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Research Article

Estimation of Yield Loss Due to Potato Late Blight in Lukanga Village of Lubero Territory/Democratic Republic of the Congo

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Abstract

Late Blight is one of important diseases of potato. This disease is present in the agro-ecological environment of Lubero. As a matter of concern, this study aims at assessing the level of tolerance of three potato varieties to this disease and estimating the loss in yield. For this reason, an experiment was carried out in the experimental field of the Faculty of Agronomic Sciences of the Adventist University of Lukanga in the main season of 2023, with an experimental device with complete random blocks. Three potato varieties (Carolus, Kinigi and Sarpo mira) were used with fungicide treatment and non-treatment to estimate the yield loss due to Late Blight. The data concerned the rate of attack of foliar Late Blight and the parameters of potato yield under natural infection. The results showed that tolerance varies from a variety to another, considering the three varieties and is very significant ($p<0.001$). The Carolus variety was more susceptible with a value of the area under the disease progression curve (AUDPC = 1030) and the Sarpo mira variety the most resistant (AUDPC = 0.000). For the loss of yield, it also varies depending on varieties and is proportional to the susceptibility to foliar Late Blight. It was between 2 and 70% respectively for Sarpo mira and Carolus. Sarpo mira variety, being the most resistant, must both be used for sustainable agriculture that respects the environment and taken in potato breeding program.

Keywords

Late Blight, Yield Loss, Potato, Varietal Resistance, Lubero Territory

1. Introduction

The potato is the world's most important non-grain foodstuff, at the fourth position in production after rice, wheat and maize. Its production, worldwide, has been estimated at 374,777,763.43 tons from a surface area of 17,788,408 ha in 2022 [1]. It is a crop of great importance, and the FAO classifies it as one of the crops contributing to food security

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worldwide. 2/3 of its production is consumed directly fresh, with the remainder used in animal feed and industry [2].

In Africa, northern countries such as Egypt, Algeria and Morocco are among the continent's leading producers. In Sub-Saharan Africa, most production takes place in East Africa (71%) and, Southern and West Africa represent respectively 21% and 8% of continental production. Potato yield, on this continent, potato yield varies from 6 to 10 t/ha [3]. This low yield in Africa can be attributed to certain production constraints for potato cultivation. In East Africa, in Uganda, disease was cited as the major constraint, followed by pests, the high cost of pesticides, fertilizers and other agricultural inputs, lack of access to suitable land for potato cultivation and climate disruption [4]. In Rwanda, inaccessibility to agricultural credit was the major constraint, followed by Late Blight disease, lack of healthy planting materials, etc. [5].

In the Democratic Republic of Congo (DRC), production was estimated at 106,743 tons from an area of 23,273 ha, in 2022 [1]. The ratio between gross production and arable area gives an average production of around five tons per ha, below 25 tons, which is the production potential at high altitude [6]. As in Africa in general, this country faces a number of constraints in potato cultivation. In this country, potato production constraints have already been identified in just one province, South Kivu. Diseases and pests were cited as major constraints, followed by climate disruption, low-quality seed and other constraints [7]. Among diseases, potato Late Blight appears [8]. This high-loss disease is caused by a fungus, *Phytophtora infestans*, an Oomycete of the Pythiaceae family [9].

The largest production areas are located in the North-Kivu province [8]. In North-Kivu, potato is most widely grown in the Lubero territory, in high-altitude regions. This production zone straddling the equator benefits from an equatorial climate tempered by mountains, with annual temperatures below 20 ℃, and regular, abundant rainfall, factors that favor the development of this disease [10, 11].

This disease causes a major economic loss. In Rwanda and Burundi, yield loss due to potato Late Blight can be estimated at 75% if no fungicide treatment is applied [12]. Chemical control is most widely used, with synthetic products such as Mancozeb, Metalaxyl and Carbendazim. [13, 14]. This control method has certain disadvantages for the environment, due to the toxicity of some synthetic products [15]. The use of resistant varieties is a good alternative for economic reasons and respect for the environment [16]. In Lubero territory and Lukanga village, some potato varieties are cultivated, and the Late Blight disease is present. Preliminary studies, such as the evaluation of varietal resistance and yield loss due to Late Blight are necessary in order to determine the fitting strategies for managing this disease. As far as we know, there is no documentation in this research domain on Lubero territory. Hence, the need of this study in this zone of the Democratic Republic of Congo on potato-growing.

2. Materials and Methods

2.1. Experimental Site

The experiment was conducted in North-Kivu Province, Lubero Territory, precisely in the village of Lukanga, in the experimental field of the Faculty of Agronomic Sciences of the Adventist University of Lukanga from July to November 2023. The experimental site is located at 1935 m of altitude, latitude-South 00.05828°, and longitude-East 029.30068° (source: Active observation on the experimental site using the GARMIN 64 GPS mobile). The village of Lukanga is characterized by an average temperature varying between 15.8 and 17.1 ℃ with an average annual rainfall of 1510 mm. It benefits from an equatorial climate tempered by high mountains. It is also characterized by two rainy seasons from March to May and from August to mid-December [11].

2.2. Plant Material

Three elite potato varieties from Lubero territory were used in this study. These were Carolus, Sarpo mira and Kinigi. All these varieties have been introduced into the Democratic Republic of Congo. Carolus originates from Holland [17], Sarpo mira from Austria Hungary [18] and Kinigi from Rwanda [5].

2.3. Experimental Setup

The experiment was conducted using a randomized complete block design (RCBD) with three replications. Treatments were randomly assigned within the blocks [19]. As the aim was to estimate yield loss, for each variety in all three blocks, there were both fungicide-treated and untreated plots. In total, we had 18 plots of 2 × 1.8 m with 24 plants each. The layout was of 14.1 m length and 8.5 m of width, oriented against the slope direction. The distance between blocks was of 1 m and 0.5 m between plots. For the treated plots, the fungicide Winner 72 WP containing Metalaxyl and Mancozeb was used.

2.4. Experiment Conducting

Before planting, preparatory work was carried out, consisting of clearing and ploughing the experimental site. After segmenting the land into experimental plots, planting took place at 60 cm × 50 cm spacing. Each plot had 24 plants arranged in four rows. For fertilization, organic matter based on cow manure was used at a dose of 20 t/ha [8]. Thirty days after emergence, maintenance consisted of weeding and ridging. Winner 72 WP fungicide was applied three times at 14-day intervals in the treated plots.

2.5. Data Collection

The data concerned plant pathology and some yield components (number of unmarketable tubers, marketable tubers per plant) and yield. Disease rating was based on the scale proposed by the International Potato Center (CIP) for estimating the rate of leaf attack by Late Blight [20]. Data were collected three times during the vegetative phase, from the 35th day, after *Phytophtora infestans* establishment and fruiting to the 49th day. Three observations were taken at one-week intervals in order to calculate the Area under the disease progression curve. It was calculated considering the leaf attack rate [21], using the following formula:

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

With $_{Yi+1}$ = percentage of leaf damage at $_{i+1}$ days after planting, t_i= age of plants within days from planting to observation i, t_{i+1}= age of plants within days from planting to observation $_{i+1}$, n= number of observations made. The higher the value of the curve was, the more sensitive the variety was. Yield components (number of marketable and unmarketable tubers) and yield (t/ha) were taken at the end of the crop cycle. Tubers > 30 mm in diameter were considered as marketable tubers. [8]. Yield was estimated per hectare by toning, taking into account the average weight of tubers per category per plant and the density per hectare, which was of 33333.33 at 60 ×50 cm spacing. For all the parameters studied, data were taken from six plants taken randomly in the central rows per plot. For yield loss considering tuber weight, the calculation from plot weight with and without fungicide treatment enabled us to make the estimation (%) *Yield loss* = $\frac{Yield\ F1-Yield\ F0}{Field\ F1}$x 100 where yield F1 is the yield obtained on treated plots and yield F0 the yield obtained on untreated plots [22]. The loss in tons per ha was calculated as the difference between the yield obtained on treated plots and the yield on untreated plots. The value-cost ratio (VCR) enabled us to assess the economic profitability of fungal treatment, considering the VCR>2. The value-cost ratio was calculated as follows: VAP /CTF [23] where VAP= Value of additional production attributable to the fungicide treatment expressed in monetary value (American dollars) and CTF= Cost of fungicide treatment.

2.6. Data Statistical Analysis

Data analysis consisted essentially of ANOVA with the generalized linear model (GLM) using Genstat.2015 software. Varieties were taken as a factor, as well as replications. It was applied to assess the level of tolerance of the three varieties to Late Blight as well as yield parameters under natural Late Blight infection. For yield loss due to Late Blight and the value-cost ratio, a simple description was made based on calculations according to the formulas above. The pairwise correlation of quantitative variables was tested by Pearson correlation with the GGally package under R software 4.3.0 [24]. Graphs showing averages were produced with the ggplot2 package [25].

3. Results

3.1. Level of Tolerance of the Three Varieties to Foliar Late Blight

Generally, the tolerance level in terms of the area under the disease progression curve (AUDPC) of Late Blight varied between 0 and 1780 for these three varieties (figure 1). Sarpo mira was not attacked by Late Blight unlike Carolus with an average AUDPC=1030 and Kinigi with 123. The results of the analysis of variance reported in Table 1. indicate that the level of tolerance to foliar Late Blight is very highly significant between these three varieties (p<0.001). That is, Sarpo mira is more tolerant to Late Blight and Carolus more susceptible. The Kinigi variety is moderately tolerant to this disease.

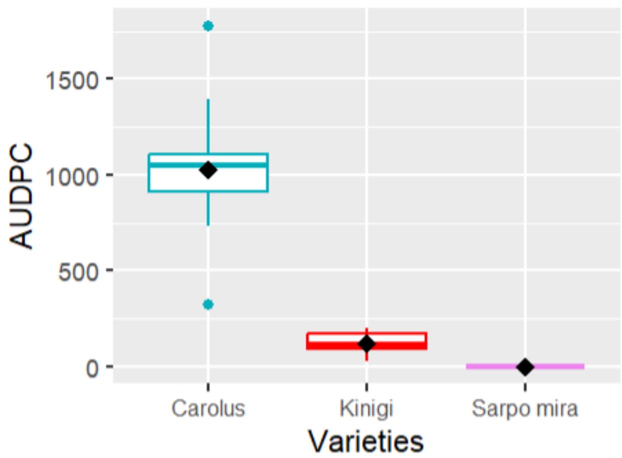

Figure 1. *Area under the disease progression curve (AUDPC) value.*

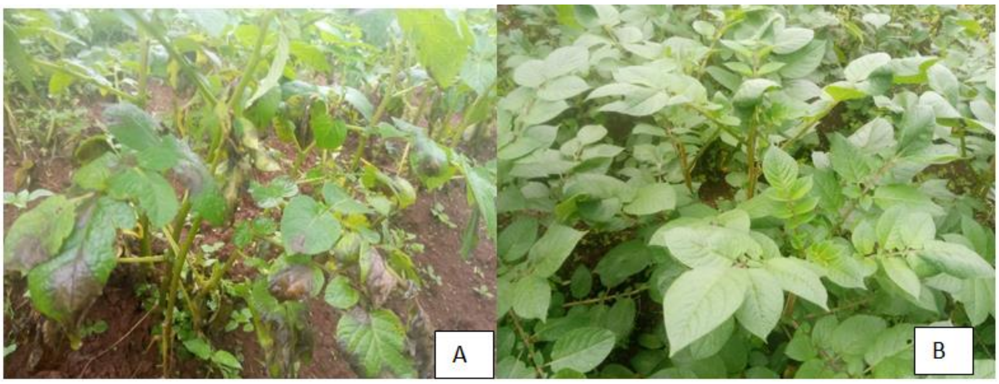

Figure 2. *First symptoms on Carolus (A) and no symptoms on Sarpo mira (B).*

Table 1. *Analysis of variance of AUDPC.*

Source of variation	DF	SS	MS	F	p
Blocks	2	49898	24949	0.78	0.463
Varieties	2	11385566	5692783	178.72	<.001
Blocks *varieties	4	32218	8054	0.25	0.906
Residual	45	1433393	31853		
Total	53	12901075			

Note: DF = Degree of freedom, SS= Sum of squares, MS= mean squares

3.2. Yield Varietal Response to Natural Late Blight Infection

Results show that the number of unmarketable tubers varies from 3 to 12 for all three varieties. The Kinigi variety had the highest average number (7.89), while the Sarpo mira variety had the lowest (2) (figure 3a). The number of marketable tubers varies from zero to nine per plant under Late Blight infection. The Carolus variety did not initiate this type of tuber under Late Blight infection, all its tubers were unmarketable and the Kinigi variety presented a high average number (5.11) per plant (figure 3b). Marketable yields varied between zero and 24 t/ha for these three potato varieties under natural Late Blight infection. The Carolus variety did not record this marketable yield due to its susceptibility to this disease, while the most resistant Sarpo mira variety recorded a high average yield of 20.16 t/ha under natural Late Blight infection, followed by the Kinigi variety (figure 3c). The total yield per hectare under natural Late Blight infection ranged from 2.17 to 25 t/ha for all three varieties. Yield was successively 20.16, 14.36 and 5.56 t/ha for the Sarpo mira, Kinigi and Carolus varieties, depending on their level of tolerance to Late Blight (figure 3d). The analysis of variance indicates the significative difference of all these traits in terms of varieties under natural Late Blight infection (table 2).

Table 2. *Analysis of variance of yield components and yield (With mean squares).*

Traits	Blocks	Varieties	Blocks*verities	Residual
NUT	0.130ns	177.463***	1.546ns	9.819
NMT	1.907ns	142.907***	3.269ns	2.381
YMT	34.9 ns	1243.9***	9.2ns	15.6
TY	2.3ns	974.5***	24.2ns	16.2

Note: NUT: Number of unmarketable tubers per plant, NMT= Number of marketable tubers per plant, YMT = yield of marketable tubers (t/ha) and TY= Total yield (t/ha). ns= non-significant, ***= highly significant p< 0.001.

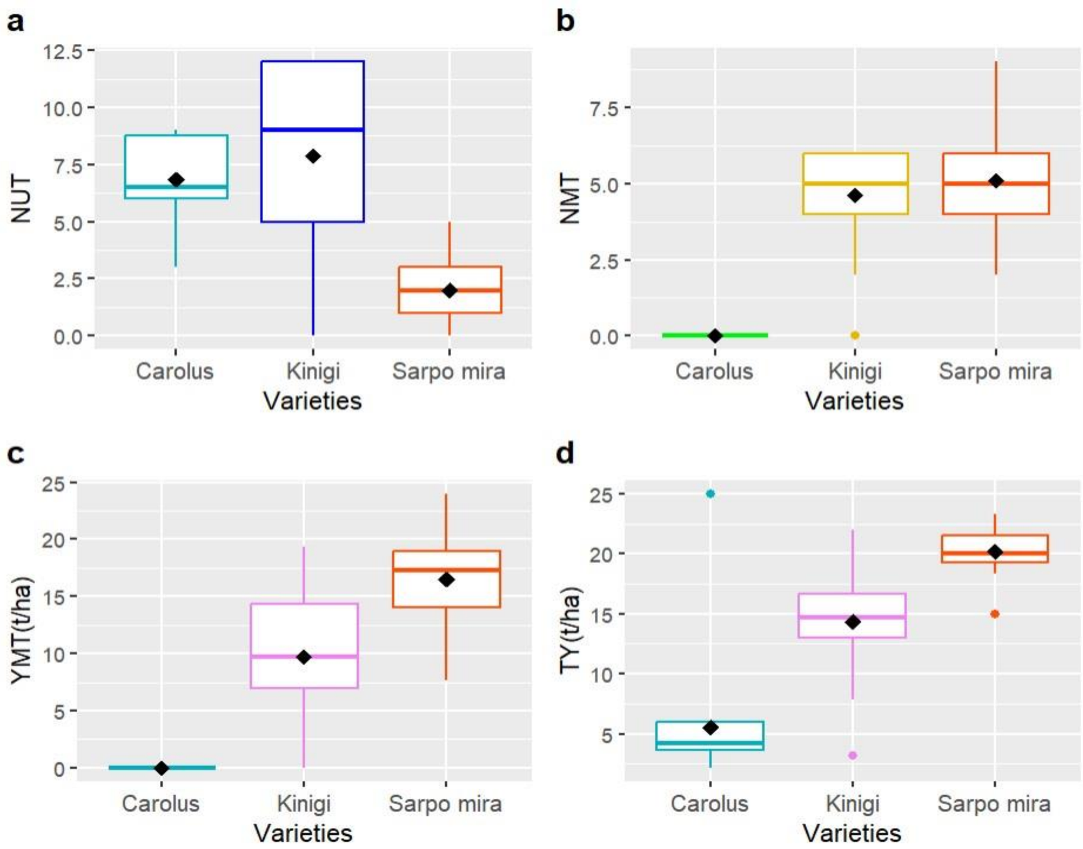

Figure 3*. Means of yield components and yield.*

Note: NUT: Number of unmarketable tubers per plant (figure 3a), NMT= Number of marketable tubers per plant (figure 3b), YMT = Yield of marketable tubers (t/ha) (figure 3c) and TY= Total yield (t/ha) (figure 3d).

3.3. Estimated Yield Loss Due to Late Blight in three Potato varieties

Estimations of yield loss due to the lack of treatment of potato with fungicide range from 0.52 to 12.9 2 t/ha or 2 to 70% with the greatest loss for the Carolus variety (Table 3). As the Sarpo mira variety showed no symptoms of Late Blight, the loss was 2% (0.52 t/ha).

Table 3*. Value of yield loss due to potato Late Blight.*

Varieties	Yield F1 (t/ha)	Yield F0 (t/ha)	Loss (t/ha)	Loss (%)
Carolus	18.46	5.56	12.91	70
Kinigi	20.56	14.36	6.21	30
Sarpo mira	20.7	20.16	0.52	2

Yield F1 = Yield on treated plots, Yield F0= Yield on untreated plots

3.4. Correlation Between Performance Parameters and AUDPC

The pairwise correlations between the quantitative variables are presented in the matrix below. There are highly significant negative correlations between yield parameters such as the number of marketable tubers (NMT), yield of marketable tubers (YMT), total yield (TY) and area under the disease progression curve (AUDPC). In other way, the increase in

Late Blight attack reduces the number of marketable tubers, their yield and total yield. Similarly, the number of unmarketable tubers reduces marketable and total yield (figure 4).

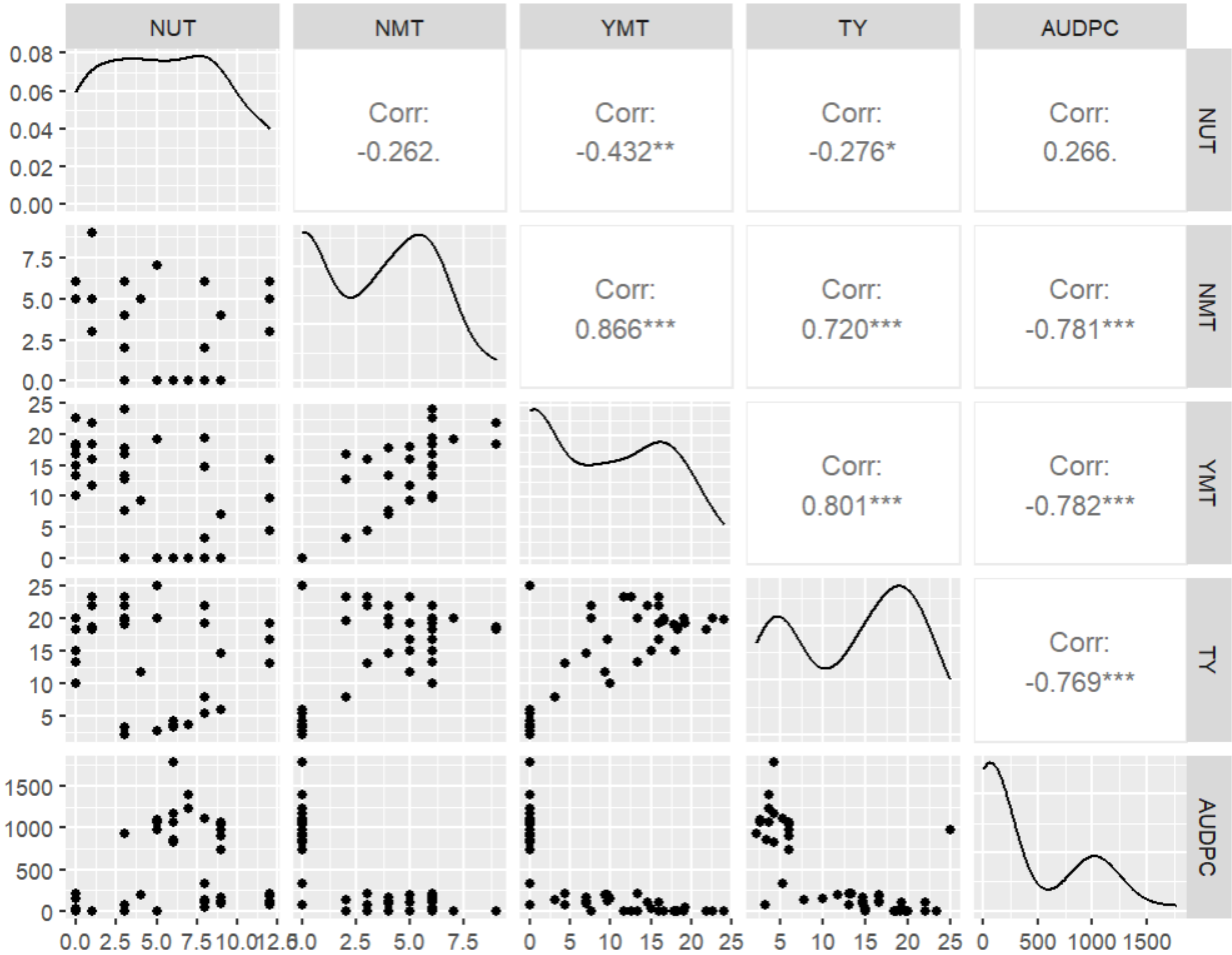

Figure 4. Pearson correlation matrix. Note: NUT: Number of unmarketable tubers per plant, NMT= Number of marketable tubers per plant, YMT = Yield of marketable tubers (t/ha), TY= Total yield (t/ha) and AUDPC=Area under the disease progression curve.

3.5. Justification for Fungicide Application on Potato

The value-cost ratio values were 25.32, 12.18 and 1.01 respectively for the Carolus, Kinigi and Sarpo mira varieties. For the Carolus and Kinigi varieties, fungicide treatment is justified, acceptable and beneficial. For Sarpo mira, however, fungicide treatment is not justified. It means that this variety can be grown without or with less fungicide.

Table 4. Value-cost ratio (VCR) for the three varieties.

Varieties	Fungicide purchase cost/ha	Fungicide application cost/ha	Total cost/ha	Additional yield (t/ha)	Additional monetary value	VCR
Carolus	$134.00 us	$48.00 us	$182.00 us	12.91	$4608.87 us	25.32
Kinigi	$134.00 us	$48.00 us	$182.00 us	6.21	$2216.97 us	12.18
Sarpo mira	$134.00 us	$48.00 us	$182.00 us	0.52	$185.64 us	1.01

Note: Costs are estimated for three treatments in one growing season.

4. Discussion

This study focused on estimating the yield loss due to potato Late Blight using three potato varieties. The main findings indicate that tolerance to foliar Late Blight varies from one variety to another. In this study, Carolus was more attacked (AUDPC=1030) than Kinigi; Sarpo mira was not attacked by this disease during the experimental period. These results may be explained by the genetic inheritance of resistance in each of these three varieties. For instance, Sarpo mira contains the R3a, R3b, R4, Rpi-Smira1 and Rpi-Smira 2/R8 genes, which give it its high resistance level [26, 27]. Such results of varietal difference in Late Blight tolerance have already been found in Uganda and Rwanda in screening experiments [28, 29].

As for the response of the three varieties on yield under natural Late Blight infection, there is a highly significant difference. The Carolus variety recorded a low yield of less than 6 t/ha under no fungicide treatment, while the Sarpo mira variety recorded the highest yield (20.16 t/ha). This difference is always explained by the genetic inheritance of resistance and yield. There are high-yield, medium-yield and low-yield varieties. For Carolus, susceptibility to this disease led to a decrease in yield. This difference in varietal response on yield under infection has also been reported both in Rwanda and Ethiopia [28, 30].

Yield loss also varied according to varieties, with the most susceptible variety causing a high loss of 70% and the unaffected Sarpo mira 2%. This can be explained by the negative correlation between AUDPC and total yield (figure 4). The more susceptible the variety is, the lower the yield is. Late Blight of the foliage leads to the death of the aerial part and consequently limits and disrupts photosynthetic activity, which is very useful for plant development. For the Sarpo mira variety, this 2% loss can be attributed to other fungal diseases which can benefit from untreated potato Late Blight. Several researchers in Central and East Africa have already demonstrated that loss can exceed 75% [31, 32].

For the economic justification of the use of Winner 72 WP fungicide, for the Carolus variety, and Kinigi the value-cost ratio (VCR) was 25.32 and 12.18> 2, i.e. fungicide application is economically justified for these two varieties. For Sarpo mira, the value was less than 2, i.e. fungicide application is not justified. This variety can be grown without the use of fungicides, or the number of applications can be reduced by exploiting its resistance to Late Blight. In Madagascar, VCR values ranging from 5.8 to 19.6 have been found, explaining the justification for fungicide use in potato cultivation in this country [23].

5. Conclusion

The aim of this study is to assess the level of tolerance to Late Blight of three varieties in the climatic conditions of Lubero territory in Lukanga village and to estimate yield loss due to non-treatment with fungicide. The results showed that Late Blight is a one of the major constraints of potato in this territory, with yield loss estimated at 70 %. As the Sarpo mira variety is resistant to Late Blight, it was not attacked under natural infection. It can be exploited as a gene source in the potato breeding program in the Democratic Republic of Congo.

Abbreviations

ANOVA	Analysis of Variance
AUDPC	Area Under the Disease Progression Curve
CIP	International Potato Center
CTF	Cost of Fungicide Treatment
DRC	Democratic Republic of the Congo
GLM	Generalized Linear Model
NMT	Number of Marketable Tubers Per Plant
NUT	Number of Unmarketable Tubers Per Plant
RCBD	Randomized Complete Block Design
TY	Total yield
UNILUK	Adventist University of Lukanga
VAP	Value of Additional Production Attributable to the Fungicide Treatment
VCR	Value-cost Ratio
YMT	Yield of Marketable Tubers

Author Contributions

Katembo Vihabwa Abishay: Conceptualization, Formal Analysis, Funding acquisition, Methodology, Software, Visualization, Writing – original draft

Kasereka Mulonga Germain: Methodology, Supervision, Writing – review & editing

Katembo Banganire Alphonse: Supervision

Kasi Kasika Gr âce: Data curation

Kasereka Katswangene Phalek: Methodology, Validation, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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