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Response of commercial potato genotypes *Solanum tuberosum* L. to *Phytophthora infestans* (Mont.) de Bary late blight attack

Respuesta de genotipos comerciales de papa *Solanum tuberosum* L. al ataque de tizón tardío *Phytophthora infestans* (Mont.) de Bary

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ABSTRACT

Potato (*Solanum tuberosum* L.) cultivation is an important agricultural activity in the Andean region. The late blight *Phytophthora infestans* (Mont.) de Bary, considered one of the limiting diseases in production, represents a threat to food security and causes losses ranging from 30 to 100% of yield. This research evaluated the response to the disease in four commercial materials widely planted in the department of Nariño. The evaluation was carried out under field conditions, in the municipality of Pasto, at AGROSAVIA's Obonuco research center, with natural inoculum, under a randomized complete block design with four replications. The response variables evaluated were incidence, severity, leaf area index and yield in the commercial categories. The ICA Única variety, reported as highly resistant in 2001, presented damage levels close to 75%, with a yield reduction of 49.88%, caused mainly by low yields of first category tubers, indicating a loss of its level of resistance, with damage levels similar to the highly susceptible control Diacol Capiro, which presented 100% of the area with symptoms of the disease and a reduction of 89% in yield. The genotypes Pastusa Suprema with disease tolerance characteristics and Superior showed the best performance with a severity level of 30% in each case and yield reductions of 30.5% and 40.92%, respectively. The results highlight the importance of these genotypes and their role as pillars in the integrated management of the disease through the planting of varieties with favorable behavior against the disease.

Key words: Disease tolerance; phytopathogen; yield; andean crop; tuber.

RESUMEN

El cultivo de papa (*Solanum tuberosum* L.) constituye una actividad agrícola importante en la zona andina. El tizón tardío *Phytophthora infestans* (Mont.) de Bary, considerado como una de las enfermedades limitantes en su producción, representa una amenaza para la seguridad alimentaria y ocasiona pérdidas, que varían entre el 30 a 100% del rendimiento. En esta investigación se evaluó la respuesta a la enfermedad de cuatro genotipos comerciales, sembrados en el departamento de Nariño. La evaluación se realizó en condiciones de campo, en el municipio de Pasto en el centro de investigación Obonuco de AGROSAVIA, con inóculo natural, bajo un diseño de bloques completos al azar, con 4 repeticiones, las variables de respuesta evaluadas fueron incidencia, severidad, índice de área foliar y rendimiento en categorías comerciales. La variedad ICA Única, reportada como altamente resistente en 2001 presentó niveles de daño cercanos al 75%, con una disminución del rendimiento del 49,88%, ocasionada principalmente por bajo rendimiento de tubérculos de primera categoría, indicando una pérdida de su nivel de resistencia y con niveles de daño similares al testigo altamente susceptible Diacol Capiro el cual, presentó un 100% de área con síntomas de la enfermedad y disminución del 89% en el rendimiento. Los genotipos Pastusa Suprema quien presentó características de tolerancia a la enfermedad y Superior, evidenciaron el mejor comportamiento con un nivel de severidad de 30% en cada caso y reducción del rendimiento en 30.5% y 40.92% respectivamente. Los resultados destacan la importancia de estos genotipos y su papel como pilares en el manejo integrado de la enfermedad a través de la siembra de variedades con comportamiento favorable en contra de la enfermedad.

Palabras clave: Tolerancia a enfermedades; fitopatógenos; rendimiento; cultivos andinos; tubérculos.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is ranked globally third in importance as a food product after rice and wheat (Bertone *et al*., 2007; Campos & Ortiz, 2019); it is the most important tuber produced worldwide, cultivated in more than 125 countries (Vazques *et al*., 2022), and world production surpassed 462'000,000 t in 2019 (Faostat, 2019). In Colombia, the crop occupies about 132,161 hectares, with a national production of 2,751,837 t/year, and an average yield of 20.5 t/ha (Agronet, 2019). Its cultivation benefits 110,000 families and generates 75,000 direct jobs and 189,000 indirect jobs (Fedepapa, 2018). The department of Nariño participates with a planted area of approximately 26,325 hectares, with a production of 585,303 t/year and a departmental average yield of 22,2 t/ha (MADR, 2019).

In the phytosanitary component, late blight is considered the most restrictive disease for its production to the point where it can be categorized as a threat to world food security (Shakya *et al*., 2015). The role of the disease in the Irish potato famine of the 1840's, where crop losses caused the deaths of approximately one million people and the forced displacement of a similar number, is well known (Sparks *et al*., 2014). Its causal agent is the Oomycete *Phytophthora infestans* (Mont.) de Bary, which has great genetic plasticity and high levels of virulence not only in potato but also in other species related to its botanical family (Silva *et al*., 2009; Delesma *et al*., 2020).

If climatic conditions are ideal for the attack of *P. infestans*, together with the planting of susceptible varieties, significant levels of severity can be reached, with important decreases in crop yield (Vazques *et al*., 2022). For example, according to Barquero *et al*. (2005), if no protection strategy is applied, losses could reach up to 100% depending on the phenological stage in which the disease is developed. In the Andean region, yield reductions in the range of 30 to 100% have been reported (Delesma *et al*., 2020), and for mild regions such as North America, the estimated average reduction due to the disease is around 16% of crop yield, equivalent to US$7.2 billion per year (Stefańczyk *et al*., 2017). As a result of the above, the disease also represents a significant impact on crop production costs, considering that the item of sanitary applications for its management implies between 10 and 30% of the total production costs in the country (García *et al*., 2008; Mejia & Castellanos 2018).

Within this context, varietal resistance, in other words, the growing of varieties resistant to potato late blight, has established itself not only as a profitable way to manage the disease but also as a practice that, within an integrated management program, is environmentally friendly (Haesaert *et al*., 2015). Based on this, the development and use of resistant varieties is likely to play a key role in the sustainable management of the disease, improving the efficiency of chemical management and reducing the number of fungicide applications in conventional production systems (Pacilly *et al*., 2018). In the case of potato late blight, Skelsey *et al*. (2010) showed that the deployment of a partially resistant variety could slow the spread of the disease and stop the epidemic in the field; however, it cannot completely prevent the infection.

Considering the crucial role that disease resistance plays, as a strategy for the sustainable management of the disease and in order to advance breeding programs for the species, it is important to know the current level of susceptibility or resistance to the disease that is present in the commercial genotypes planted in the different regions. In the case of the department of Nariño, Benavides *et al*. (2021) determined that for the year 2019, within the *Tuberosum* group of potatoes, the most economically important cultivated materials are the cultivars Diacol Capiro (38%), Pastusa Suprema (20%), ICA Única (16%), Superior (4%), and Parda Pastusa (4%). On the basis of the above, the aim of this work was to evaluate the response of commercial potato genotypes present in the production area of the department of Nariño to the attack of late blight *Phytophthora infestans* (Mont.) de Bary.

MATERIALS AND METHODS

Field tests. The research was conducted at the Obonuco research center of AGROSAVIA, located in the municipality of San Juan de Pasto, coordinates 1°11'45.90" N, 77°18'5.70" W at an altitude of 2766 m.a.s.l. The trials were conducted in open field with conventional agronomic management up to 52 days after sowing (DAS) and with natural inoculum during an evaluation cycle that corresponded to the first semester of 2019.

Climate monitoring. The registration of climatic data was conducted from the seeding stage of the crop to harvest, recording the precipitation, relative humidity, and temperature variables. Data was collected on a daily basis every half an hour. The equipment used was a Davis Ventage Pro 2 weather station.

Plant Material. Four commercial genotypes of potato *Solanum tuberosum Andigena* Group, identified as economically significant and with the largest planted area in the department of Nariño, were evaluated in this experiment under field conditions. The genotypes evaluated were Diacol Capiro (DC), ICA Única (IU), Pastusa Suprema (PS), and Superior (S). The seed used to establish the experimental lots corresponded to basic category seed, produced under the guidelines of Resolution 3168 of 2015 of the Colombian Agricultural Institute (ICA).

Experimental design and treatments. The assessment was established under a completely randomized block design with 4^2 factorial arrangements with 4 replications; each experimental plot was composed of 4 furrows of 5 meters long, for a total of 32 experimental plots. The factors were the four commercial genotypeswith and without late blight management at the phenological stages of tuberization, tuber filling, and harvest. The planting distance used was 1.20 meters between rows and 0.30 meters between plants. The agronomic management applied was the standard for the eight treatments. Practices such as fertilization, cultural tasks such as weeding and hilling, and pest and disease management were carried out identically in the eight treatments up to day 52 after sowing (DAS). From this moment on, chemical applications to control late blight were suspended in the treatments without chemical disease management (Table 1).

Table 1. Commercial genotypes evaluated with and without chemical disease management.

No. Treatment	Treatment name	Treatment description
1	DC with management	Diacol Capiro with chemical management for *P. infestans* throughout the crop cycle.
2	IÚ with management	ICA Única with chemical management for *P. infestans* during the entire crop cycle.
3	PS with management	Pastusa Suprema with chemical management for *P. infestans* during the entire crop cycle.
4	S with management	Superior with chemical management for *P. infestans* throughout the crop cycle.
5	DC without management	Diacol Capiro without chemical management for *P. infestans* from 52 DAS to the harvest stage.
6	IÚ without management	ICA Única without chemical management for *P. infestans* from 52 DAS to the harvest stage.
7	PS without management	Pastusa Suprema without chemical management for *P. infestans* from 52 DAS to the harvest stage.
8	S without management	Superior without chemical management for *P. infestans* from 52 DAS to the harvest stage.

Severity assessment. The severity of late blight was evaluated on 10 randomly assigned plants per experimental plot that were labeled at the beginning of the vegetative cycle. The diseased area was determined from the contrast between the area with the presence of representative symptoms of late blight, such as brown spots with a wet appearance and whitish structures on the underside of the leaves, in contrast to the tissue that is still green. This evaluation was performed every seven days. The severity scale used was the one proposed by James *et al*. (1971) and modified in trials by Pérez & Forbes (2008), who illustrate severity levels of 1, 10, 25 and 50%, using the extrapolation technique, the progress of the disease continued to build up to levels of 100% in the total number of evaluated plants.

Calculation of area under the disease progress curve. The AUDPC (Area under the disease progress curve) was calculated using the formula proposed by Campbell & Madden (1990), Equation 1:

$$\boldsymbol{A}UDPC = \sum_{i=1}^{Ni-1} ((Yi + (Yi + 1))/2) * (ti + 1 - ti)$$

Where: **t** = time taken for each reading, **Yi** = percentage of leaf area affected in each reading, **n** = number of readings.

Here, the severity data collected during the phenological stages of plant growth, flowering, and senescence served as the basis for the AUDPC calculation. The periodicity of the sample data (weekly) was used as the time frame. The data is expressed as a percentage per day/week/month, and the interpretation is that the higher the AUDPC value, the more susceptible the genotype evaluated.

Leaf area index (LAI). Leaf area was calculated based on the measurement of the aerial part of the plant section through the use of a scanner with a reference line of 1 cm. The free software ImageJ (version 1.45) was used for the calculation.

The leaf area index was determined using the following equation proposed by Campostrini & Yamanisi (2001), Equation 2:

LAI=LA/SA

Where, **LAI** = Leaf área index, **LA** = Leaf area cm^2, **SA** = Soil area cm^2

Yield. The commercial yield consisted of the total harvest obtained in each treatment (the sum of the yield of the four replications). Subsequently, the yield evaluation was carried out according to the commercial quality in five classes: zero or very large potato (greater than 90 mm of equatorial diameter), first class potato (between 71-90 mm of equatorial diameter), second or even potato (between 51-70 mm of equatorial diameter), third class potato (between 31-50 mm of equatorial diameter), and richer or very small potato (between 15-30 mm of equatorial diameter). The weight in kg per class was taken in each of the experimental plots.

Statistical analysis. IBM SPSS Statistics version 25 and R-Studio version 3.6.2 were used for the analysis of the variables evaluated. The Kolmogorov-Smirnov test was performed to verify the normality of the data, and the homogeneity of variance test or homoscedasticity test was performed to verify that the variance is constant. An analysis of variance and a Tukey mean comparison test were conducted on the variables that presented significant statistical differences ($P<0.05$).

RESULTS AND DISCUSSION

The evaluation period that lasted from March 4 to August 22 (2019), 166 days from planting to harvest, presented the following environmental conditions (Figure 1 and Figure 2); an average temperature of 13.01°C, an average maximum temperature of 19.06°C, and an average minimum temperature of 7.13°C; accumulated precipitation of 340.04 mm, with homogeneous rainfall during the development of the experiment, and an average relative humidity of 78.82%. These conditions together were favorable for the onset and development of late blight disease in the four cultivars evaluated (Leesutthiphonchai *et al*., 2018).

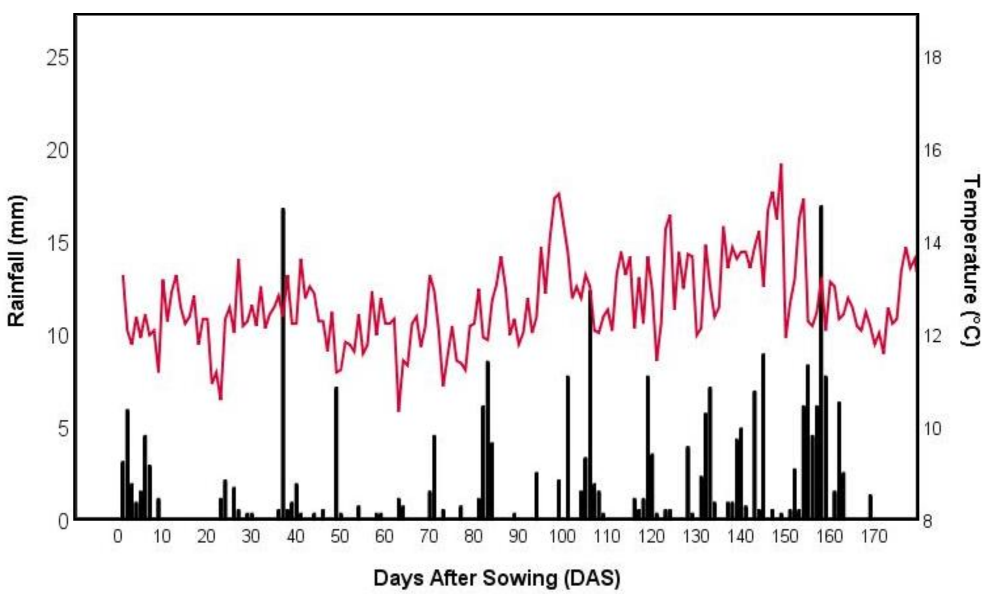


Figure 1. Precipitation (bars) (mm) and average temperature (lines) (°C) during the second evaluation cycle.

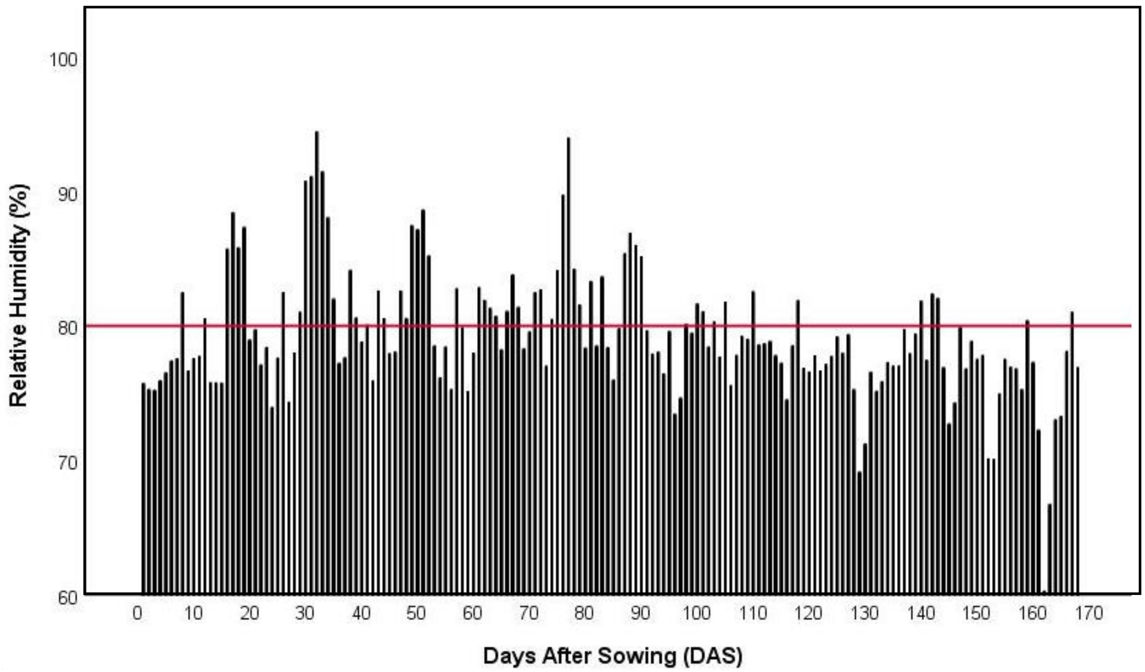
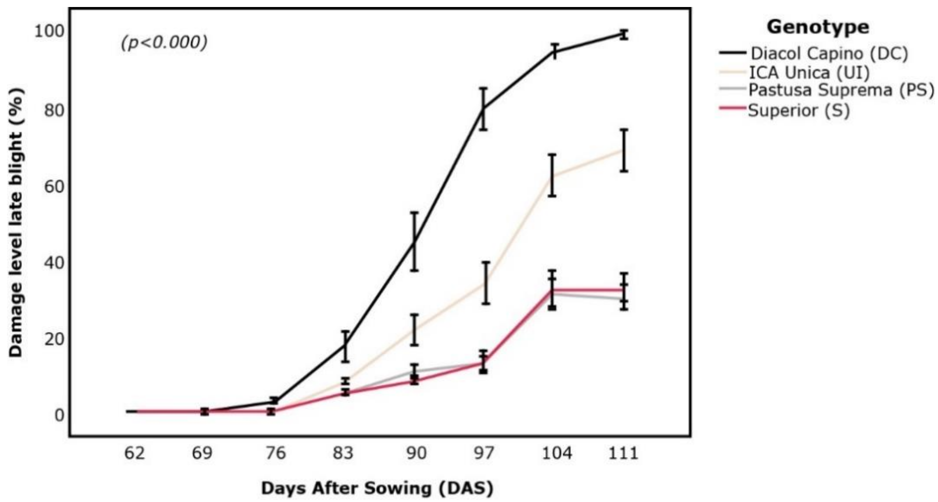


Figure 2. Relative humidity (%) present during the evaluation of response to *P. infestans*., in the municipality of Pasto.

Carrying out the registration and the subsequent analysis of climatic variables is fundamental to the development of agronomic and sanitary management recommendations for the crop (Kessel *et al*., 2018). Climatic variables such as relative humidity, precipitation, and temperature are relevant factors for the proper development of late blight epidemic. In studies performed by Sparks *et al*. (2014), a 24-hour average temperature of 15°C with a daily amplitude of 5°C resulted in nighttime temperatures closer to the optimal constant temperature for pathogen (*P. infestans*) sporulation and infection (Shakya *et al*., 2015); interestingly, the higher the temperature, the longer the period of relative humidity required for infection to occur.

Similarly, the lesion growth rate is affected by daytime temperatures rather than nighttime temperatures; for example, on days with high-temperature conditions, the lesions undergo a desiccation process, which besides affecting the lesion growth rate, affects incubation and sporulation processes (Shakya *et al*., 2015).

In Figure 3, it is shown the level of damage caused by late blight in the different genotypes evaluated. The data indicate the presence of statistical differences between treatments (p<0.000), where the Diacol Capiro variety presented the highest level of damage 111 DAS (100%), followed by ICA Única (75%), Pastusa Suprema, and clone Superior (30% level of damage).



***different letters represent the existence of significant differences, vertical bars represent the standard error

Figure 3. Late blight damage level (%) in 4 commercial potato genotypes.

Similarly, Figure 4 evidences the existence of significant statistical differences in the AUDPC variable among the evaluated treatments (p<0. 0000). The different letters over each bar represent the existence of statistical differences between treatments; it is possible to observe how the variety Diacol Capiro presented the highest AUDPC with values of 1855.87; the ICA Única variety with 1068.15; whereas the Pastusa Suprema variety had 497.43, and clone Superior presented a value of 491.75. It can be inferred that the development of the late blight disease epidemic was more severe in the Diacol Capiro variety, followed by ICA Única; also that the growth and development of the disease were slower in the Pastusa Suprema and Superior materials given the much lower values than those presented by the Diacol Capiro and ICA Única varieties under the environmental conditions present during the first semester of 2019.

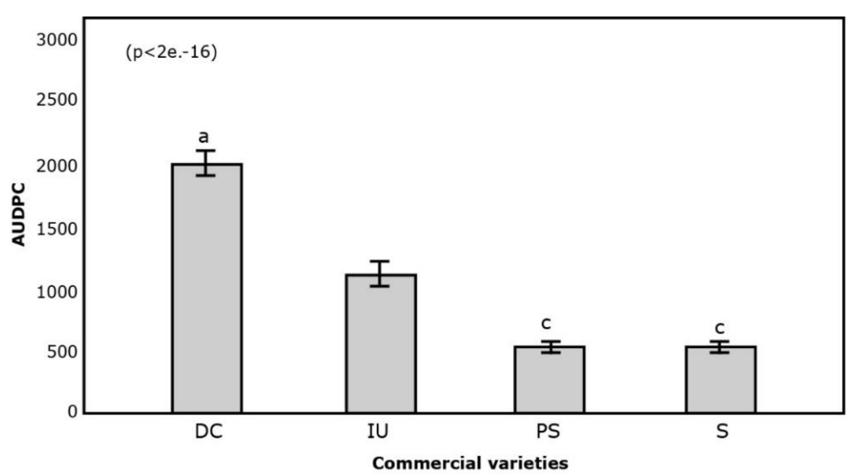


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Figure 4. Area under the disease progress curve (AUDPC) of four commercial potato genotypes in interaction with late blight.

Late blight control in both developed and developing countries has been based primarily on the use of fungicides. The economic and environmental limits of this type of management, portrayed as systematic and frequent spraying programs, have reached their limits, so a change is needed that integrates control strategies based on reasoned applications of pesticides combined with genetic control (resistant genotypes) (Andrivon *et al*., 2006; Vazques *et al*., 2022). While it is expected that varietal resistance can play an important role in disease control (Forbes 2012; Kessel *et al*., 2018), the resistance levels of current genotype are not high enough to avoid the need to protect most of the potato cultivated area with fungicide applications (Kessel *et al*., 2018).

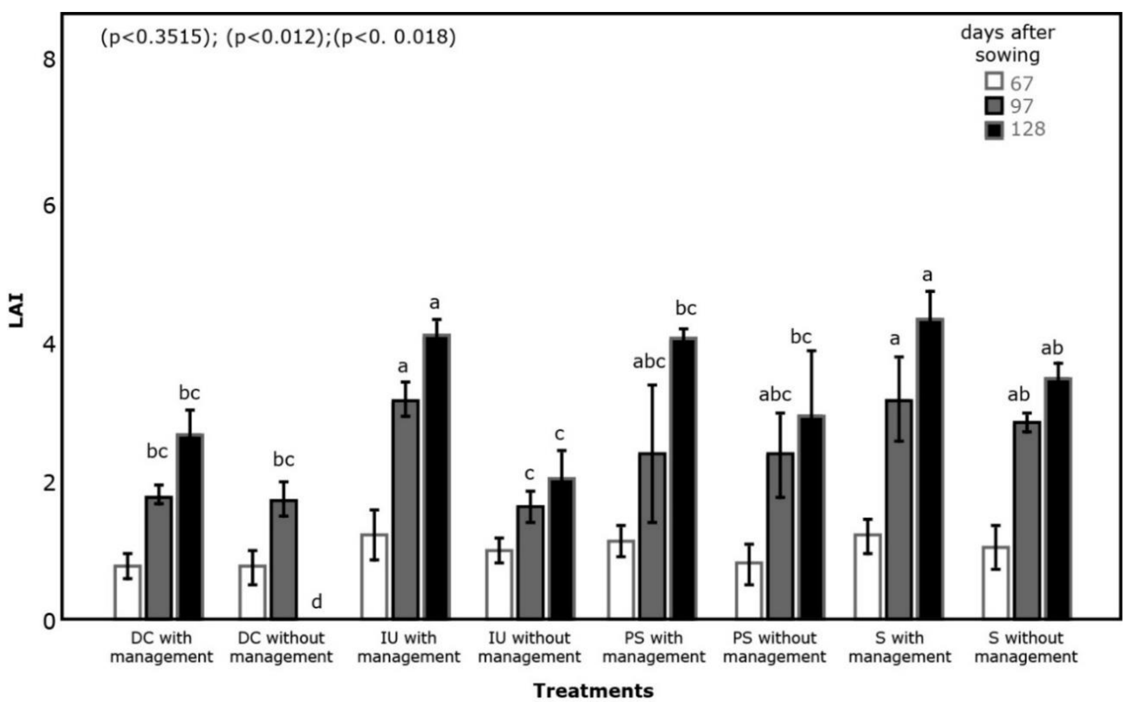
The main source of R genes conferring resistance to this pathogen comes from *Solanum* species from Mexico, mainly located in the Toluca Valley, which is considered as a center of diversity and even the origin of *P. infestans*. Mexican resistance (R) genes include R1-R11 from *Solanum demissum*; Rpi-blb1, Rpi-blb2, and Rpi-blb3 from *Solanum bulbocastanum*; Rpi-sto1 and Rpi-pta from *Solanum stoloniferum*; Rpiamr3 from *Solanum Americanum*; Rpi-mch1 from *Solanum michoacanum,* and Rpi1 from *Solanum pinnatisectum* (Aguilera *et al*., 2018).

Long-lasting resistant varieties have had limited adoption due to slow dissemination, low seed multiplication rate, and because the tubers are perishable (Kessel *et al*., 2018). In industrialized countries, there are highly developed seed production industries that can quickly multiply and distribute a new variety. These systems do not exist in developing countries, and new varieties are generally propagated from farmer to farmer, so it is a much slower and undesirable process (Forbes, 2012).

There is also pressure from industrial potato processors to grow specific varieties. In Colombia, such variety is Diacol Capiro, a variety that, since its release date, was labelled susceptible to late blight and used in this study as our susceptibility control. Diacol Capiro has very good processing and palatability, among other characteristics that propel its cultivation. A similar situation is seen in other developing countries where the disease is mismanaged for many reasons, such as high disease pressure, problems with access to fungicides, and inadequate knowledge of the dynamics of the disease among farmers. Moreover, many of the varieties released as resistant to late blight have lost this resistance and have become susceptible in relatively short periods of time due to the evolution of the pathogen (Forbes, 2012).

In the potato crop, the attack of the pathogen occurs mainly in the aerial part of the plant, affecting leaves and stems. This damage seriously affects the leaf area index, which is a variable that explains the relationship between the leaf area and the area occupied by it in the field (Morales *et al*., 2011). In Figure 5, it is observed the effect of late blight on the leaf area index (LAI). The figure shows that the leaf area started to be severely affected after 67 DAS. The epidemics of the disease had not progressed into their logarithmic phase (Figure 3); therefore, no statistically significant differences were observed between treatments ($p<0.35$).

At 94 DAS, there were statistical differences between treatments for the leaf area index variable ($p<0.012$), a situation that occurred due to the fact that, at that point, there was a severe affection, especially in the Diacol Capiro variety, causing decapitation and stem breakage. As the epidemic progressed, at 119 DDS, it was possible to evidence the existence of statistically significant differences between treatments ($p< 0.018$), a situation attributed to the severe damage caused by *P. infestans* in susceptible varieties such as Diacol Capiro, and to a lesser extent, ICA ÚNICA; genotypes such as Pastusa Suprema and Superior, in spite of showing symptoms of the disease and the fact that the epidemic progressed considerably, the leaf area index variable was not as severely affected as in the other materials in the treatments without chemical management of the disease.



***** Different letters represent the existence of statistical differences between treatments, the vertical bars represent the standard error**

Figure 5. Leaf area index in the eight commercial potato materials in interaction with late blight.

Two of the factors related to the yield of different crops are the photosynthetic rate and the harvest index; the latter allows analyzing how the distribution of assimilates occurs in the different organs of the plant, especially those directed to the organ of economic interest (Soto *et al*., 2018). In the case of potato, foliage growth and expansion of leaf area are quite fast during the early stages of crop development; once the reserves of the seed tuber are consumed, the leaves become the source of products synthesized through the photosynthesis process. This crop is characterized by completely covering the soil 40-45 days after sowing (Morales *et al*., 2011).

According to Morales *et al*. (2011), the efficiency of the use of light depends on the existence of certain conditions, such as the availability of water, nutrients, the amount of radiation, the age, and condition of the foliage. In this sense, the LAI depends on the accumulation of dry matter during the vegetative stage; the higher the leaf biomass and the LAI at which the plant reaches tuberization, the greater the amount of radiation intercepted during the tuberization and tuber-filling stage, resulting in higher yield potential. If there is an interruption in growth at the tuberization and filling stage, the tuber growth period will be shortened, resulting in yield reductions. In the case of a *P. infestans* attack, it generates a low harvest index because the plant is unable to take advantage of the large amount of foliage produced (unpublished results).

Therefore, after analyzing the information previously discussed, we can see that the presence of the disease generates a considerable reduction in the leaf area index due to the attack of the pathogen, considerably reducing the surface area of light uptake, affecting processes such as dry matter accumulation in the different organs of the plant, severely affecting crop yield. Figure 6 shows the existence of significant statistical differences ($p< 3.07e^{-05}$) for total yield among the different assessed materials. It is important to highlight that the Pastusa Suprema variety showed a significant performance in terms of the reduction of the development and advance of the damage caused by the pathogen *P. infestans*, reflected in a not-so-severe reduction of LAI and consequently a lower reduction of total yield compared to the other genotypes evaluated without chemical management.

Although multi-environment tests were not performed, it is valid to suggest the need for these tests in different locations producing the crop; however, it is valid to highlight that this material can also play an important role in the sustainable management of the late blight disease in the producing areas of the municipality of Pasto, where about 1000 ha of the crop are reported to be established in the municipality (MADR, 2019).

During this research, the evaluations included the stage between tuberization and tuber filling. Although it is valid to highlight that there was no presence of the disease in tubers, it is important to recognize the importance of tuberization in the commercial yield of the crop since if it remains free of the pathogen, the formation of as many tubers as the genetics of the plant can express will be induced. Under specific management conditions, the development of these tubers will depend on the events that occur after this phenological stage, corresponding to tuber filling (Romero *et al*., 2012).

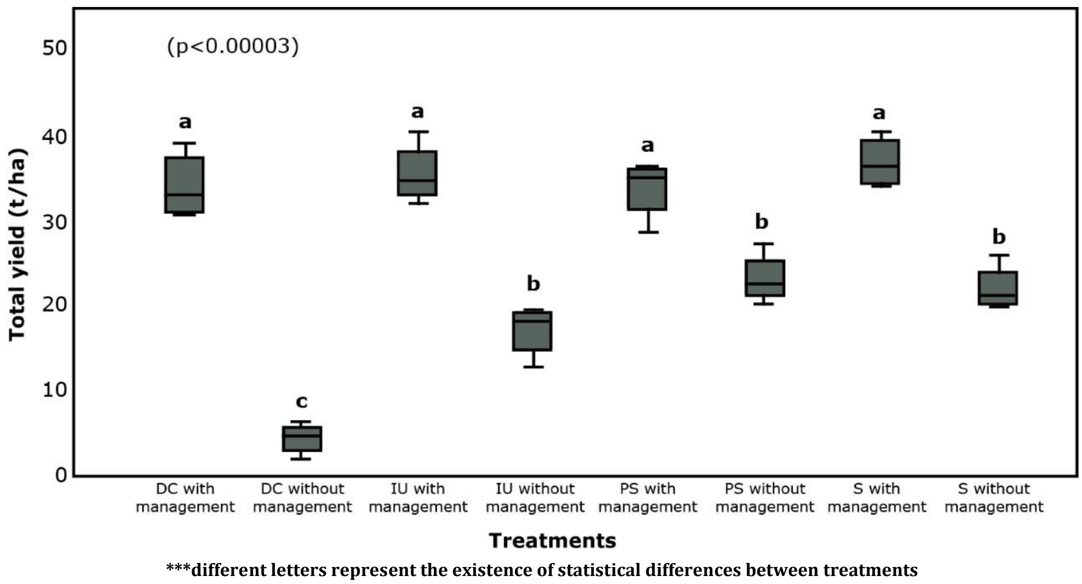
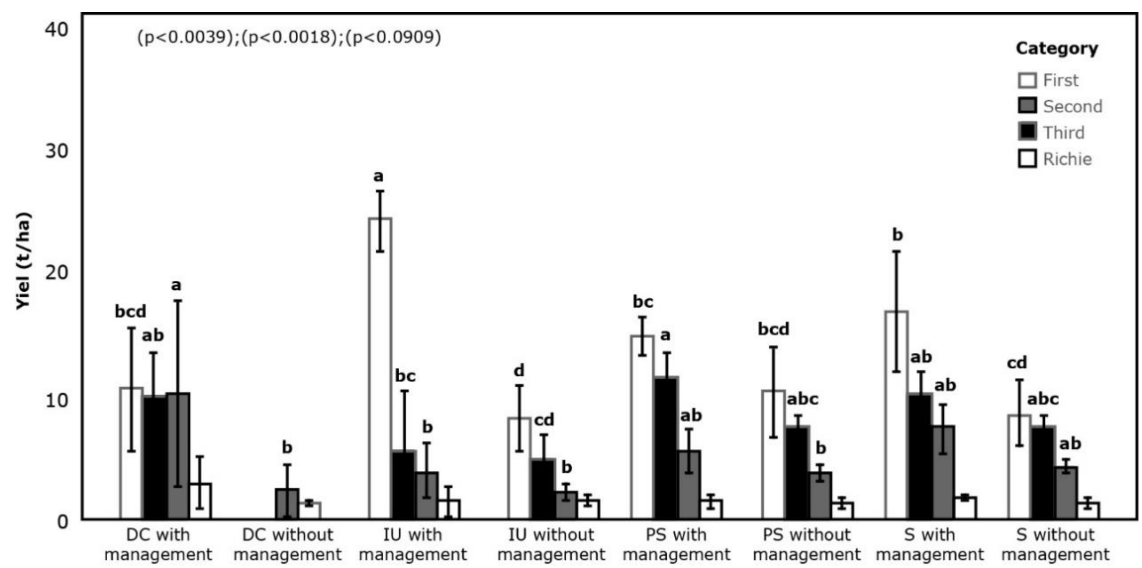


Figure 6. Total yield (t/ha) of commercial genotypes evaluated with and without chemical management of late blight disease.

Tuber growth rate depends on the net assimilation rate (NAR) present in the vegetative stage. If there are no environmental constraints related to water and nutrient supply or reducing factors such as diseases or pests, tuber growth will depend on the radiation intercepted by the crop, temperature, and CO_2 concentration (Morales *et al*., 2011). Oliveira & Derrick (2021) state that the time the leaf area index remains physiologically active is an influential factor in the final yield of tubers. Therefore, it is crucial to protect and guarantee proper leaf development in order to ensure greater production of photoassimilates and their accumulation in the different organs of interest, especially in the tuber, an organ of economic interest in this particular production system.

According to Golovko & Tabalenkova (2019), it has been demonstrated for many crops, including potato, that the rate of photosynthesis in individual leaves reaches a maximum sometime before the end of leaf expansion, found a continuous decrease in photosynthetic rate with age, and further demonstrated that late foliage maturity was associated with an increase in tuber size distribution in favor of large tubers. The symptoms and the high severity of the disease generate a determinant reduction in yield. This could be observed mainly in the ICA Única and Diacol Capiro commercial varieties, which presented high levels of damage and low yields, clearly reflecting that the attack of *P. infestans*, since it occurs mainly in the area of the plant, affects tuber yield in the crop, which is determined by the amount of photosynthetically active radiation intercepted by the foliage, by the efficiency with which the intercepted radiation is converted into dry matter, and by the proportion of dry matter accumulation translocated to the tubers (Betancourth *et al*., 2008).

It is important to highlight that there were significant differences for tuber yield, according to commercial class, for first (p<0.0039) and second class (t/ha) (p<0.0018), respectively. The third-class yield variable (p<0.0909) did not present statistically significant differences. In Figure 7, it is possible to observe the yield obtained by the Diacol Capiro variety with and without chemical management of the disease at harvest, distributed in the different commercial classes commonly used in the commercial selection of potatoes; the Diacol Capiro variety without chemical management of the disease during the tuberization and filling stage did not produce first and second grade potatoes (100% loss for these classes).



***different letters represent the existence of significant statistical differences, vertical bars represent the standard error

Figure 7. Yield (t/ha) first, second, third, riche, and total classes, genotypes evaluated with and without chemical management of late blight disease.

For the third category, there was a decrease of 76.83% in the treatment without chemical management of the disease; the total yield was seriously affected by the damage caused by the pathogen *P. infestans*, generating a decrease of 89.06% with respect to this same variety with the chemical management calendar of the disease. The high susceptibility of the Diacol Capiro material to late blight is a factor that puts at risk the environmental and economic sustainability of potato-producing areas in the country and in the department of Nariño.

The ICA Única variety was seriously affected in its production by the development and evolution of the epidemic of the late blight disease; for first-class tubers, there was a decrease of 66.11%; for second-class tubers there was a 13.51% reduction; for third-class tubers there was a reduction of 43.66%, this decrease in the production of tubers of different classes in the ICA Única variety, generated a reduction in the total yield of 49.88% expressed in t/ha, concluding that, in spite of the high level of damage, the main effect of the presence of the disease is the reduction in the yield of first category tubers, these tubers determine in great measure the economic profitability of the crop, assuming that the planting of this material in periods of high rainfall and relative humidity above 80%, generate a high risk of attack by the disease and economic risk due to a decrease in yield.

The Pastusa Suprema variety with and without chemical disease management showed a reduction of 30.5% in first-class tubers, 35.57% in second-class tubers and 32.25% in third-class tubers; the overall yield reduction (t/ha) was 31.75%. Based on the results obtained for this material in terms of level of damage and yield, it is possible to suggest that this variety presents resistance characteristics to the disease due to the fact that it showed a considerably lower level of damage (30% of affected area) and acceptable total yield in comparison with the other evaluated materials during this research, which showed higher levels of damage and lower yields. Therefore, it is valid to infer that the planting of this variety considerably reduces the risk of commercial yield reduction due to the presence of late blight disease in the production area of the municipality of Pasto.

The commercial yield obtained for the Superior genotype with and without chemical management of the disease presented a reduction of 49.44% in the yield of first-class tubers; the second-class tubers presented a reduction of 28.57%, and the third-class tubers presented a reduction of 40.92%. This reduction in the different classes according to tuber diameter generated a reduction in total yield (t/ha) of 39.64%. The Superior clon showed a 10% greater loss in total yield compared to Pastusa Suprema without chemical management of the disease and 9% less yield loss than that of ICA Única without chemical management of the disease.

Romero *et al*., (2012) demonstrated that the duration of the foliage, where it remains with physiological activity, and its influence on potato tuber production is of high importance. In the potato crop, there is a capture between 87 to 96% of photosynthetically active radiation, when LAI of 3 to 4.5 is present; the higher the LAI, the more growth is presented in the tubers (Soto *et al*., 2018). At the tuber formation or tuberization stage, disease damage levels between 90 to 100% allowed tuber formation; however, it is important to highlight that the greatest impact on total yield occurs when the pathogen attack occurs before the tuber formation period. The production and later translocation of carbohydrates and sugars resulting from photosynthesis to the tubers, which are the main carbohydrate reserve organ and organ of economic interest of the plant, is directly related to the photosynthetic area of the plant, which is affected by reducing agents such as diseases (Morales *et al*., 2011).

During this research, it was possible to observe that materials such as Diacol Capiro and ICA Única did not manage to produce a significant number of tubers of superior commercial classes due to the high level of damage generated in the aerial part of the plant, hindering the production of photosynthates required for the filling and proper development of the tuber. This process was seriously affected by the attack of *P. infestans*, deteriorating the quality and number of leaves, affecting the leaf area, and negatively influencing the photosynthesis process (Romero *et al*., 2012). Therefore, taking into account the information discussed above, it is advisable to apply management techniques focused on delaying the onset of attack; a clear example of these practices could be the application of protective fungicides during high relative humidity periods.

An analysis of the behavior of the different genotypes evaluated shows that genotypes such as Pastusa Suprema and Superior showed a reduction in the level of damage and in the advance of the disease compared to the ICA Única and Diacol Capiro varieties. It was possible to observe that the Pastusa Suprema variety continues to conserve desirable levels of resistance to *P. infestans*, 17 years after its release (Ñústez, 2011; Barrientos & Ñústez., 2014), evidencing that polygenic or quantitative resistance becomes a very good option to reduce the impact of the disease in the productive system. The Superior clon also constitutes an option for the sustainable management of the disease; therefore, the two materials constitute an efficient option for the management of late blight in the production area of the municipality of Pasto, optimizing the chemical management of the disease and contributing to the sustainability of potato cultivation in the study area.

CONCLUSIONS

The commercial Pastusa Suprema and Superior presented developmental and yield characteristics that can be associated with resistance to late blight disease attack and should be considered valid alternatives for potato production systems. These materials can also be part of integrated management plans for multiyear vegetable production systems. This is because, during this research, it was possible to show that these materials have a negative influence on the development of the late blight epidemic; in addition to observing that, despite the fact that a considerable level of damage was generated, yields showed a moderate reduction, which allows reducing the risk of yield loss due to the disease.

The loss of the level of resistance of the variety ICA Única is evident, which according to the results of this research presented a level of damage close to 75%, with a reduction in the global yield of 49.88%, marked mainly by the reduction of first category tubers 66.11%. The level of damage and the reduction in yield are considered significant, concluding that the variety is moderately susceptible. The Diacol Capiro variety, due to its susceptibility, presented significant losses with respect to total commercial yield; planting it in areas with high inoculum pressure could be unfeasible and contribute to the spread of the disease, in addition to the negative economic impact of its cultivation and maintenance.

Because of the behavior of the responses of the genotypes evaluated, it is important to design management plans in susceptible varieties that preserve the foliage for longer periods; in this way, the photosynthetic machinery could fix the necessary energy to allow the grower to be competitive in a commercial setting.

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