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Resilience of Potato Crop (*Solanum tuberosum* L.) to Hail Simulation at CIP Illpa

Resiliencia del cultivo de papa (*Solanum tuberosum* L.) frente a la simulación de granizo en CIP Illpa

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Abstract

Agricultural activity in recent decades has been affected by climate change, reducing harvests year after year; hail can damage crops depending on the size and intensity of the hail, potentially harming or even compromising the crop as a total loss. Understanding climate changes and the damage they cause in agriculture is essential for planning production systems, crop selection, seed variety, fertilizer application, among other actions. Once the potato crop is damaged by hail, it is important to know the resilience of the crop and take actions to continue or replace the crop. The objectives were to determine the resilience of the potato crop (*Solanum tuberosum* L.) against hail simulations at CIP Illpa; analyze the yields of the potato crop with different percentages of damage to the crop and analyze resilience in different phenological phases. The research methodology has a quantitative, experimental, descriptive, and sequential time approach, with an inferential non-parametric statistical design of completely randomized blocks (CRB) distributed in a factorial design of A3xB3xC2, where factor A represents the varieties; B represents the level of damage, and factor C the phenological phases. The results show that the Silver variety with simulated damage of 60% in the flowering phenological phase presents the greatest yield loss of the crop at 36.81%, and 27.24% in the Imilla negra variety. The interaction between the proposed factors does not show significance in its variables.

Keywords: Resilience, Andean crop, climate change, potato.

Resumen

La actividad agrícola en las últimas décadas se ha visto afectada por el cambio climático, reduciendo las cosechas año tras año; el granizo puede dañar los cultivos dependiendo del tamaño e intensidad del mismo, pudiendo perjudicar o incluso comprometer el cultivo como pérdida total. Comprender los cambios climáticos y el daño que causan en la agricultura es esencial para planificar los sistemas de producción, selección de cultivos, variedad de semillas, aplicación de fertilizantes, entre otras acciones. Una vez que el cultivo de papa es dañado por el granizo, es importante conocer la resiliencia del cultivo y tomar acciones para continuar o reemplazar el cultivo. Los objetivos fueron determinar la resiliencia del cultivo de papa (*Solanum tuberosum* L.) frente a simulaciones de granizo en CIP Illpa; analizar los rendimientos del cultivo de papa con diferentes porcentajes de daño al cultivo y analizar la resiliencia en diferentes fases fenológicas. La metodología de investigación tiene un enfoque cuantitativo, experimental, descriptivo y de tiempo secuencial, con un diseño estadístico inferencial no paramétrico de bloques completamente al azar (BCA) distribuidos en un diseño factorial de A3xB3xC2, donde el factor A representa las variedades; B representa el nivel de daño, y el factor C las fases fenológicas. Los resultados muestran que la variedad Silver con daño simulado del 60% en la fase fenológica de floración presenta la mayor pérdida de rendimiento del cultivo con 36.81%, y 27.24% en la variedad Imilla negra. La interacción entre los factores propuestos no muestra significancia en sus variables.

Keywords: Resiliencia, cultivo andino, cambio climático, papa.

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Introduction

The United Nations indicates that climate change is directly or indirectly attributed to human activity, altering weather phenomena irregularly (Zare et al., 2018). In the altiplano of Puno, climatic changes are often unpredictable, causing damage to crops with negative economic consequences for farmers; agriculture in the altiplano is rainfed, indicating that it depends on good weather for good yields. Consequently, climate changes negatively affect the production of Andean crops (Estupiñan et al., 2009).

Climate change is affecting the entire ecological and economic system of the planet. Agricultural systems in the altiplano of Puno and surrounding regions are highly dependent on climatic factors, making them highly vulnerable to changes (Martens et al., 1998). The potato crop is strategic for food security in the altiplano of Peru and Bolivia. Climate scenarios indicate that extreme changes and changes in weather behavior will occur more frequently, which could impact Andean crops differently (Avilez et al., 2016).

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Weather phenomena are a limiting factor that affects production development and crop quality. This characteristic is complex and requires techniques and studies to counteract climatic adversities (Molina et al., 2016). Consequently, climate changes such as droughts, floods, frosts, hail, hurricanes, cyclones, among other anomalies, presented in certain seasons or phases of the crop, will significantly affect the yield of Andean crops (Marmolejo Gutarra, 2018). In the altiplano of Peru and Bolivia, Andean crops have traditionally been the food and economic sustenance for local populations; on the other hand, Andean crops provide nutrients, proteins, fibers, fats, and other essentials for existence (Solano et al., 2021). However, the environmental conditions of the altiplano region are often very harsh during planting times, damaging crops to the point of total loss; incidents such as frosts, droughts, hail, pests, and diseases harm the farmer's economy. Many of the plant deteriorations are caused by sequential factors resulting from weather phenomena, leading to economically significant losses in production (Argote Vega et al., 2010).

Native potatoes are grown at altitudes between 2,000 and 4,200 meters above sea level. In some places, they are exposed to high temperatures, solar radiation, drought, flooding, and extreme cold (Quispe et al., 2021). Given these considerations, the present research aims to determine the resilience capacity of the potato crop against simulated climate changes (hail) at CE Illpa and determine the yield of the potato crop, simulating resilient damage from hail in different phenological phases.

Materials and Methods

The research was conducted at the Research and Production Center (CIP) Illpa of the National University of Altiplano–Puno, during the 2021-2022 agricultural campaign, located between UTM coordinates: E: 384749, N: 8263755 m. Altitude: 3854 m above sea level, 15 minutes from the city of Puno by public transport, Pan-American highway, Sillustani detour. The soil characteristics of the experimental unit present a clayey loam texture, with an organic matter content of 1.19%; pH 6.63; electrical conductivity of 0.18 ds/m; and medium Cation Exchange Capacity (CEC).

Potato Varieties (*solanum Tuberosum* L)

In Table 1, two potato varieties are presented: Imilla Negra and Silver; cultivars native to the area and the region.

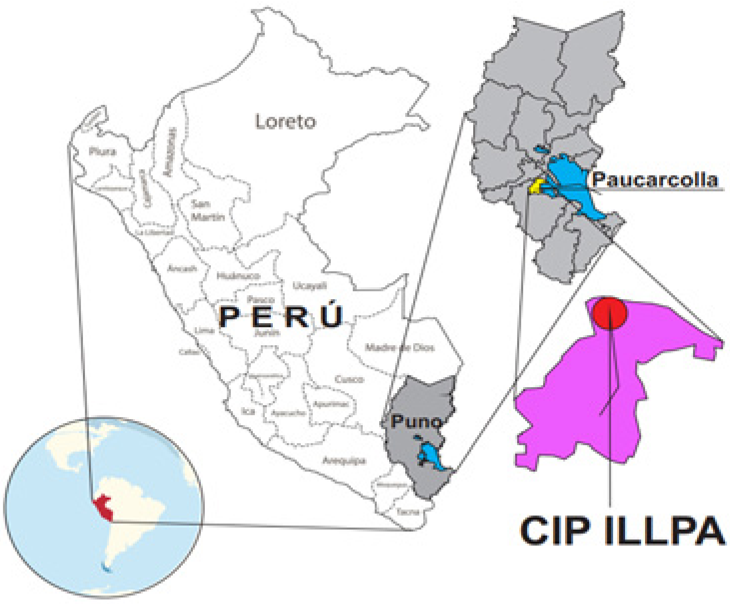
Table 1

Potato varieties used in the 2021-2022 agricultural campaign

No	Variety Potato	Color Skin	Size Seed	Origin	Department	Altitude (msnm)
1	Imilla Negra	Dark	Medium	CIP Illpa	Puno	3854
2	Silver	White	Medium	CIP Illpa	Puno	3854

Figure 1

Geographic location of the potato crop resilience research against hail simulations, agricultural campaign 2021-2022.



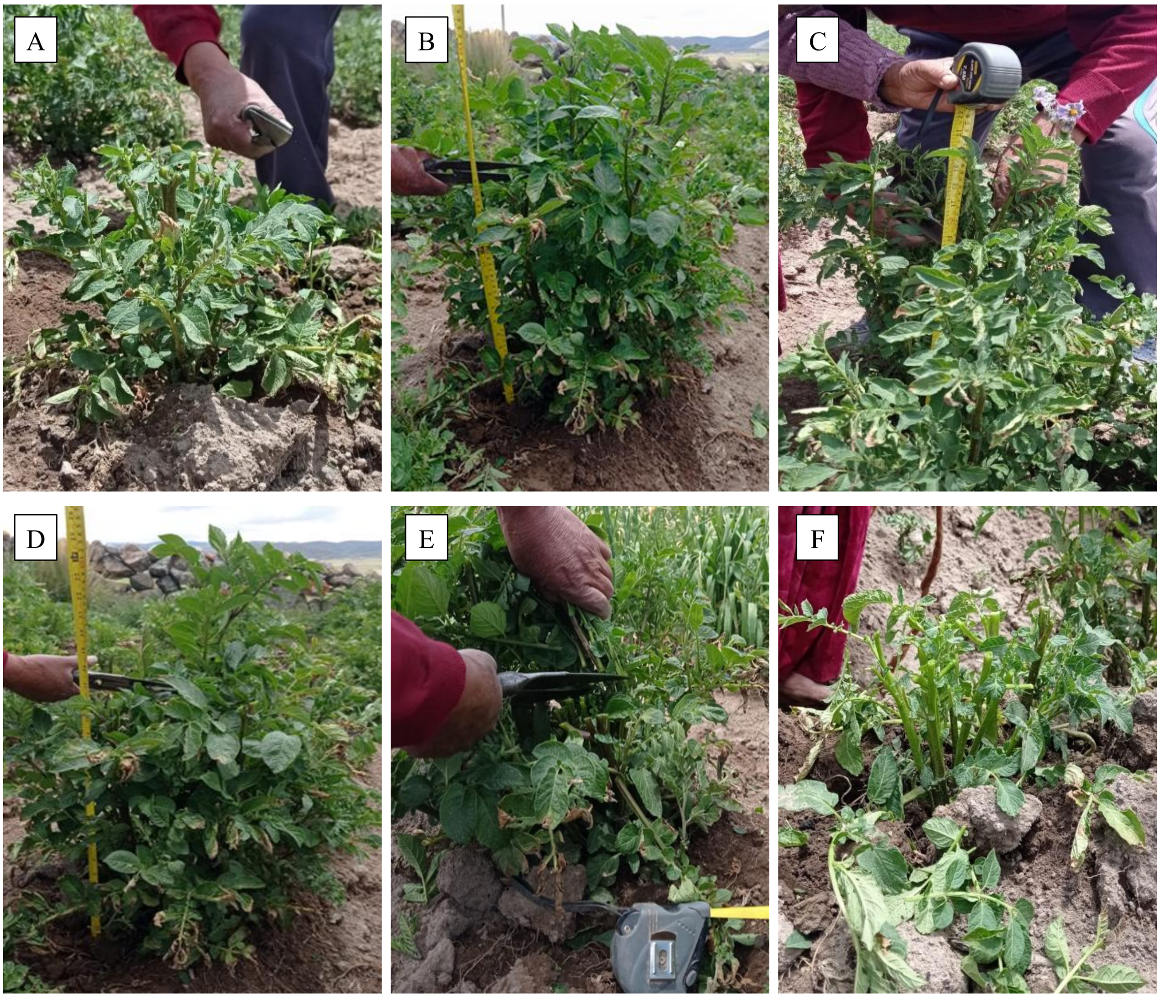
Methodological Design

The research was conducted under a Completely Randomized Block Design, with factors AxBxC where A = potato varieties; B = percentage of damage caused; and C = phenological phases; 2x3x3 with 5 repetitions, making a total of 90 experimental units evaluated. The study's conduction includes different phases from soil preparation, planting, cultural practices, and harvesting, adhering to local customs and regulations. On the other hand, the simulation of damage caused to the potato plant was carried out in three phenological phases and three percentages of damage. Seed selection, planting, spacing, planting density, fertilization, cultural care, pest and disease control, and tuber harvesting were according to (Sifuentes et al., 2018), and data collection was done directly.

Data and graphs were analyzed using R Studio statistical software (Reyes-González et al., 2021); variance analysis (ANOVA) and mean comparison tests were performed. The normality tests of Shapiro-Francia, Kolmogorov-Smirnov, and Shapiro-Wilk ($P<0.05$) were conducted (Montiel et al., 2017). The bars are represented by the mean (±SE). For multivariate analysis, component analysis was used (Mariana et al., 2017).

Figure 2

Phenological phases and levels of simulated damage in potato crop



A = Interaction of variety and percentage of damage; B = Interaction of variety and phenological phases; C = Interaction of percentage of damage and phenological phase; D = Dispersion graph of errors; E = Frequency distribution of the resilience of the potato crop.

Results and Discussions

Resilience of the Potato Crop

According to the variance analysis determining the resilience of the potato crop, it is observed in Table 2 of the variance analysis. Varieties, simulated damage, and phenological phases show highly significant statistical differences; likewise, the interaction between Variety – Damage; Damage–Phenological phases, both present highly significant significance; however, the interaction between variety and phenological phase is significant. On the other hand, in the interaction of Variety, simulated damage, and phenological phases, there is no statistical significance, indicating that the variables act independently regarding the resilience of the potato crop as evidence of yield.

The verification of normality assumptions was performed according to Shapiro-Wilk, with 0.9937, p-value 0.9491, being greater than or equal to 0.05; likewise, the verification test with Kolmogorov-Smirnov is 0.052065, p-value of 0.7928, indicating that it is within the acceptable range. On the other hand, the verification of variance homogeneity was performed with the Bartley R. Danielsen test between the resilience of the potato crop and the factors Variety, % of Simulated Damage, and the phenological phase, resulting in 12.925, df = 17, p-value = 0.7412; for the yield data with potato variety, it has a 0.0067 which is less than or equal to 0.05, indicating that it is within the permitted parameters; on the other hand, it has a median of 10562.92 and an average of 1212.689 kilograms per hectare.

Figure 3

Statistical analysis of interactions between variety, damage, and phenological phases affecting potato crop resilience

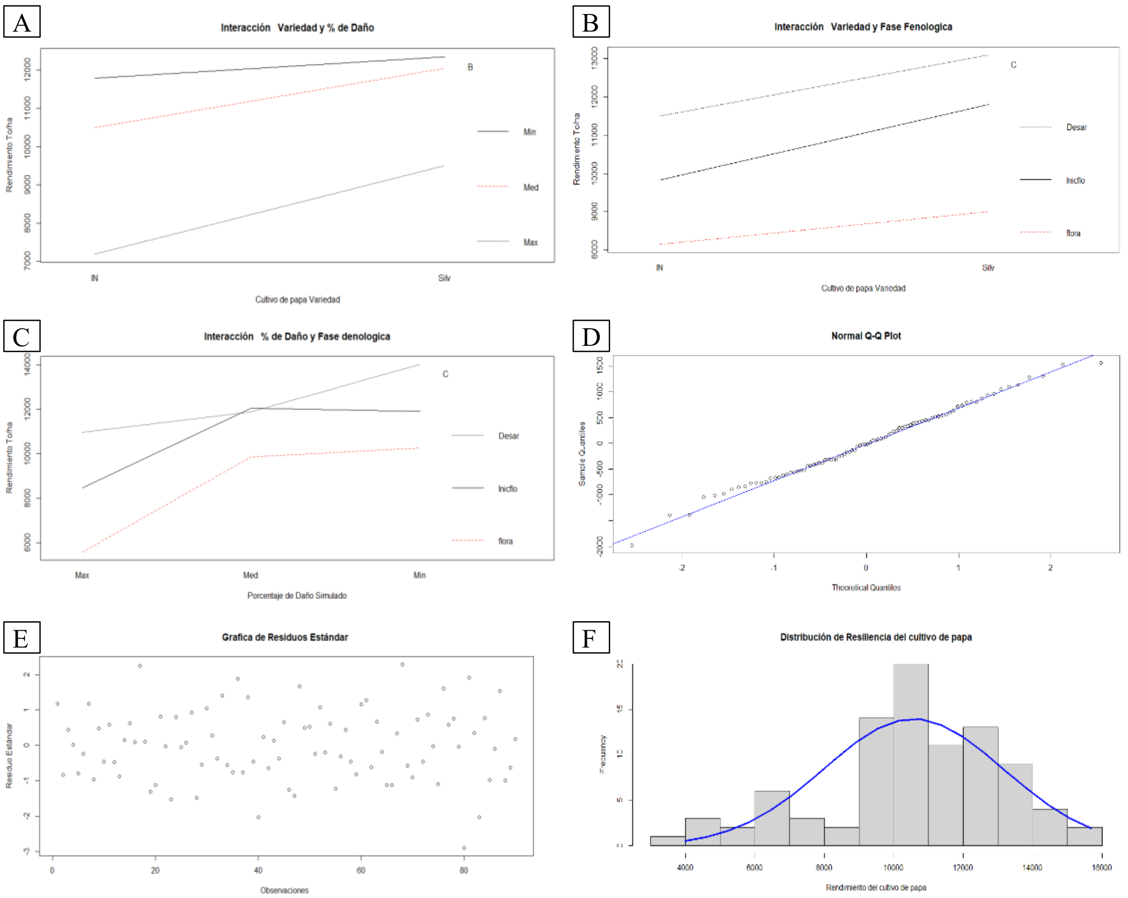


Table 2

Variance analysis of the resilience of the potato crop against hail simulations

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	Sig
A	1	48917275	48917275	83.803	1.08E-13	***
B	2	231315047	115657523	198.14	< 2e-16	***
C	2	212351647	106175824	181.897	< 2e-16	***
A:B	2	11400873	5700436	9.766	0.000177	***
A:C	2	4822854	2411427	4.131	0.020024	*
B:C	4	35331710	8832927	15.132	5.04E-09	***
A:B:C	4	3393173	848293	1.453	0.225442	
Residual	72	42027498	583715			

When adjusting the P value according to Bonferroni between the yield factors and the percentage of damage at 20% simulated, significance is 2.4e-06; likewise, for yield and phenological phases, it is highly significant in the flowering onset phase with 1.9e-08, with a coefficient of variability of 7.232969.

Table 3

Yield of variables from the potato crop study in hail simulations

	Rto Kg/ha	std	Min	Max	Q25	Q50	Q75
I. Neg	9825.676	2563.052	3986.75	14464.58	9258.54	10288.45	11245.46
Silver	11300.159	2391.256	5997.38	15682.75	9903.48	11385.42	12796.33
D. Max	8342.989	2600.416	3986.75	13259.86	6383.298	8461.44	10203.8
D. Med	11273.896	1535.28	8614.26	14986.76	10270.815	10963.38	12607.84
D. Min	12071.867	1798.34	9655.17	15682.75	10384.003	11943.12	13216.14
Desar	12305.105	1739.825	9258.54	15682.75	11170.595	12481.35	13256.93
Florac	8568.089	2297.91	3986.75	11385.42	6475.22	9719.2	10282.56
Inic. Flo	10815.559	2167.904	6486.52	14986.76	9656.347	10951.76	12633.25

The resilience of the potato crop is directly related to the crop yield; likewise, it clearly influences the expression of the plant, which can be attributed to the time of resilience and the percentage of damage caused. It was also observed that over time, solar radiation and plant stress weaken the crop, significantly influencing yield; the range of lower yield variation from simulated damage is between 3986.75 Kg/ha for the Imilla negra variety and 5997.38 Kg/ha for the Silver variety. Similar results were reported by (Marmolejo, 2018), who evaluated the agronomic behavior of potato varieties expanding the agricultural frontier of potato (*Solanum tuberosum* L.) to reduce the effects of climate change under similar environmental conditions. On the other hand, (Martin & Jerez, 2017) conducted studies to see the effects of temperatures on the yield of the potato (*Solanum tuberosum* L.) variety Romano, with a total yield of (12.5 t ha-1). However, (Reategui et al., 2019) achieved yields of 18830, 14525, 6110, 8657 kg/ha in the varieties S. andigenum, S. curtilobum, S. juzepczukii, and S. stenotum, respectively; however, the data obtained in this work has an average of 1212.689 kg/ha.

Effects of Damage Simulation on Potato Crop in Different Phenological Phases

Vegetative Development

In Table 4, data from the simulation of damage caused to the potato plant is observed, showing an ascending trend in the different phenological phases. The reduction in yield increases as the potato crop grows. It should be noted that the yield of tuber production decreases by 27.24% and 36.81% in the Imilla negra and Silver varieties, respectively, during the flowering phase; it is understood that in this phenological phase there is a greater photosynthetic demand for filling and producing tubers, which is reflected in the results obtained, causing a substantial decrease in the yield of the potato crop, especially in the Silver variety. However, in the vegetative development phase, there is no significant loss due to having more time for resilience or recovery capacity of the potato crop.

Table 4

Decrease in yield compared to the control crop in hail simulations

	Imilla negra	Silver
Damage 60%	15.26 %	26.4 %
Damage 40%	4.22 %	16.82 %
Damage 20%	-0.23 %	12.95 %
Vegetative Development	-0.23 %	12.95 %
Flowering	27.24 %	36.81 %
Start of Flowering	4.22 %	16.82 %

Irigoyen et al. (2011) indicate that defoliation occurring in the early phenological phases does not cause losses in crop production; however, when there is total defoliation (100%), it can change the course of production. On the other hand, Fairlie & Ortega (2016) found in research on the effect of simulated frost presence in different phenological states that the most susceptible phenological stages were emergence and the beginning of stolon formation when aerial damage exceeded 50%. In this case, it reduces yield by 30% to 50%. At the beginning of flowering, 100 days after planting, yield decreases by 15% to 55% in the potato crop. Meanwhile, Caicedo et al. (2009) indicate that mutilating different parts of the plant will have varying consequences on yield; damage to the apical part will decrease crop production, whereas damage to the middle region does not represent production loss and may even lead to an increase in production due to the elimination of leaf surface that affects the lower leaves. Caicedo et al. (2009) indicate that defoliation of lower leaves does not negatively impact the plants; however, if it occurs during the tuberization phase, it can result in yield losses due to the production of hormones that induce tuber formation.

Vegetative Growth Recovery

The recovery or resilience of the leaf mass during the vegetative growth phenological phase of the potato crop shows relatively quick recovery; in this phenological phase, it is observed that plants defoliated with more than 30% mutilation exhibit sprouting of new axillary buds, indicating a rapid resilience. However, in Silver variety potato plants with simulated damage to more than 60% of their leaves, recovery is slower compared to the Imilla negra variety. Nevertheless, in plants defoliated at 20%, there is resilience in just six days, indicating a quick recovery relative to the Silver variety. On the other hand, Murphy et al. (1967) suggest that defoliations below 25% in the early phenological phases can recover the leaf area compared to the control crop.

The behavior of plants in their resilience under simulated damage of 40% shows that when apical buds are mutilated, vertical growth or negative geotropism limits their growth, while at the same time, it enhances the growth of lateral branches, compensating for existing damage. In contrast, for plants mutilated with simulated damage of 60%, the lower leaves are exposed, which compensates for photosynthesis in the plants. To understand the resilience of the potato crop against adverse climatic conditions like hail, several factors must be considered: the duration of hail fall, the size of the hail, the intensity, the duration of exposure to hail in the crop, the climate, the soil, soil moisture, soil type, nutrients in the soil, leaf damage, turgidity or wilting of the leaves, type of crop, variety, percentage of damage, and the phenological phases of the crop, among others (Porras & Gallardo, 2011).

Conclusions

The resilience of the potato crop is relatively high; it may take an average of eight to twelve days to generate new axillary buds and be resilient against damage caused by hail; the Imilla negra variety is susceptible to damage but also shows better resilience compared to the Silver variety. In the case of damage from hail, the phenological stage that causes the most loss is the flowering stage, followed by the start of flowering; additionally, the greatest yield loss occurs with 60% simulated damage, indicating that the Silver variety with simulated damage of 60% during the flowering phenological phase presents the highest yield loss in potato crops. On the other hand, it is estimated that the resilience of the potato crop in real hail events would significantly increase yield loss due to exposure to sub-zero temperatures for longer periods, which causes greater stress on the potato crop.

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Conflicts of Interest

The authors have no conflicts of interest in reporting and publishing this research.

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