



Resistance of selected potato varieties to *Phytophthora infestans* in Nyamagabe, Musanze, and Gicumbi districts, Rwanda.

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ABSTRACT

Objectives: This study aimed to evaluate the resistance of selected farmer-preferred potato varieties to late blight disease (*Phytophthora infestans* (Mont.) de Bary) and to determine their yield performance under field conditions in major potato-growing regions of Rwanda.

Methodology and Results: Nine potato varieties (Gisubizo, Kazeneza, Izihirwe, Nkunganire, Twihaze, Kirundo, Kinigi, Gikungu and Victoria) were evaluated across Nyamagabe, Musanze, and Gicumbi districts during the 2021–2022 growing seasons using a Randomized Complete Block Design. Disease severity was assessed and the Area Under Disease Progress Curve (AUDPC) was calculated and analysed for significant difference at $P \leq 0.05$. Potato varieties Twihaze, Kirundo, and Gikungu exhibited the highest resistance (mean scale 1.29 – 3.57), while Victoria was highly susceptible (scale 9). Resistant varieties, particularly Nkunganire and Kinigi, produced significantly higher healthy tuber yields (up to 12.5 t/ha). A strong negative correlation ($r = -0.82$ to -1) was found between AUDPC and yield. Significant differences ($P < 0.001$) in resistance were observed.

Conclusions and application of findings : The findings demonstrate that varietal resistance can be a key strategy for managing late blight and improving potato productivity in Rwanda. Varieties such as Twihaze, Kirundo, Nkunganire, and Kinigi exhibited both high resistance and superior yield performance, making them suitable candidates for wider adoption. Promoting these resistant cultivars can significantly reduce reliance on chemical fungicides, lower production costs, and enhance environmental sustainability. Furthermore, the strong inverse relationship between disease severity and yield highlights the importance of integrating resistant varieties into national crop improvement and extension programs. These results provide practical guidance for farmers, researchers, and policymakers in selecting appropriate potato varieties to enhance food security and resilience in late blight-prone regions.

Keywords: *Phytophthora infestans*, late blight resistance, potato varieties, AUDPC, Rwanda, yield performance.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is a globally significant food crop, ranking fourth in human consumption after maize, rice, and wheat (FAOSTAT, 2019). It provides essential micronutrients, including vitamin C and lysine, and offers higher yields of both energy and protein per unit area compared to cereal crops (Hirpa *et al.*, 2010). In Rwanda, potato is a vital food and cash crop, ranking fourth among the most widely grown crops in 2019 (Muhinyuza *et al.*, 2012; FAOSTAT, 2019). The crop's short vegetative period (4 months) compared to 6 months for maize and other common crops such as cassava, banana, wheat and rice, makes it crucial for food security in Rwanda, where it is cultivated by 14.4% of households in nearly every province of the country (NISR, 2023). The country is among the top ten potato producers in Africa, contributing 9.5% of national crop production and with an annual consumption of 145 kg per capita (Rukundo, 2019). Despite its importance, the national potato yield of 8.4 - 9.4 tons per hectare is significantly lower than the potential yield of 30 - 40 tons per hectare (NISR, 2020). A major constraint to potato production worldwide is late blight disease, caused by the pathogenic oomycete *Phytophthora infestans* (Mont.) de Bary (Cooke *et al.*, 2006). This disease is particularly severe in cool and wet climates, which are characteristic of the tropical highlands of Rwanda (Cooke *et al.*, 2006; Rwanda Agriculture Board (RAB, , 2018). Late blight can affect the foliage, stems, and tubers, and under favorable conditions, it can

destroy an entire field within 7-14 days, with potential production losses ranging from 30 to 100% (Agrios, 2005). In Rwanda, late blight has been documented to be prevalent in the northwestern regions (specifically in Gisenyi, Nyabihu, Musanze and Gicumbi districts) and the southwestern region (Nyamagabe district). This disease can cause yield losses approaching 100% if appropriate control measures are not implemented (RAB, 2018; Muhinyuza *et al.*, 2012). The pathogen population in Rwanda is predominantly composed of the US-1 lineage and its variants (RW-1 and RW-2) (Njoroge, 2019). Effective management of late blight often relies on a combination of resistant cultivars such as Mabondo, sanitation measures, and chemical pesticides (Muhinyuza *et al.*, 2012; Agrios, 2005). However, the emergence of aggressive strains (e.g. 2_A1 lineage) has rendered traditional control methods ineffective, underscoring the need for resistant varieties (Njoroge, 2019). Rwanda has released new potato varieties since 2019, such as Gisubizo, Kazeneza, Izihirwe, Nkunganire, and Twihaze, and these are preferred by farmers for their high yield and market suitability. However, there is a lack of information on their specific resistance levels to the *Phytophthora infestans* biotypes that are currently prevalent in the country's main potato-growing districts. Therefore, this study evaluated the resistance of the recently released potato varieties to *Phytophthora infestans* in the key production zones of Nyamagabe, Musanze, and Gicumbi districts.

MATERIALS AND METHODS

Description of study sites: The study was carried out in Nyamagabe, Musanze and Gicumbi districts of Rwanda (**Fig. 1**). The areas were selected for this study as they represent three distinct agro-ecological zones. Nyamagabe is situated within the Congo Nile Crest highlands (Upper Midlands Agro-Ecological Zone 1, UM1), Musanze district is

located in the volcanic highlands (Upper Highland Zone 2, UH-2), while Gicumbi district lies within the Buberuka highlands (Lower Highland Zone 1, LH-1) (Jaetzold and Schmidt, 1983). The districts are among the largest potato producing areas and usually have high intensity of potato late blight (Muhinyuza *et al.*, 2015; NISR, 2021).

Rwanda has three agricultural seasons and potatoes are mainly grown from March to June and September to December across the country. In parts of the selected zones like

Musanze, farmers also grow potatoes from June to September (NISR, 2021). A summary of the key characteristics of the three study sites is presented in **Table 1** and **Fig. 1**.

Table 1. Key characteristics of the three study sites

Feature	Musanze district	Gicumbi district	Nyamagabe District
Altitude (m ASL)	1,482 – 4,507 m	1,340 – 2,409 m	1,800 – 2,700 m
Rainfall (Bimodal)	1,400 to 1,800 mm	903 to 1,349 mm	1,300 to 1,450 mm
Average Min. Temp.	8.9 - 10.6 °C	12.8 - 13.4 °C	12.4 - 12.8 °C
Average Max. Temp.	19.8 - 21.8 °C	20.8 - 22.5 °C	22.5 t- 24.0 °C
Predominant Soil Type	Andosols	Ultisols	Ultisols and Inceptisols (Acidic: pH 3.6 - 5.0)
Population engaged in Agriculture	Over 91%	91%	92.7%

Source: (Nzeyimana *et al.*, 2014; Rugazura and Murugesan, 2015; Gicumbi District, 2018; RMA, 2022).

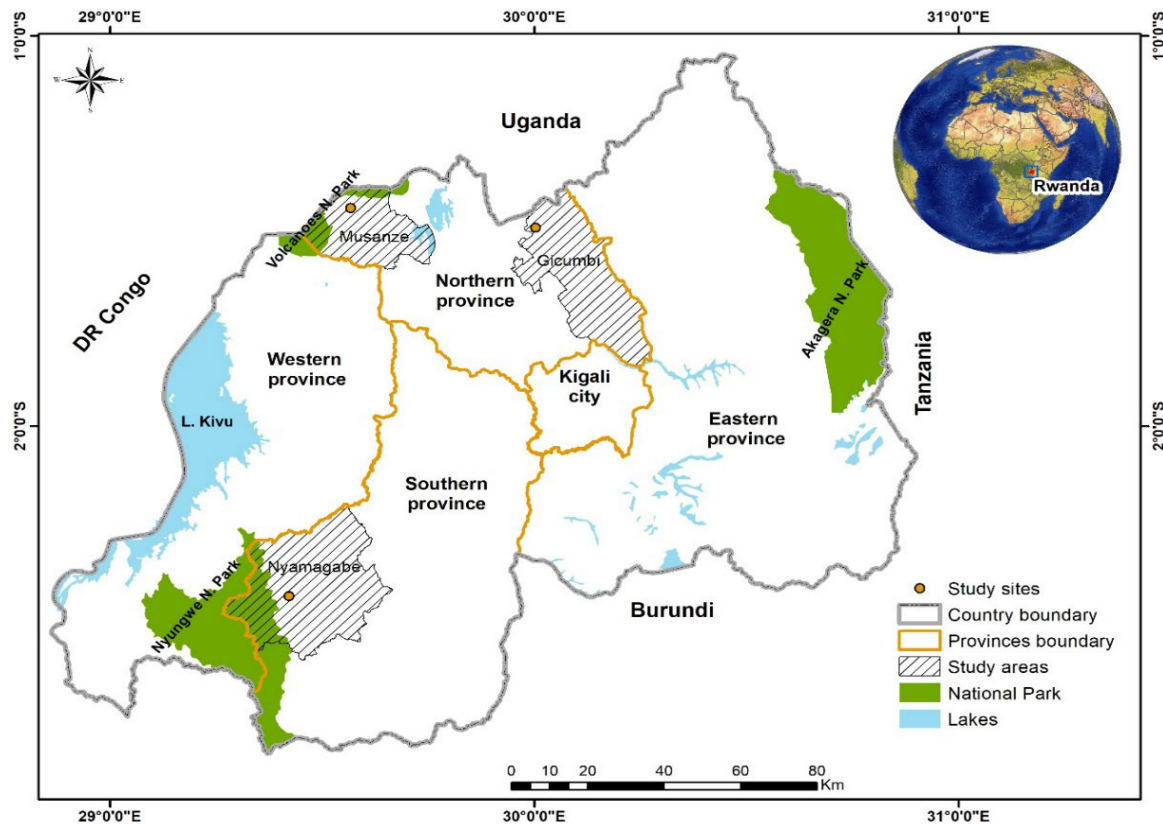


Fig. 1. Map showing the location of study sites in Nyamagabe, Musanze and Gicumbi districts of Rwanda.

Experimental setup for determining host plant resistance : Nine potato varieties, comprising seven newly released varieties and two local checks, were identified for the study based on their suitability for the distinct agro-ecological conditions of the target districts, the checks were selected based on past use as benchmarks for participatory farmer evaluation. The new varieties were Gisubizo, Kazeneza, Izihirwe, Nkunganire, Twihaze, Kirundo and Kinigi (**Table 2**). Healthy certified tuber seeds of each variety were obtained from Seed Potato Fund (SPF), which is the legally authorized entity to provide certified potato tuber seeds in the whole country. Each selected district w of one experimental field. The experiment was arranged in a Randomized Complete Block Design (RCBD), with each potato variety as a treatment. As a result, there were nine treatments, each replicated thrice in plots

measuring 4m by 3m . A spacing of 0.8m between rows and 0.3 m within rows was used when planting the potatoes. The experimental alleys had 1 meter between blocks and 0.5 meter between two consecutive plots /hills. The borders for each experimental site were planted with the susceptible variety Victoria to serve as disease spreader. The experiments were carried out in the short rain season from October 2021 to January 2022. Infection by potato late blight was naturally achieved and no pesticide was applied during the field experiments. Other agronomic standard practices were carried out until harvesting of the experimental crops. Plant nutrition was managed through application of 30 tons per hectare of organic manure and 150 Kg per hectare of NPK 17-17-17 during planting. Another 50 Kg per hectare of NPK 17-17-17 was applied during earthing up.

Table 2: Potato varieties used in evaluation of host resistance to late blight disease.

Local name of variety	Breeding code	Year of release
Gisubizo	Namesake with Kinigi	2020
Kazeneza	CIP 393077.159	2019
Izihirwe	CIP 396018.241	2019
Nkunganire	CIP 393280.64	2019
Twihaze	CIP 393371.58	2019
Kirundo	RW 8201.19	1983
Kinigi	CIP 378699.2	1983
Gikungu	CIP 387233.24	1992
Victoria	CIP 381381.20	1989

Note: Gikungu was used as the resistant local check and Victoria as the susceptible local check.
Source: (Muhinyuza *et al.*, 2015; CIP, 2022)

Quantitative analysis of late blight severity on susceptible hosts: Field assessments for potato late blight were conducted from the crop emergence stage until harvest. A systematic sampling pattern was employed, where 25 potato plants were randomly selected along each diagonal line in each field, resulting in a total of 50 plants assessed per field. Disease incidence and severity were recorded at regular intervals from the first appearance of symptoms until 101 days after planting. The Disease incidence (I) was calculated as the proportion of infected

plants relative to the total number of plant units assessed, expressed as a percentage (Cooke *et al.*, 2006):

$$\text{Disease incidence (I)} = \frac{\text{Number of infected plant units}}{\text{Total number of plant units assessed}} \times 100$$

Potato late blight severity was evaluated using a standardized descriptive key (Rakotonindrainana *et al.*, 2012) (**Table 3**), observations were conducted at 6 to 10- day intervals throughout the growing season, consistent with established

protocol (Forbes *et al.*, 2014). At each experimental site data collection ceased when the severity on the susceptible control variety 'Victoria' reached 100%.

Table 3: Visual assessment key used to estimate late blight severity on potato

Severity (%)	Description of visual assessment
0.0	No symptom in the plot
0.1	Only a few plants were affected here and there, up to 4 spots per plot
1.0	Up to 10 spots per plot
5.0	About 50 spots per plot or general light spotting
10.0	Up to 10% of leaves per plot destroyed, the plot looks green
25.0	Up to 25% of leaves per plot destroyed, nearly every leaflet with lesions, the plot looks green flecked with brown
50.0	Up to 50% of leaves per plot destroyed, the plot looks neither predominantly brown nor green
75.0	Up to 75% of leaves per plot destroyed, the plot looks predominantly brown
90.0	Up to 90% of leaves per plot destroyed
95.0	Up to 95% of leaves per plot destroyed, only a few leaves left green, part of the stems are still green
100	No more green part in the plot, all part of plants are brown

Source: Rakotonindraina *et al.* (2012)

The area under disease progress curve (AUDPC) was calculated to quantify the temporal progress of the disease at each trial site. The calculation used the formula from Wilcoxon *et al.* (1975), as revised by Meena *et al.* (2011):

$$AUDPC = \sum_{i=1}^{n-1} \left(\frac{Y_i + Y_{i+1}}{2} \right) (t_{i+1} - t_i)$$

Where:

- **t** is the time (days) of each assessment,
- **y** is the percentage of affected foliage at each observation, as determined using the rating scale of Rakotonindraina *et al.* (2012), and
- **n** is the total number of assessment (observations).

To standardize the AUDPC for the varying durations of assessment periods across fields, the Relative Area Under Disease Progress Curve (RAUDPC) was determined using the formula of Yuen and Forbes (2009); Forbes *et al.* (2014):

$$RAUDPC = (AUDPC/N) \times 100$$

Where:

- **AUDPC** is the area under disease progress curve,
- **N** is the total duration of the assessment period, defined as the difference in days between last and the first days of data collection on disease severity.

R software was used to plot graphs.

Host resistance assessment : To rank the host resistance (susceptibility) levels of potato varieties to *Phytophthora infestans*, a scale ranging from 0 to 9 was used (Hansen *et al.*, 2005; Forbes *et al.*, 2014) (Table 4). The scale / level (0 to 9) was determined from the values of RAUDPC and the higher the rank, the higher the susceptibility. It was acceptable to apply this scale in this study because the different trials that were compared employed a susceptible variety (Victoria) as a common reference genotype (Forbes *et al.*, 2014; Yuen & Forbes, 2009). The resistance scales were determined using the equation:

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

The assigned susceptibility scale and observed disease measures (RAUDPC) for the control

cultivar (local check cultivars) are represented by Sy and Dy, respectively (most susceptible cultivar). The determined susceptibility scale value and observed disease measurement for the cultivar in question are represented by Sx and Dx, respectively. To calculate a constant, the known susceptibility value of the control

variety is divided by its resistance measure, specifically the RAUDPC. The susceptibility value of a genotype then was calculated by multiplying the constant by the resistance measure (RAUDPC) of each target variety (Forbes *et al.*, 2014; Yuen and Forbes, 2009).

Table 4. Description of susceptibility scales of potato varieties to *Phytophthora infestans*

Susceptibility scale	Description criteria
0	Very of very low
1	Very low
2	Very low to low
3	Low
4	Low to medium
5	Medium
6	Medium to high
7	High
8	High to very high
9	Very high

Source: variety Forbes *et al.* (2014); Yuen and Forbes (2009).

Potato yield determination: For all potato varieties, the harvesting was done at four months after planting when the plants were fully mature. This occurred on the 20th, 18th, and 24th of January 2022 in Musanze, Gicumbi, and Nyamagabe districts, respectively, following the principle that the first planted plots were the first to be harvested. The tubers of each plot were sorted by separating healthy and rotted tubers, the two categories were weighed separately and used to calculate the total yield per hectare.

Data analyses: The field data were analyzed using R software 4.0.2 version. The data for incidence, severity, and yield of potatoes were subjected to Analysis of Variance (ANOVA) and a Generalized Linear Model (GLM) to determine the variations among the potato varieties and agro-ecological zones. Tukey's test was used to compare the means at $P < 0.05$. The Spearman method was used to calculate the correlation between yield and the AUDPC.

RESULTS

The Area Under Disease Progress Curve (AUDPC) differed significantly among the potato varieties ($F = 362.81$, $DF = 8, 54$, $P < 0.001$) (Table 5). Twihaze variety demonstrated the highest level of resistance, with the lowest AUDPC of 527, 793 and 883 in Nyamagabe, Musanze, and Gicumbi districts, respectively. It was followed by Kirundo variety, with AUDPC of 966, 899 and 1,443 in the three

districts, respectively. In contrast, Victoria variety was the most susceptible, recording the highest AUDPC values of 3,667, 4,003 and 3,437 in the districts, respectively. Izihirwe variety, with AUDPC values of 2,595, 2,794 and 2,392 was the next most susceptible. Furthermore, a significant locality-variety interaction was observed ($F = 12.57$, $DF = 16, 54$, $P < 0.001$).

Table 5: Means (\pm SE) of the Area Under Disease Progress Curve of potato late blight on nine potato varieties in Nyamagabe, Musanze, and Gicumbi districts of Rwanda

Potato varieties	Locality			F-value	P-value
	Nyamagabe	Musanze	Gicumbi		
Gikungu	1211 \pm 43 ^{bcA}	1426 \pm 112 ^{ba}	1367 \pm 134 ^{ba}	1.07	0.400
Victoria	3667 \pm 65 ^{gA}	4003 \pm 58 ^{fc}	3437 \pm 31 ^{Ea}	1.85	0.001
Gisubizo	1994 \pm 93 ^{da}	2176 \pm 77 ^{da}	1893 \pm 174 ^{cdA}	1.41	0.310
Kazeneza	2128 \pm 32 ^{deA}	1861 \pm 207 ^{cdA}	2249 \pm 91 ^{da}	2.37	0.170
Izihirwe	2595 \pm 35 ^{fb}	2794 \pm 38 ^{ec}	2392 \pm 11 ^{da}	47.8	<0.001
Nkunganire	1318 \pm 81 ^{ca}	1253 \pm 11 ^{ba}	1247 \pm 23 ^{bcA}	0.83	0.480
Twihaze	527 \pm 11 ^{aa}	793 \pm 69 ^{ab}	883 \pm 81 ^{ab}	13.58	0.006
Kirundo	966 \pm 109 ^{ba}	999 \pm 72 ^{abAB}	1040 \pm 25 ^{abA}	0.24	0.795
Kinigi	2358 \pm 68 ^{efB}	1891 \pm 92 ^{da}	1978 \pm 40 ^{cdA}	11.08	0.010
F-value	208.32	114.11	87.51		
P-value	<0.001	<0.001	<0.001		

Same upper-case letters along the columns indicate no significant difference between the potato varieties at each location, while same lowercase letters across rows indicate no significant difference between the different localities for each variety at $\alpha = 0.05$ according to Tukey's test.

Based on a rating scale of 0 to 9, the least susceptible potato varieties were Twihaze, Kirundo and Gikungu. Twihaze recorded the lowest scale values of 1.29, 1.75, and 2.3 in Nyamagabe, Musanze, and Gicumbi districts, respectively, followed by Kirundo (2.37, 2.22, and 2.67) and Gikungu (2.97, 3.19, and 3.57) (Table 6). In contrast, the varieties Victoria,

Izihirwe and Kazeneza were classified as susceptible. Victoria was consistently rated at the maximum score of 9 across all three districts, Izihirwe scored 6.37, 6.27, and 6.26, and Kazeneza scored 5.52, 4.15, and 5.89 in Nyamagabe, Musanze, and Gicumbi, respectively (Table 6, Plate 1).

Table 6: Means (\pm SE) of susceptibility scale values of nine potato varieties to potato blight disease in Nyamagabe, Musanze, and Gicumbi districts of Rwanda

Potato variety	Locality			F-value	P-value
	Nyamagabe	Musanze	Gicumbi		
Gikungu	2.97 \pm 0.12 ^{bcA}	3.19 \pm 0.22 ^{bAB}	3.57 \pm 0.33 ^{abB}	5.55	0.043
Victoria	9.00 \pm 0.00 ^{gA}	9.00 \pm 0.00 ^{fA}	9.00 \pm 0.00 ^{fA}	0	1
Gisubizo	4.09 \pm 0.31 ^{dA}	4.84 \pm 0.07 ^{dA}	4.96 \pm 0.50 ^{cdA}	2.28	0.182
Kazeneza	5.52 \pm 0.16 ^{deA}	4.15 \pm 0.51 ^{cdA}	5.89 \pm 0.27 ^{deB}	7.46	0.023
Izihirwe	6.37 \pm 0.18 ^{fA}	6.27 \pm 0.14 ^{eA}	6.26 \pm 0.08 ^{eA}	44.07	0.201
Nkunganire	3.24 \pm 0.22 ^{cA}	2.75 \pm 0.06 ^{abA}	3.31 \pm 0.06 ^{abA}	4.98	0.053
Twihaze	1.29 \pm 0.03 ^{aA}	1.75 \pm 0.18 ^{aB}	2.30 \pm 0.21 ^{aB}	15.76	0.004
Kirundo	2.37 \pm 0.24 ^{bA}	2.22 \pm 0.18 ^{abA}	2.76 \pm 0.67 ^{abA}	2.37	0.170
Kinigi	5.79 \pm 0.12 ^{efAB}	4.23 \pm 0.25 ^{cdA}	5.18 \pm 0.10 ^{deAB}	7.59	0.022
F-value	259.33	96.81	80.51		
p-value	<0.001	<0.001	<0.001		

Same uppercase letters along columns indicate no significant difference between the potato varieties at the same location, while same lowercase letters across rows indicate no significant difference between the different localities for each variety at $\alpha = 0.05$ according to the Tukey test. Scale description by Hansen *et al.* (2005): 0 (very of very low); 1 (very low); 2 (very low to low); 3 (low); 4 (low to medium); 5 (medium); 6 (medium to high); 7 (high); 8 (high to very high); 9 (very high).



Plate 1: Severe symptoms of late blight disease on potato in Gicumbi district, Rwanda.

Yield assessment: The yield of healthy potato tubers differed significantly both among the nine varieties (F = 16.64, DF = 8, 16, P < 0.001) and

across the three districts (F = 6.63, DF = 2, 16, P < 0.001). Among the varieties, Victoria consistently produced the lowest yields, whereas

Kinigi and Nkunganire were the highest-yielding. Specifically, Victoria yielded a mean of 2.5, 3.8, and 4.7/ha in Nyamagabe, Musanze, and Gicumbi districts, respectively. In contrast, Kinigi recorded the highest yields of 12.1 t/ha in Gicumbi and 10.7 t/ha in Musanze, while Nkunganire yielded 10.4 t/ha in Nyamagabe. The resistant Twihaze variety produced yields of 12.5 t/ha in Gicumbi, 11.3 t/ha in Musanze, and 11.3 t/ha in Nyamagabe. At the district level, the

highest recorded yield (12.5 t/ha) was observed for the Twihaze variety, followed by 12.1t/ha for the Kinigi variety in Gicumbi district. This was followed by yields of 11.3 t/ha for the Twihaze variety in Musanze district and 11.2 t/ha for the same variety in Nyamagabe districts. The lowest individual yield was 2.5 t/ha from the susceptible variety Victoria in Nyamagabe (Table 7).

Table 7: Means (\pm SE) of the harvested healthy tubers (ton/ha) of nine potato varieties in Nyamagabe, Musanze, and Gicumbi districts of Rwanda

Potato variety	Locality			F-value	P-value
	Nyamagabe (Tonnes/Ha)	Musanze (Tonnes/Ha)	Gicumbi (Tonnes/Ha)		
Gikungu	9.5 \pm 0.9 ^{bcB}	10.7 \pm 1.3 ^{ca}	9.8 \pm 1.1 ^{abcA}	1.07	0.4011
Victoria	2.5 \pm 0.5 ^{aA}	3.8 \pm 0.1 ^{aA}	4.7 \pm 0.7 ^{abA}	18.13	0.0029
Gisubizo	7.8 \pm 0.7 ^{bcA}	9.5 \pm 1.3 ^{bcA}	9.6 \pm 0.5 ^{abcB}	9.48	0.0138
Kazeneza	7.7 \pm 1.2 ^{bcA}	9.1 \pm 0.9 ^{bcA}	9.3 \pm 1.0 ^{abcA}	5.04	0.05
Izihirwe	7.7 \pm 1.2 ^{bcA}	10.7 \pm 1.3 ^{ca}	10.4 \pm 1.1 ^{bcA}	1.82	0.2399
Nkunganire	8.3 \pm 2.2 ^{bcA}	10.4 \pm 0.5 ^{ca}	9.8 \pm 0.8 ^{abcA}	1.78	0.2461
Twihaze	11.2 \pm 0.6 ^{ca}	11.3 \pm 0.6 ^{ca}	12.5 \pm 1.3 ^{ca}	11.01	0.0098
Kirundo	10.0 \pm 0.5 ^{ca}	11.1 \pm 0.4 ^{cb}	10.4 \pm 1.1 ^{bcA}	0.55	0.6015
Kinigi	8.3 \pm 0.5 ^{ca}	10.7 \pm 0.1 ^{ca}	12.1 \pm 0.4 ^{ca}	1.95	0.2226
F-value	6.96	10.43	5.17		
p-value	0.0003	<0.0001	0.0018		

Same uppercase letters along columns indicate no significant difference in harvested yield among the potato varieties per site, while same lowercase letters across rows indicate no significant difference between the localities for each variety at $\alpha = 0.05$ according to the Tukey test.

Correlation between AUDPC and potato yield : The Pearson correlation analysis revealed a strong and statistically significant negative relationship ($P < 0.05$) between the Area Under Disease Progress Curve and the quantity of harvested healthy tubers across all nine potato cultivars and all three districts. This high negative correlation (with r values reaching -1.00) indicates that as the severity of late blight increases, there is a substantial and proportional decrease in the yield of healthy tubers. Cultivars

such as Victoria and Izihirwe, which recorded the highest AUDPC values (e.g. 4003 \pm 58 for Victoria in Musanze), consistently produced the lowest healthy tuber yields (3.8 \pm 0.1 t/ha). In contrast, resistant varieties like Twihaze, which maintained the lowest AUDPC scores (e.g. 527 \pm 11 in Nyamagabe), had significantly higher healthy tuber biomass (Table 8). Statistically significant differences were observed among the cultivars within each locality ($P < 0.001$) (Table 8).

Table 8: Pearson correlation coefficients (*r*) of the AUDPC against harvested healthy tubers of nine potato varieties in Nyamagabe, Musanze, and Gicumbi districts

Potato Variety	Nyamagabe		Musanze		Gicumbi		F-value	P-value
	<i>r</i> -value	P-value	<i>r</i> -value	P-value	<i>r</i> -value	P-value		
Gikungu	-0.95	0.02	-0.82	0.05	-1	<0.01	1.07	0.401
Victoria	-1	<0.01	-0.99	<0.01	-0.98	0.01	18.13	0.003
Gisubizo	-0.88	0.04	-0.85	0.05	-0.91	0.03	9.48	0.014
Kazeneza	-0.92	0.03	-0.98	<0.01	-0.89	0.04	5.04	0.05
Izihirwe	-1	<0.01	-0.99	<0.01	-0.99	<0.01	1.82	0.24
Nkunganire	-0.94	0.03	-0.9	0.04	-0.92	0.03	1.78	0.246
Twihaze	-0.98	0.01	-0.95	0.02	-0.97	0.01	11.01	0.01
Kirundo	-0.96	0.02	-0.94	0.03	-0.98	0.01	0.55	0.602
Kinigi	-0.96	0.02	-0.93	0.03	-0.95	0.02	1.95	0.223

The amount of harvested tubers that were rotten due to late blight infection varied significantly among the potato varieties ($\chi^2= 74.14$, DF = 8, P<0.001) and across the localities ($\chi^2= 57.28$, DF = 2, P<0.001). The cultivar Victoria displayed the highest quantity of rotten tubers across all three districts, with 8.5 t/ha in Nyamagabe, 8.2 t/ha in Musanze, and 7.9 t/ha in Gicumbi. Conversely, the lowest quantity of rotten tubers was for Twihaze cultivar at 1.5 t/ha in Nyamagabe, 1.8 t/ha in Musanze, and 1.2t/ha in Gicumbi (Plate 2; Table 9).

Table 9. Means (\pm SE) of harvested rotten tubers of nine potato varieties grown between September 2021 and January 2022 in Nyamagabe, Musanze and Gicumbi districts of Rwanda

Potato varieties	Locality			F-value	P-value
	Nyamagabe (Tonnes/Ha)	Musanze (Tonnes/Ha)	Gicumbi (Tonnes/Ha)		
Gikungu	3.5 \pm 0.4 ^{abA}	3.2 \pm 0.5 ^{abA}	3.8 \pm 0.3 ^{abA}	0.52	0.62
Victoria	8.5 \pm 0.6 ^{dA}	8.2 \pm 0.4 ^{dA}	7.9 \pm 0.7 ^{dA}	0.32	0.73
Gisubizo	4.8 \pm 0.5 ^{bA}	4.5 \pm 0.3 ^{bA}	4.7 \pm 0.4 ^{bA}	0.14	0.87
Kazeneza	5.4 \pm 0.3 ^{bcA}	4.9 \pm 0.4 ^{bcA}	5.3 \pm 0.2 ^{bcA}	0.74	0.51
Izihirwe	6.5 \pm 0.5 ^{cdA}	6.1 \pm 0.3 ^{cdA}	6.4 \pm 0.4 ^{cdA}	0.28	0.76
Nkunganire	3.1 \pm 0.3 ^{abA}	2.8 \pm 0.2 ^{abA}	3.2 \pm 0.4 ^{abA}	0.44	0.66
Twihaze	1.5 \pm 0.2 ^{aA}	1.8 \pm 0.1 ^{aA}	1.2 \pm 0.2 ^{aA}	3.12	0.11
Kirundo	2.5 \pm 0.4 ^{aA}	2.2 \pm 0.3 ^{aA}	2.6 \pm 0.5 ^{aA}	0.29	0.75
Kinigi	6.6 \pm 0.4 ^{bcA}	5.2 \pm 0.2 ^{bcA}	5.9 \pm 0.5 ^{bcA}	0.81	0.48
F-value	28.45	34.12	26.88		
p-value	<0.0001	<0.0001	<0.0001		

Same uppercase letters along each column indicate no significant difference between the potato varieties in a given locality, while same lowercase letters across rows indicate no significant difference between the localities for a specific variety at $\alpha = 0.05$ according to the Tukey test.

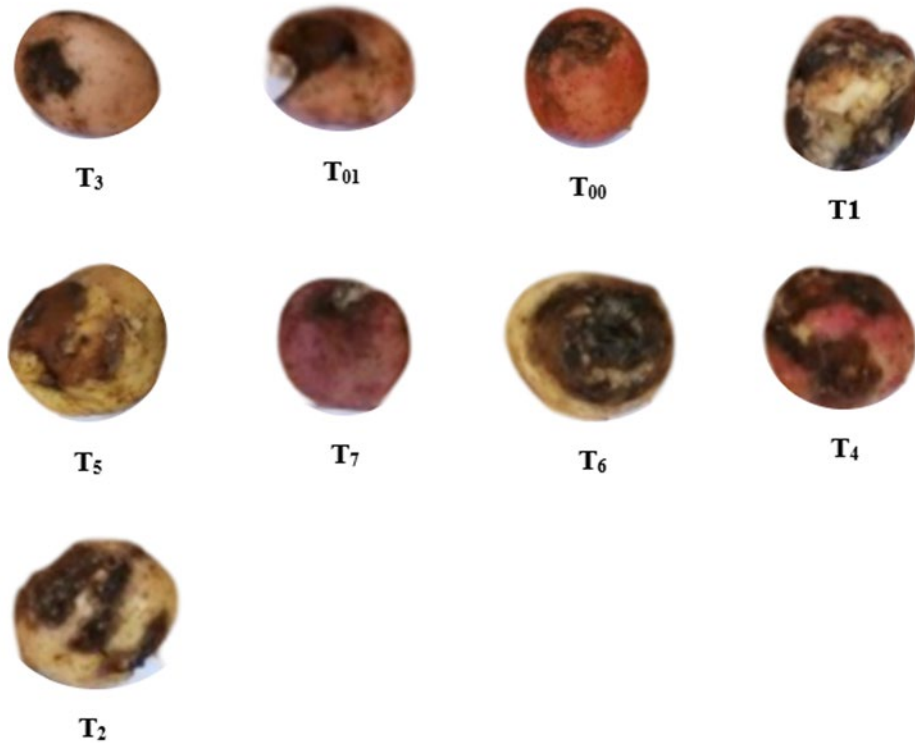


Plate 2. Rotten tubers of nine potato varieties due to infection by *Phytophthora infestans* in Rwanda. T00 = Gikungu, T01 = Victoria, T1 = Gisubizo, T2 = Kazenzeza, T3 = Izihirwe, T4 = Nkunganire, T5 = Twihaze, T6 = Kirundo, T7 = Kinigi.

Correlation between late blight susceptibility scale and tuber rot : The Pearson correlation analysis revealed a strong, positive, and statistically significant relationship ($P < 0.05$) between the late blight susceptibility scale and the quantity of harvested rotten tubers across all nine potato cultivars and all three study districts (Nyamagabe, Musanze, and Gicumbi). Cultivars such as Victoria, which displayed the highest susceptibility index (9.00 ± 00), had the highest quantity of rotten tubers across all districts,

ranging from 7.9 ± 0.4 to 8.5 ± 0.7 t/ha. Conversely, cultivar Twihaze, which showed the lowest susceptibility (1.29 ± 0.03 to 2.30 ± 0.21), yielded the minimum quantity of rotten tubers (1.2 ± 0.1 to 1.8 ± 0.2 (t/ha) (Table 10). The correlation coefficients (r) remained consistently high ($r \geq 0.84$, $P < 0.05$) in Nyamagabe, Musanze, and Gicumbi, indicating that disease susceptibility is a reliable predictor of tuber decay across different environments.

Table 10: Pearson correlation coefficients (*r*) of the Late Blight Susceptibility Scale against harvested rotten tubers of nine potato varieties in Nyamagabe, Musanze and Gicumbi districts.

Potato Variety	Nyamagabe		Musanze		Gicumbi	
	<i>r</i> -value	<i>P</i> -value	<i>r</i> -value	<i>P</i> -value	<i>r</i> -value	<i>P</i> -value
Gikungu	0.89	0.04	0.92	0.02	0.94	0.01
Victoria	0.99	<0.01	0.98	<0.01	0.99	<0.01
Gisubizo	0.85	0.05	0.88	0.04	0.91	0.02
Kazeneza	0.92	0.02	0.95	0.01	0.93	0.01
Izihirwe	0.96	0.01	0.94	0.01	0.97	<0.01
Nkunganire	0.87	0.05	0.89	0.04	0.9	0.03
Twihaze	0.95	0.01	0.92	0.02	0.94	0.01
Kirundo	0.84	0.05	0.86	0.05	0.88	0.04
Kinigi	0.91	0.02	0.93	0.01	0.95	0.01

DISCUSSION

The findings of this study reveal significant variations in potato varieties' susceptibility to late blight disease and their respective yields across the three districts in Rwanda. Based on a scale of 0 to 9, Twihaze, Kirundo, and Gikungu were identified as the least susceptible varieties, with infection levels being consistently lower than other varieties in the three districts. This supports the findings of Nyankanga *et al.* (2014), showing that vulnerability of potato varieties to late blight disease depends on their genetic makeup and environmental factors. Twihaze variety, particularly, displayed strong resistance with scale values ranging from 1.29 to 2.3, with consistent performance in the different agroecological zones. This observation confirmed the findings by Rukundo *et al.* (2022) during the pre-lease selection of various potato clones. Conversely, Victoria, Izihirwe, and Kazeneza cultivars were rated as more susceptible, with Victoria demonstrating the highest susceptibility (scale 9) in all districts. This finding is in agreement with the previous research findings of Shimira *et al.* (2020) and Muhinyuza *et al.* (2022). The analysis indicated that the yield of healthy tubers is heavily influenced by resistance to the pathogen, with the least susceptible varieties achieving higher yields compared to the susceptible ones. Previous studies Katembo *et al.* (2024)

highlighted the importance of blight resistance in potato productivity, which is important for food security and farmer income. The observed variance in yield between districts also suggests potential interactions between local environmental factors and potato varieties, as reported by Jégo *et al.* (2025). The results showed a strong and statistically significant negative relationship ($P < 0.05$) between the Area Under Disease Progress Curve and the quantity of harvested healthy tubers across all varieties and localities, except for the Kinigi variety in Nyamagabe district. This suggests that as disease severity increases, the yield of healthy tubers tends to decline, which is expected. Virmond *et al.* (2017) highlighted the inverse relationship that exists between disease pressure and crop productivity. On the aspect of tuber rot, the results further emphasize the relationship of late blight susceptibility to overall tuber quality. The observed positive correlation between susceptibility levels and the amount of harvested rotten tubers indicates that late blight is a primary driver of quality loss in Rwandan potato production. The quantity of rotten tubers were positively correlated with the susceptibility level. Handayani *et al.* (2019) reported that resistant cultivars tend to have lower disease incidence, ultimately leading to less tuber rot and higher marketable yields.

Additionally, Seifu (2017) noted that late blight significantly contributes to tuber quality deterioration, particularly in susceptible varieties. In highly susceptible cultivars like Victoria, the rapid progression of the disease in the foliage likely facilitates the washing of zoospores into the soil, leading to widespread tuber infection (Sudermann, 2026). This explains why more susceptible varieties consistently exhibited higher biomass of decayed tubers (Yuen and Forbes, 2009). In Nyamagabe District, the Kinigi variety did not conform to the yield trends observed in other districts, as it had less than expected yield despite its documented resistance and favorable agronomic traits. This suggests that the expression of Kinigi's genetic potential may have been constrained by location-specific factors, such as disease pressure, climatic conditions, soil characteristics, or other agroecological stresses. These findings highlight the variability in varietal performance across environments and underscore the importance of genotype × environment interactions, while remaining consistent with previous reports by Muhinyuza

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Ethics approval: The experimental research and field studies on plants, including the establishment of experiments in three study areas (Musanze, Gicumbi, and Nyamagabe

et al. (2022) describing the generally superior agronomic and quality attributes of the Kinigi cultivar. The study confirmed that late blight disease is a major biotic constraint to potato production in Nyamagabe, Musanze and Gicumbi districts of Rwanda. While most current potato cultivars are perceived by farmers to have low to moderate resistance to late blight disease, more resistant cultivars were identified including Twihaze, Kirundo, and Gikungu. Therefore, there is need for increased sensitization of farmers on potato late blight disease and its management practices in Rwanda. Besides, farmers can be advised to adopt varieties Twihaze, Kirundo and Gikungu as part of management strategies for late blight disease. In Musanze farmers can be advised to plant variety Twihaze, Kirundo and Nkunganire while the farmers in Gicumbi district can adopt varieties Twihaze, Kirundo and Gikungu to manage late blight disease. This study contributes to existing literature that underscores the importance of multi-site evaluation in varietal selection (Virmond *et al.*, 2017; Rosero *et al.*, 2023; Katembo *et al.*, 2024).

districts) and the collection of plant materials, were conducted in accordance with relevant institutional, national, and international guidelines and legislation. All necessary permits and/or licenses for the collection of plant or seed specimens were obtained from the National Council for Science and Technology (NCST), Rwanda (Research Permit No: NCST/482/354/2022). This study did not involve human direct participation.

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