step in identifying the genes that are resistant to *P. infestans*. The potato accessions and wild species that are resistant to blight pathogen are introgression sources of new resistance genes to be introduced into some elite potato varieties using different plant breeding or biotechnology tools. The availability of the potato plant and blight disease genome sequences serves as a building block for further research in developing potato cultivars that are tolerant to the disease.

Conclusion

Potato blight has been one of the major biotic factors limiting potato production which results in food insecurity. The use of several disease management approaches has been adopted by farmers. Most of these methods are not effective because most growers don't have the proper knowledge of the approaches. The chemical method seems to be the most effective but the cost is high and the negative effects on the ecosystem are alarming. The development and release of tolerant varieties against *P. infestans* is a promising approach that will not only enhance potato production for food security and sustainability but also save the environment. Breeding for blight resistance and availability will be a success story for the grower, the consumers, and the ecosystem at large.

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Declarations

Limitations of the study

None

Competing Interests

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REFERENCES

1. Bilen G, lassaletta L, Garnier, J. A vast range of opportunities for feeding the world in 2050: trade off between diet, N contamination and international trade. Environmental Research Letters. (2015);10(2);25001. DOI: 10.1088/1748-9326/10/2/025001

2. Owoo, NS. Demographic considerations and food security in Nigeria. J. Soc. Econ. Dev. (2021); 23, 128-167. https://doi.org/10.1007/s40847-020-00116-y

3. Food and Agriculture Organization [FAO]. The State of Food Security and Nutrition in the World 2018. Building Climate Resilience for Food Security and Nutrition, Food and Agriculture Organization, Rome, (2018).

4. Royal Society. Reaping the Benefits: Science and the Sustainable Intensification of Global Agriculture. The Royal Society, London, (2009).

5. Prabha, N, Nanda HC, Sharma SK. Genetic Divergence Analysis in Potato (*Solanum tuberosum* L.). Int. J. Curr. Microbiol. App. Sci. (2018);7 (2):3152-3157.

6. Loebenstein G, Fuentes S, Cohen J, Salazar LF. Sweet potato. In: Loebenstein, G., Thottappilly, G. (eds) Virus and virus like diseases of major crops in developing countries. Springer, Dordrecht, (2003). https://doi.org/10.1007/978-94-007-0791-7_9

7. Lal, MK, A. Kumar, A. Kumar and J. P. Raigong, (2020). Minerals in Potato. In: Raigond, P. Singh, B., Dutt, S., Chakrabarti, S.K (eds) Potato. Springer, Singapore. https://doi.org/10.1007/978-981-15-7662-1_6

8. Chowdappa, P, Nirmal Kumar BJ, Madhura S, Mohan Kumar SP, Myers KL, Fry E, Cooke DEL. Severe outbreaks of late blight on potato and tomato in South India caused by recent changes in the *Phytophthora infestans* population. Plant Pathology, (2015); 64(1):191-199.

9. Amadi, CO, Ghislain M, Kahya SS, Dabels V, Nnadi NE, Amadi G. Prospects of mitigating late blight disease of potato in nigeria through deployment of triple *r* (3*r*) stacked gene transgenic varieties. Nigerian Agricultural Journal (2021); 52(2), 108.

10. Ahmed NM, Khan MA, Khan NA, Ali MA. Prediction of potato late blight disease based upon environmental factors in Faisalabad, Pakistan. Journal of Plant Pathology and Microbiology. (2015);**S3**:008

11. Shailbala A, Kumar A. Eco-friendly management of late blight of potato– A review. J. Appl. & Nat. Sci. (2017) 9(2), 821 – 835.

12. Newbery F, Qi A, Fitt BD. Modelling impacts of climate change on arable crop diseases: progress, challenges and applications. Current Opinion in Plant Biology, (2016);32;101-109.

13. Muluadam B. Review on epidemiology, sampling techniques, management strategies of late blight (*phytophthora infestans*) of potato and its yield loss. Asian Journal of Advances in Research. (2012);4(1): 199-207.

14. Guchi E. Disease management practice on potato (*Solanum tuberosum* L.) in Ethiopia. World Journal of Agricultural Research, (2015);3(1):34-42.

15. Forbes GA, Landeo JA. Late blight. In: (Gopal, J.P.K.S.M. ed.) Handbook of potato production, improvement and post harvest management, Haworth Press Inc., Binghamton, New York, (2006);279-320.

16. Leah TL. Fungal, oomycete, and plasmodiophorid diseases of potato and their control. In Potato Production Worldwide, (2022). https://doi.org/10.1016/B978-0-12-822925-5.00012-8

17. Min JK, CHng KS, Jong-Ho P. Control Efficacy of *Bacillus velezensis* AFB2-2 against Potato Late Blight caused by *Phytophhora infestans* in Organic Potato Cultivation. Plant Pathol. (2021);10.5423/PPJ.FT.09.2021.0138

18. Mehi L, Sharma S, Yadav S, Kumar S. Management of Late Blight of Potato. Potato - From Incas to All Over the World. InTech Publisher, (2018). http://dx.doi.org/10.5772/intechopen.72472

19. Van der Waals JE, Korsten L, Aveling TAS. A review of early blight of potato. African Plant Protection. (2001);7(2). https://hdl.handle.net/10520/EJC87837

20. Binyam, T. Late blight of potato (*phytophthora infestans)* Biology, Economic Importance and its Management Approaches. Journal of Biology, Agriculture and Healthcare. (2014);4(25): 215-225

21 Lucas GB, Cambell CL, Lucas LT. Diseases caused by Airborne Fungi. In: Introduction to Plant Diseases. Springer, Boston, (1992). https://doi.org/10.1007/978-1-4615-7294-7_13

22. Agrios GN. *Plant pathology*. Academic press, (2005).

23. Agbowuro GO, Afolabi,MS, Olamiriki EF, Awoyemi SO. Rice Blast Disease (*Magnaporthe oryzae*): A Menace to Rice Production and Humanity. International Journal of Pathogen Research, (2020); 4(3): 32-39.

24. Pablo LC, Adriana BA, Marcelo AH. Reaction of late blight in response to nitrogen management in Argentine potato cultivars. Crop Protection. (2012);42:69-73

25. Roy SK,Sharma RC, Trehan SP. Integrated nutrient management by using farmyard manure and fertilizers in potato-sunlower-paddy rice rotation in the Punjab. The Journal of Agricultural Science. (2001);137:271-278.

26. Sadana, D. and Didwania, N. 2015. Bioefficacy of fungicides and plant extracts against Alternaria solani causing early blight of tomato. International Conference of Plant Marine and Environmental, Sciene. (2015);1(2);38-42.

27. Youyo W, Congying Z, Jiao L, Lufang W, Wenbin G, Jizhi J. Itrin A extracted from Bacillus subtilis WL-2 affects Phytophthora infestan via cell structure disruption, oxidation stress, and energy supplydysfunction. Fron. Microbiol. (2020);11-2020. https://doi.org/10.3389/fmicb.2020.536083

28. Wang G, Liu Z, Lin R, Li E, Mao Z, Ling J, Yang Y, Yin WB, Xie B. Biosynthesis of antibiotic Leucin statins in bio-control fungus *Purpureocillium lilacinum* and their inhibition on Phytophthora revealed by genome mining. PLoS Pathog. (2016);12(7):1-30.

29. O'herlihy EA, Duffy EM, Cassells AC. The effects of arbuscular mycorrhizal fungi and chitosan sprays on yield and late blight resistance in potato crops from micro-plants. Folia Geobotanica, (2013);38: 201-207

30. Gupta SK, Thind TS. *Disease problems in vegetable production*. Scientific Publishers, (2018).

31. Matthews G. *Pesticides: health, safety and the environment*. John Wiley & Sons, (2015).

32. Nieder, R.,Benbi DK, Reichl FX. Health Risks Associated with Pesticides in Soils. In *Soil Components and Human Health* (2018) (pp. 503-573). Springer, Dordrecht.

33. Hasan MM., Rafii MY , Ismail MR , Mahmood M, Alam MA, Rahim HA, Malek HA, Latif MA. Introgression of blast resistance genes into the elite rice variety MR263 through marker-assisted backcrossing. J. Sci. Food Agric. (2016);96(4): 1297-1305.