Plant Protection, 08 (03) 2024. 365-373 DOI:10.33804/pp.008.03.4873

Check for updates

Available Online at EScience Press
Plant Protection
ISSN: 2617-1287 (Online), 2617-1279 (Print)
http://esciencepress.net/journals/PP

Research Article

ASSESSING POTATO CULTIVARS FOR RESISTANCE AGAINST LATE BLIGHT UNDER HIGH ALTITUDINAL CONDITIONS OF NORTH WESTERN HIMALAYAS

[a]Waseem Ali Dar, [a]Bilal Ahmad Bhat, [a]Mohammad Mudasir Magray, [b]Farooq Ahmad Bhat, [c]Reyaz ul Mir, [c]Mohammad Anwar Khan, [d]Feroz Ahmad Parry, [e]Sajad Majeed Zargar

[a] Mountain Agriculture Research and Extension Station, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, India.
[b] Division of Plant Pathology, Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, India.
[c] Division of Genetics and Plant Breeding, Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, India.
[d] Division of Horticulture, Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, India.
[e] Division of Plant Biotechnology, Faculty of Horticulture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, India.

ARTICLE INFO

Article history
Received: 10th October, 2023
Revised: 2nd July, 2024
Accepted: 7th July, 2024

Keywords
Late blight of potato
Phytophthora infestans
AUDPC
Rate of disease spread
Susceptibility scale

ABSTRACT

Different stages in plant development significantly influence the incidence of potato late blight disease in India. In the present study, the disease progression was monitored weekly in five selected potato cultivars viz. Kufri Jyoti, Kufri Giriraj, Gulmarg Special, Shalimar Potato-I, and Gurez local, during the 2018 and 2019 cropping seasons. The severity of potato late blight, caused by *Phytophthora infestans*, increased with fluctuations in weather variables. Calculations for the area under the disease progress curve (AUDPC) and the rate of disease spread (r-value) at different growth stages of potatoes were used to track disease progression. Notably, the Kufri Jyoti cultivar demonstrated resistance compared to the other cultivars, with lower severity values and susceptibility scale values (48.40%; 5.6 and 4.9) in 2018 and 2019, respectively. The average rate of disease progress was also lower in Kufri Jyoti (0.064 and 0.060) compared to the local cultivar (0.076 and 0.074) in 2018 and 2019, respectively. These observations indicate that weather parameters have a strong positive impact on the incidence of potato late blight.

Corresponding Author: Waseem Ali Dar
Email: luckywasim2017@gmail.com

INTRODUCTION

Potato (*Solanum tuberosum* L.) is the most widely cultivated and consumed tuber crop worldwide. It is an important crop for food security and hunger relief due to its ability to mature earlier than other crops (Ayda, 2015; Hassan et al., 2015). Its high yield per unit area and nutritional value provide significant advantages for food security (Ali et al., 2015; Chala and Dechasa, 2015).

The potato crop faces various constraints from both biotic and abiotic factors. Major production challenges include late blight disease, lack of improved varieties, and periodic water stress (Girma et al., 2004; Gebremedhin et al., 2008; Adane et al., 2010; Hassan et al., 2015; Nisa et al., 2022). Globally, potato tuber yield loss due to late blight is estimated at $12 billion (Haverkort et al., 2009). In India, a 10-15% reduction in yield has been observed due to the occurrence of potato late blight (Lozoya-Saldana, 2011; Mehi et al., 2016). Every year, late blight of potato appears epidemically in the Himalayan and Nilgiri hills and sporadically in cold deserts, central, and Deccan plateau (Dutt, 1979).

Late blight disease of potato, caused by *Phytophthora infestans* (Mont.) de Bary, is economically significant and particularly devastating in the high Himalayan temperate regions. It is also a major concern for potato growers worldwide (Hijmans et al., 2000; Guenther et al., 2001). *P. infestans* infects potato crops via sporangia and zoospores/oospores formed on volunteer potatoes under moist conditions during cool and wet weather (Johnson, 2010; Goss et al., 2014; Fry et al., 2015). The disease intensity of late blight at high altitudes is high due to sandy and clay soils contaminated with oospores, which remain infectious for up to 48 months (Turkensteen et al., 2008).

The lifecycle and aggressiveness of the late blight pathogen are strongly influenced by weather variables and resistance to fungicides within the local pathogen population (Doster et al., 1989). Late blight disease progresses rapidly when temperatures exceed 28-30°C and relative humidity is 90-95% for two days or more (Razukas et al., 2007; Mohsan et al., 2016). The current climate change patterns are influencing the appearance of late blight of potato, leading to moderate to high disease severity even in the plains (Mehi et al., 2016). Weather variables play a significant role in the development of potato late blight under natural epidemic conditions.

Researchers worldwide are continually monitoring the re-emergence of late blight disease in potatoes and employing various management strategies. Different sowing dates and the impact of environmental parameters are key to understanding disease development and refining management approaches (Dang et al., 1995; Singh et al., 1998). Developing technical knowledge about the epidemiological factors that drive the progression of late blight and finding ways to minimize losses from this disease are major challenges in potato production. Calculations of the area under the disease progress curve (AUDPC) and the rate of disease spread (r-value) can be used to forecast late blight, inform management strategies, and classify potato genotypes for susceptibility or resistance (Andrivon et al., 2003). However, no efforts have been reported so far that use AUDPC and r-value in relation to disease development at different plant growth stages.

The objective of the present study was to estimate susceptibility and the rate of disease spread at different plant growth stages to reduce fungicide input while achieving acceptable control of late blight.

MATERIALS AND METHODS

The monitoring of potato late blight outbreak and disease development was conducted during the 2018 and 2019 cropping seasons at the Mountain Agriculture Research and Extension Station (MAR & ES), Gurez, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir (SKUAST-K), Jammu and Kashmir, India. The station is located at a latitude of 34° 38' 1.57" N and a longitude of 74° 50' 25.27" E, with an altitude of 2430 meters above sea level in the Northwestern Himalayas, India. The area is characterized by a cold climate with high humidity, long rainy days (May-June), and a short semi-dry season (August to October), with a single cropping season from May to October.

Five popular potato cultivars (Kufri Jyoti, Kufri Giriraj, Gulmarg Special, Shalimar Potato-I, and Gurez local) were obtained from the farm manager of the research station (MAR & ES). The experiment was laid out in a Randomized Complete Block Design with three replications. The spacing between plants was 30 cm, and the spacing between rows was 75 cm, in a plot measuring 2.0 m × 2.0 m. The percentage of total leaf area showing symptoms of late blight was recorded at 7-day intervals from the onset of symptoms and continued until the susceptible cultivar showed complete blighting, assessed as either 8 (97.5%) or 9 (100%) on the 1-9 scale Henfling (1979). The intensity of late blight in each cultivar/plot was recorded, and the area under the disease progress curve (AUDPC) was calculated using the midpoint method (Campbell and Madden, 1990). AUDPC values for each cultivar were computed based on lesion number and the percentage of leaf area affected. The calculation was made using the formula proposed by Wilcoxson et al. (1975).

$$AUDPC = \sum^{n}_{i=1} [(Si + Si\text{-}_1) x0.5 (t_2\text{-}t_1)]$$

Where

S_i = Amount of disease at i^{th} time, i ranges from 1 to n

S_{i-1} = Amount of disease at $(i-1)^{th}$ time

t_2-t_1 = Number of days between two observations

n = Number of successive evaluation of disease

AUDPC is commonly used to compare different varieties or treatments (Jeger et al., 2004) and to evaluate the resistance of plant species to pathogens (Mikulova et al., 2008; Irfaq et al., 2009). To standardize AUDPC values across years before analysis, the metric was converted into relative AUDPC (rAUDPC) as described by Fry (1983). Resistance scale values of different potato cultivars were assessed for resistance and susceptibility using AUDPC or rAUDPC values, following the method proposed by Yuen and Forbes (2009) with the following equation:

$$Sx = Sy \times \frac{Dx}{Dy}$$

Where, Sy represents the assigned susceptibility scale value and Dy the observed disease measure (AUDPC or rAUDPC) for the standard genotype. Similarly, Sx represents the calculated susceptibility scale value and Dx the observed disease measure for the genotype in question.

The rate of disease spread, r, is a frequently used measure of temporal disease progress in general epidemics. This rate was determined using the following formula against time:

$r = 2.3/t \{\log X_2/1- X_2 - \log X_1/1- X_1\}$

Where r is the rate of disease spread during the non-logarithmic phase, X_1 is the disease index at the initial week time (t_1), and X_2 is the disease index at a subsequent week time (t_2), which is a parameter in the logistic growth equation (Zadoks and Schein, 1979) and can be estimated from a time series of disease progression after logit transformation of severity (Berkson, 1944). The apparent rate of infection, expressed in units per day, was calculated by first transforming the disease index into logits using ln[Y/(1-Y)], where Y represents the proportion of infected tissues and 1-Y represents the proportion of healthy tissue. Logit values (y) were regressed against time (x) to obtain a regression line, the slope of which represents the apparent rate of infection.

RESULTS

The performance of potato cultivars planted in 2018 and 2019 showed varied responses to late blight. Symptoms of late blight began at the pre-flowering stage 35 days after transplanting (DAP), and disease severity was assessed weekly under natural epiphytotic infection conditions.

Among the tested cultivars, one showed resistance, one susceptibility, and three moderate resistance based on AUDPC values, susceptibility scale values, and disease spread rates. The results presented in Table 1a and 1b indicated that late blight incidence was higher in 2018 compared to 2019. AUDPC values in 2019 ranged from 1272 for Kufri Jyoti to 2380 for Gurez local, significantly lower ($P = 0.05$) than the AUDPC values in 2018, which ranged from 1540 for Kufri Jyoti to 2493 for Gurez local. Similarly, rAUDPC values varied from 0.25 to 0.54 in 2018 and 0.22 to 0.52 in 2019, with Kufri Jyoti showing the minimum and Gurez local the maximum severity.

Potato late blight severity increased from mid-August to the 3rd week of September, coinciding with a rise in maximum and minimum temperatures from 18°C to 24°C and 2°C to 12°C, respectively. Relative humidity (85-95%) also increased due to rainfall (15.5-20.75 mm) and average wind speeds of 1-5.5 km/h during this period. These rainfall events likely had a direct impact on the observed disease scores.

Comparing the two epidemics, fluctuations in environmental variables were more pronounced in 2018 than in 2019 (Figure 1a and 1b). Among the tested cultivars, late blight severity varied from 48.40% to 85.44% during both 2018 and 2019, with relative AUDPC values consistently below 0.025 for resistant and moderately susceptible cultivars, and slightly higher at 0.52 and 0.54 (Table 2). Average rAUDPC values indicated similar levels of relative resistance across both cropping seasons (Figure 2). Mean values of disease severity and the extent of variation during the cropping seasons suggest that prevailing growing conditions play a significant role in disease development. Lower mean values with a limited range indicate a low incidence of potato late blight, while intermediate and higher mean values with greater ranges suggest moderate to high incidences of late blight, respectively.

Potato late blight severity was recorded weekly, and severity values were transformed into logits to estimate the initial disease slope for each epidemic, representing the rate of infection over time. However, the rate of disease spread was lower in 2019 (ranging from 0.060 logit/day to 0.074 logit/day with a mean of 0.094 logit/day) than in 2018 (ranging from 0.064 logit/day to 0.076 logit/day with a mean of 0.404 logit/day). Apparent infection rates were relatively consistent within cultivars for each test year, ranging from 0.064 to 0.075 in 2018 and from 0.059 to 0.062 per day in 2019 (Table 1a and 1b). During both cropping seasons, infection responses of the cultivars were significantly lower than those of the susceptible check (Table 3a and 3b).

Table1a. Area under disease progress curve (AUDPC), relative AUDPC, susceptibility scale value and apparent rate of infection/logit per unit per day for late blight of potato caused by *P. infestans* during 2018.

Genotype	AUDPC	rAUDPC	Susceptibility scale value	rate of disease spread (r)
Kufri Jyoti	1540 ± 2.94	0.25 ± 1.41	5.6	0.062
Kufri Giriraj	1929 ± 2.47	0.34 ± 1.06	6.0	0.067
Shalimar Potato-I	1988 ± 1.41	0.36 ± 1.39	6.2	0.068
Gulmarg Special	2081 ± 1.41	0.37 ± 1.40	6.5	0.070
Gurez Local	2493 ± 1.05	0.54 ± 1.06	9	0.075

Table 1b. Area under disease progress curve (AUDPC), relative AUDPC, susceptibility scale value and apparent rate of infection/logit per unit per day for late blight of potato caused by *P. infestans* during 2019.

Genotype	AUDPC	rAUDPC	Susceptibility scale value	rate of disease spread (r)
Kufri Jyoti	1272 ± 1.94	0.22 ± 0.014	4.9	0.052
Kufri Giriraj	1579 ± 1.06	0.26 ± 0.014	6.0	0.061
Shalimar Potato-I	1600 ± 1.41	0.30 ± 0.016	6.2	0.062
Gulmarg Special	1750 ± 1.76	0.32 ± 0.014	6.5	0.055
Gurez Local	2380 ± 3.85	0.52 ± 0.035	9	0.062

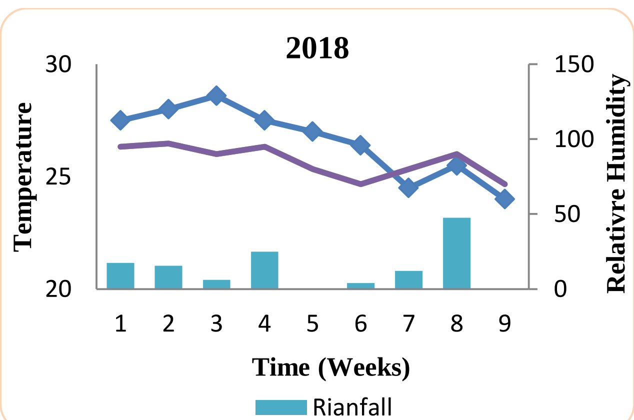

Figure 1a. Climatic parameters during disease progress period in 2018.

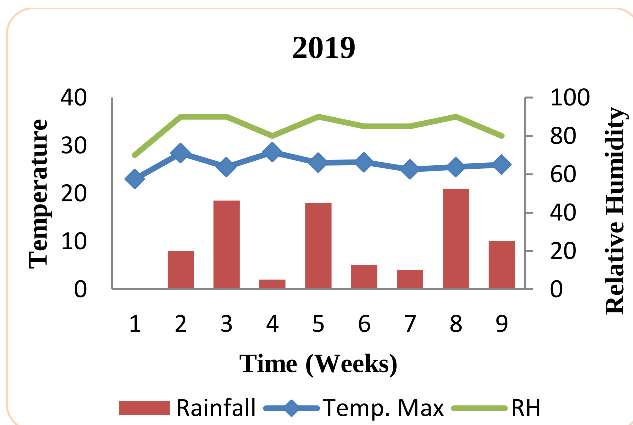

Figure 1b. Climatic parameters during disease progress period in 2019.

Table 2. Mean severity values of two epidemics 2018 and 2019.

S. No.	Genotype	Severity value
1	Kufri Jyoti	48.40%
2	Kufri Giriraj	56.47%
3	Shalimar Potato-I	62.66%
4	Gulmarg Special	49.77%
5	Gurez Local	85.44%

Out of the 5 cultivars reported to exhibit slow epidemic characteristics or reduced r-values, which were evaluated in the field, different types of reaction responses were observed: resistant, moderately resistant, or susceptible to late blight. Mean r-values and susceptibility scale values for the different cultivars across the two cropping seasons represent the differences exhibited by the susceptible versus the resistant cultivars (Table 1a and 1b).

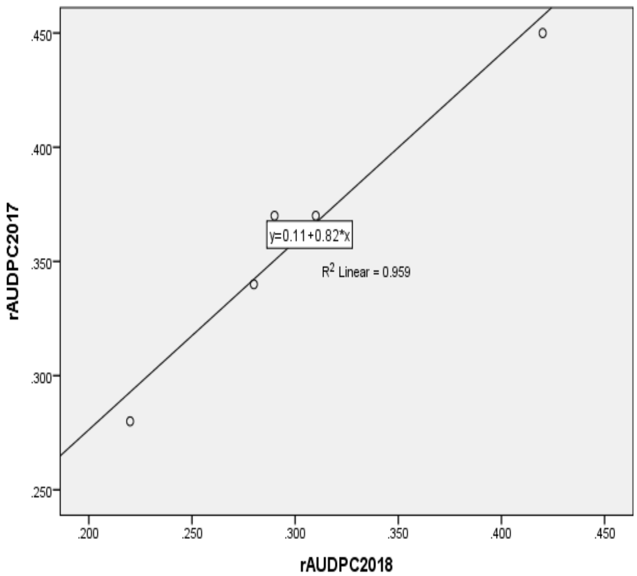

Figure 2. Comparison of yearly average relative area under disease progress curve (rAUDPC) values of potato cultivars evaluated for resistance to *P. infestans* in the field experiments during 2018 and 2019. The diagonal represents identical values for two years.

The apparent infection rate (r) in genotypes at different stages showed wide variation (Table 3a and 3b). The highest average 'r' value was observed in the cultivar Gurez Local (0.0762, 0.074), and the lowest in Kufri Jyoti (0.064, 0.062) during the 2018 and 2019 cropping seasons, respectively. Kufri Giriraj showed an average infection rate of 0.068 and 0.069, Shalimar Potato-I 0.073 and 0.068, and Gulmarg Special 0.072 and 0.061 during 2018 and 2019, respectively.

Observations on disease progress curves of potato cultivars tested over two cropping seasons are well reflected in the average disease progress curves (Figure 1a and 1b) and the corresponding logit/day lines. Among the five cultivars, Gurez Local exhibited the fastest epidemic, followed by Shalimar Potato-I, while Kufri Jyoti, Kufri Giriraj, and Gulmarg Special were slow epidemic cultivars. Based on disease reaction (disease severity and rAUDPC), potato cultivars were identified as resistant (Kufri Jyoti), moderately resistant (Kufri Giriraj, Gulmarg Special, and Shalimar Potato-I), and susceptible (Gurez Local).

The maximum rate of spread in all the cultivars was observed between 35-42 DAI and also increased from 63 to 84 DAI during both cropping seasons. In the present study, the average apparent rate of infection in potato late blight disease varied over time and did not remain consistent for a given cultivar, nor did it show a particular trend. This inconsistency is attributed to the genetic characteristics of the genotype.

DISCUSSION

The potato cultivars exhibited resistant and moderately resistant responses to late blight under field conditions, making them suitable candidates for popularization and integration into further breeding programs. Successful forecasting and prediction at various locations necessitate the evaluation of suitable weather variables for potato late blight disease development. Our findings agree with observations that maximum and minimum temperatures in the ranges of 16-20°C and 1-6°C, respectively, were favorable for potato late blight (Nadeem et al., 2015). It is evident that maximum temperatures (36.9°C and 38.1°C) and relative humidity (94% and 96.4%) exhibited a strong positive relationship with the incidence of potato late blight. The interaction among morning (maximum) relative humidity, afternoon (minimum) relative humidity, maximum temperature, and minimum temperature predicted the highest late blight incidence in potatoes (Meena et al., 2002). The Royal Netherlands Meteorological Institute recently published new climate change scenarios in the KNMI'14, which showed minor changes in humidity as the main factor influencing the establishment of *P. infestans* (Van den Hurk et al., 2014). Santosh et al. (2021) also noted that temperature (minimum and maximum), relative humidity (morning and evening), and rainfall influenced the severity of Alternaria leaf blight in makhana under the agro-climatic conditions of the Koshi region in Bihar.

During the current study, various tools such as AUDPC, rAUDPC, susceptibility scale values, and the rate of disease spread were used to assess the resistance of potato cultivars against late blight at different growth stages under high-altitude conditions in the Northwestern Himalayas. The tested potato cultivars ranged from susceptible to resistant. Resistant and moderately resistant varieties had significantly reduced AUDPC compared to susceptible ones (Jones, 1998). A relative AUDPC value of <0.05 was chosen as the disease threshold level, and cultivars with a lower disease threshold were found to be more suitable for cultivation (Nearstad et al., 2007).

Table 3a. Rate of disease spread (r) per unit per day of late blight of potato at various stages of growth in potato genotypes during 2018.

Genotype	Rate of disease spread (r)								Average
	35-42 DAI	42-49 DAI	49-56 DAI	56-63 DAI	63-70 DAI	70-77 DAI	77-84 DAI	84-91 DAI	
Kufri Jyoti	0.087	0.084	0.058	0.054	0.052	0.070	0.075	0.029	0.064
Kufri Giriraj	0.114	0.080	0.052	0.044	0.063	0.069	0.071	0.053	0.069
Shalimar Potato-I	0.169	0.086	0.041	0.062	0.066	0.071	0.75	0.023	0.073
Gulmarg Special	0.107	0.078	0.041	0.049	0.067	0.069	0.66	0.022	0.072
Gurez Local	0.101	0.097	0.073	0.053	0.050	0.075	0.071	0.070	0.076

DAI= Days after Initiation

Table 3b. Rate of disease spread (r) per unit per day of late blight of potato at various stages of growth in potato genotypes during 2019.

Genotype	Rate of disease spread (r)								Average
	35-42 DAI	42-49 DAI	49-56 DAI	56-63 DAI	64-70 DAI	70-77 DAI	77-84 DAI	84-91 DAI	
Kufri Jyoti	0.104	0.056	0.029	0.068	0.081	0.047	0.041	0.040	0.060
Kufri Giriraj	0.140	0.066	0.031	0.036	0.060	0.075	0.069	0.065	0.068
Shalimar Potato-I	0.169	0.037	0.067	0.046	0.046	0.060	0.069	0.065	0.068
Gulmarg Special	0.136	0.048	0.020	0.060	0.049	0.050	0.075	0.041	0.061
Gurez Local	0.086	0.064	0.063	0.053	0.053	0.069	0.081	0.077	0.074

DAI= Days after Initiation.

Disease severity scale and AUDPC values can be controlled in moderately resistant varieties governed by minor genes combined with reduced doses of fungicide (Anonymous, 2007). Depending on the nature of the disease progress curves, logistic values have been proven more appropriate for analyzing the progress of epidemics and comparing the rate of disease spread in several plant pathosystems. Our results align with findings that disease severities, disease progress curves, and disease progress rates were significantly affected by potato varieties, locations, and cropping seasons (Legesse et al., 2021). Similar findings were recorded earlier by Mukherjee (1994) and Mohapatra (2002) in the rice blast pathosystem.

Sinha et al. (1998) reported that disease intensity increases with the transitional development of the plant, which could explain the higher frequencies of disease observed in older plants. As the age of the plant increases beyond 35 days, its susceptibility rises, peaking at 70-100 days after sowing (Meena et al., 2004). Some experimental studies have shown that the rates of disease increase are influenced by the number of initial inoculums, with a higher number of initial foci leading to more significant disease spread (Smith et al., 1998; Jeger et al., 2004).

CONCLUSION

The experimental findings indicated that all potato cultivars significantly correlated with late blight severity. Potato cultivars exhibiting resistance to late blight should be promoted for seed production in high-altitude areas and further integrated into breeding programs. Late blight of potato is highly influenced by weather variables. The AUDPC, susceptibility scale values, and the rate of disease progress are the best tools for assessing cultivars/germplasm lines against any disease.

AUTHORS' CONTRIBUTIONS

WAD, BAB, and MMM designed, conducted the experiments, collected, arranged and analyzed the data; FAB and FAP provided technical assistance; RRM and MAK supervised the work; SMZ proofread the paper.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Adane, H., Miranda, M., Willemien, J.M., Alfons, O.L., Admasu, T., Paul, C., 2010. Analysis of seed potato systems in Ethiopia. American Journal of Potato Research 21, 45-56.

Ali, J., Afridi, S.M., Hussain, A., Paracha, G.M., Hassan, S., Parvez, M., Abbas, S., 2015. Comparative physiochemical and microbiological analysis of potato powder produce from two potato cultivars grown in Peshawar Valley, Pakistan. World Applied Science Journal 33(2), 267-270.

Andrivon, D., Corbiere, R., Lucas, J.M., Pasco, C., Gravoueille, J.M., Pelle, R., Dantec, J.P., Ellisseche, D., 2003. Resistance to late blight and soft rot in six potato progenies and glycoalkaloid contents in the tubers. American Journal of Potato Research 80, 125-134.

Anonymous. 2007. Knowing your enemy-blight. [accessed on July 5, 2020].

Ayda, T., 2015. Effect of fungicides and resistant genotypes on severity of potato late blight [*Phytophthora infestans* (Mont.) de Bary] and yield components at Haramaya, Eastern Ethiopia. MSc thesis. Haramaya University, Dire Dawa, Ethiopia. p. 101.

Berkson, J., 1944. Application of the logistic function to bio-assay. Journal of the American Statistical Association 48, 565-599.

Campbell, C.L., Madden, L.V., 1990. Introduction to plant disease epidemiology. New York: John Wiley and Sons.

Chala, G., Dechasa, N., 2015. Performance of potato (*Solanum tuberosum* L.) at different cultivars and spacing in central highlands of Ethiopia. Ethiopian Journal of Science and Technology 6(1), 23-47.

Dang, J.K., Kaushik, C.D., Sangwan, M.S., 1995. Quantitative relationship between *Alternaria* leaf blight of rapeseed-mustard and weather variables. Indian Journal of Mycology and Plant Pathology 25, 184-188.

Doster, M.A., Sweigaird, J.A., Fry, W.E., 1989. The influence of host resistance and climate on the initial appearance of foliar late blight of potato from infected seed tubers. American Potato Journal 66, 227-233.

Dutt, B.L., 1979. Bacterial and fungal diseases of potato. ICAR, New Delhi.

Fry, W.E., Apple, A.E., Bruhn, J.A., 1983. Evaluation of potato late blight forecast modified to incorporate host resistance and fungicide weathering. Journal Phytopathology 73, 1054-1059.

Fry, W.E., Brich, B.R.J., Judelson, H.S., Grunwald, N.J., Danies, G., Everts, K.L., Gevens, A.J., Gugino, B.K., Johnson, D.A., Johnson, S.B., McGrath, M.T., Myers, K.L., Ristanio, J.B., Roberts, P.D., Secor, G., Smart, C.D., 2015. Five reasons to consider *Phytophthora infestans* a re-emerging pathogen. Phytopathology 105, 966-981.

Gebremedhin, W., Endale, G., Berga, L., 2008. Potato variety development. In: Gebremedhin, W., Endale, G., Berga, L., (Eds). Root and tubers. The untapped resource. Addis Ababa, Ethiopia: EIAR. pp. 315-332.

Girma, A., Hailu, G., Gebremedhin, W., 2004. Research experience and recommended technologies for potato production in Western Oromia, Research report. Boko, Ethiopa: Oromia Agricultural Research Institute (OARI), Bako Agricultural Research Center.

Goss, E.M., Tabima, J.F., Cooke, D.E.L., Restrepo, S., Fry, W.E., Forbes, G.A., 2014. The Irish potato famine pathogen *Phytophthora infestans* originated in central Mexico rather than the Andes. Proceedings of the National Academy of Sciences of the United States of America 111, 8791-8796.

Guenther, J.F., Michael, K.C., Nolte, P., 2001. The economic impact of potato late blight on U.S. growers. Potato Research 44, 121-125.

Hassen, A., Worku, A., Tafere, M., Tolla, M., Ahmed, A., Dagnew, S.G., Selassie, Y., Molla, D., Abebe, T., 2015. Best fit practice manual for potato production and utilization. BDU-CASCAPE Working Paper 8. Addis Ababa, Ethiopia: EIAR Annual report. p. 37

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

Henfling, J.W., 1979. Late blight of potato: *Phytophthora* *infestans*. Technical Information Bulletin. International Potato Center, Lima, Peru 13.

Hijmans, R.J., Forbes, G.A., Walker, T.S., 2000. Estimating the global severity of potato late blight with GIS-linked disease forecast models. Plant Pathology 49, 675-705.

Irfaq, M., Ajab, M., Hongxiang, M., Khattak, G.S.S., 2009. Assessment of genes controlling area under disease progress curve (AUDPC) for stripe rust (*P. striiformis* f. sp. *tritici*) in two wheat (*Triticum aestivum* L.) crosses. Cytology and Geneicst 43, 241-252.

Jeger, M.J., Viljanen-Rollinson, S.L.H., 2004. The use of the area under the disease progress curve (AUDPC) to assess quantitative disease resistance in crop cultivars. Theory of Applied Genetics 102, 32-36.

Johnson, D.A., 2010 Transmission of *Phytophthora infestans* from infected potato seed tubers to emerged shoots. Plant Disease 94, 18-23.

Jones, G.D., 1998. The epidemiology of plant diseases. 3rd ed. London: Kluwer Academic Publishes, p. 388.

Legesse, N.H., Bizuneh, W.F., Shifamo, B.T., 2021. Potato variety screening for its late blight of potato (*Phytophthora infestans* (Mont.) de Bary) resistance and yield performance in Northern Shewa, Central Highlands of Ethiopia. Archives of Phytopathology and Plant Protection 54(19-20), 2440-2463.

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

Meena, P.D., Chattopadhyay, C., Fateh S., Bhoori, S., Ajit, G., 2002. Yield loss in Indian mustard due to White rust and effect of some cultural practices on *Alternaria blight* and white rust severity. Brassica 4, 18-24.

Meena, P.D., Meena, R.L., Chattopadhyay, C., Arvind, K., 2004. Identification of critical stage for disease development and biocontrol of *Alternaria* blight of Indian mustard (*Brassica juncea*). Journal Phytopathology 152, 204-209.

Mehi, L., Arora, R.K., Uma, M., Rawal, S., Yadav, S., 2016. Impact of late blight occurrence on potato production during 2013-14. International Journal of Agriculture Science 1(12), 187-192.

Mikulova, K., Bojnanska, K., Ervená, V., 2008. Assessment of partial resistance to powdery mildew in hexaploid wheat genotypes. Biologia 63, 477-481.

Mohapatra, N.K., 2002. Studies on durable resistance to blast disease of rice. Ph.D. Thesis. Utkal University, Bhubaneswar, Orissa, India.

Mohsan, M., Mustafa, A., Akhtar, S., Iqbal, M., Saeed, S., Niaz, M.Z., Bashir, M.R., 2016. Screening of potato germplasm against late blight disease. International Journal of Advance Research in Biological Sciences 3(8), 200-204.

Mukherjee, A.K., 1994. Components of slow-blasting resistance in rice. Ph.D. Thesis. Utkal University, Bhubaneswar, Orissa, India.

Nadeem, A., Khan, M.A., Khan, N.A., Ali, M.A., 2015. Prediction of potato late blight disease based upon environmental factors in Faisalabad, Pakistan. Journal Plant Pathology and Microbiology 53, 08.

Nearstad, R., Hermansen, A., Bjor, T., 2007. Exploiting host resistance to reduce the use of fungicides to control potato late blight. Plant Pathology 56, 156-166.

Nisa, T., Haq, M.I., Mukhtar, T., Khan, M.A., Irshad, G., 2022. Incidence and severity of common scab of potato caused by *Streptomyces scabies* in Punjab, Pakistan. Pakistan Journal of Botany 54(2), 723-729.

Razukas, A., Jundulas, J., Asakaviciute, R., 2007. Potato cultivars susceptibility to potato late blight (*Phytophthora infestans*). Applied Ecology and Environmental Research 6(1), 95-106.

Santosh, K., Akhtar, M.N., Kumar, M., Kumar, T., 2021. Influence of weather parameters on alternaria leaf blight severity of makhana under the agro-climate of Koshi region of Bihar. Journal of Agrometerology 23(1), 54-59.

Singh, J., Srivastava, S.K., Singh, R., 1998. Effect of planting dates on occurrence of disease pest in mustard varieties. Journal of Oilseeds Research 15, 329-333.

Smith, V.L., Campbell, C.L., Jankins, S.F., Benson, D.M., 1998. Effects of host density and number of disease foci on epidemics of southern blight of processing carrot. Phytopathology 78(5), 595-600.

Turkensteen, L.J., Flier, W.G., Waningen, R., Mulder, A., 2008. Production, survival and infectivity of oospores of *Phytophthora infestans*. Plant Pathology 49(6), 688-696.

Van den Hurk, B., Siegmund, P., Klein, T.A., Attema, J., Bakker, A., Beersma, J., Bessembinder, J., Boers, R., Brandsma, T., van den Brink, H., Drijfhout, S., Eskes, H., Haarsma, R., Hazeleger, W., Jilderda, R., Katsman, C., Lenderink, G., Loriaux, J., Meijgaard, V.E., Van N.T., Van O.G.J., Selten, F., Siebesma, P., Sterl, A., Vries, D.H., Weele, V.M., De Winter, R., Zadelhoff, V.G., 2014. KNMI'14: Climate change scenarios for the 21st century-a Netherlands perspective. Scientific Report, WR2014-01 KNMI, De Bilt.

Wilcoxson, R.D., Skovmand, B., Atif, A.H., 1975. Evaluation of wheat cultivars for their ability to retard development of stem rust. Annals of Applied Biology 80, 275-281.

Yuen, J.E., Forbes., G.A., 2009. Estimating the level of susceptibility to *Phytophthora infestans* in potato genotypes. Phytopathology 99, 783-786.

Zadoks, J.C., Schein, R.D., 1979. Epidemiology and Plant Disease Management. Oxford University Press, New York.