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Reaction to drought: A case study of native potatoes (*Solanum* spp.) cultivated in Huánuco, Perú

Reacción a sequía: Un caso de estudio de papas nativas (*Solanum* spp.) cultivadas en Huánuco, Perú

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Abstract

Climate change is an obvious threat to agriculture, food security and conservation of plant genetic resources. Potato is a globally important food. In Peru, there is high variability and diversity of wild and cultivated species, such that they are considered as one of the region's most vulnerable to the impact of climate change. With these considerations, we report the results of an investigation in which a preliminary screening of the reaction to drought of 67 native potato morphotypes was conducted to verify for differences in morphological indicators of growth, development, and production of tubers in response to continuous irrigation (CI) and restricted irrigation (RI) treatments. In the course of this study, 21 irrigations were applied to plants by CI (every 1-2 days) and, in the same period, 7 irrigations were applied to plants by RI (every 5-6 days). Comparison of characteristics average in all the morphotypes with plants under CI and RI, indicated that RI did not show differences in height of plants, length of internodes, or leaf and terminal leaflet indexes, and that RI reduced the stem thickness and dry weight of foliage. In this study, we highlight the morphotypes whose plant characteristics present higher averages with respect to their clonal counterparts that were treated with CI. The positive relationship between the number and weight of tubers harvested, as well as the significant reduction of both components of low RI yield is confirmed. In addition, we also highlight the response of some morphotypes that present higher tuber yield under RI. The native morphotypes that were identified as tolerant (according their responses in the characteristics of their plants and yield of tubers under RI) are as follows: BGR 19 ("Rayhuana"); BGR 99 ("Yuracc ñahui hualash"); BGR 170 ("Yana utcush"); and BGR 238 ("Muru huayro").

Key words*: Potato, drought, native morphotypes, morphological indicators, irrigation.*

Resumen

El cambio climático es una amenaza evidente para la agricultura, alimentación y conservación de los recursos genéticos vegetales. La papa es un alimento de importancia mundial y en el Perú se encuentra la mayor variabilidad y diversidad de especies silvestres y cultivadas donde, al mismo tiempo, se considera que es una de las regiones de mayor vulnerabilidad a los impactos del cambio climático. Con estas consideraciones, el presente trabajo da cuenta de los resultados de una investigación en la que se realizó un tamizado preliminar de la reacción a sequía de 67 morfotipos de papas nativas en el que se evaluaron diferencias en indicadores morfológicos del crecimiento, desarrollo y producción de tubérculos en respuesta a tratamientos de riego continuo (RC) y riego restringido (RR). Durante el periodo del estudio se realizaron 21 riegos a plantas bajo RC (cada 1-2 días) y, en el mismo periodo, se aplicaron 7 riegos a plantas con RR (cada 5-6 días). La comparación de promedios de las características en todos los morfotipos con plantas bajo RC y RR, indicó que el RR no produjo diferencias en la altura de plantas, longitud de entrenudos ni en los índices de hoja y del foliolo terminal y que el RR redujo el grosor de tallos y el peso seco del follaje. Sin embargo, se destacan los resultados en los que bajo

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condiciones de RR se encuentran morfotipos cuyas características de plantas presentan mayores promedios respecto a sus contrapartes clonales en condiciones de RC. Se confirma la relación positiva entre el número y peso de tubérculos cosechados y la significativa reducción de ambos componentes del rendimiento bajo RR, pero, igualmente, se destaca la respuesta de algunos morfotipos que presentan mayor rendimiento de tubérculos en condiciones de RR. Los morfotipos nativos identificados como tolerantes por sus respuestas en las características de sus plantas y en el rendimiento de tubérculos bajo condiciones de RR, fueron el BGR 19 (´Rayhuana´); el BGR 99 (´Yuracc ñahui hualash´); el BGR 170 (´Yana utcush´); y el BGR 238 (´Muru huayro´).

***Palabras claves**: Papa, sequía, morfotipos nativos, indicadores morfológicos, riego.*

Introduction

As in many regions of the world, in Peru, potato cultivation is of a huge nutritional and economic importance. Moreover, Peru has largest surface and annual production of potatoes in Latin America (Instituto Nacional de Estadística e Informática [INEI], 2013); Ministerio de Agricultura [MINAG], 2019); as it is produced in 11 mountain agro-ecosystems (Tapia, 1990), that are above 3000 masl, mostly under rainfed and highly dependent on regularity of rains and where 90% of the national production is harvested. Another characteristic of the potato in the Andes of Peru has to do with the presence of not less than 3,000 native varieties that represent a gene reserve of enormous importance, which is due to its great variability and diversity. The genetic resources contained in the native potatoes of Peru require further research to minimize the current threats that put their conservation at risk.

On the other hand, changes in the water regime, as a consequence of climate change, are an obvious threat that puts crop production at risk. In IFPRI report, O´Toole and Chang (1979) indicated that the yield of wheat and rice under irrigation will be the most affected and that changes in rainfall regimes increased the probability of reduced production. Ministerio del Ambiente (MINAM, 2010) indicated that Peru is a country that is highly vulnerable to climate change; however. According to Harris (1978), potato production can increase up to two tons, per centimeter of water applied in irrigation or rain, and that regional differences in annual yields are due to differences in water supply. Mendoza and Estrada (1979) indicated that in the Peruvian highlands, water extremes are permanent physical threats to better potato production. Egúsquiza (2014) indicated that potato cultivation is highly sensitive to lack of water, and that under mountain conditions, potato cultivation requires approximately 600 to 1000 mm of rain per hectare. However, below this range, it will be under a water deficit regime.

Mamani (1993) reported that the emergence and onset of stolonization of potato plants were the growth period most susceptible to drought. Similarly, it was found that an early drought (pre-tuberization drought) yielded smaller tubers in both sensitive and tolerant varieties in comparison with a late drought.

In this regard, we evaluated the changes in morphology of plant and yield of morphotypes of native potatoes subjected to periods of irrigation restriction to identify their levels of vulnerability, register differences in their responses, and identify morphotypes with greater tolerance to drought.

Materials and Methods

At the Regional Institute of Development (IRD, acronym from Spanish) of Sierra of the Universidad Nacional Agraria La Molina (UNALM, 11°50′48″ S, 75°23′14″ W; 3322 masl), reaction to drought cycles was evaluated in plants from sprout cuttings of 67 morphotypes from the Regional Germplasm Bank (BGR) of Huánuco. The plants were installed under a three-pound moonroof environment with soil mix, compost, and rice husk substrate (V/V 1:1:0.5). The chemical characteristics of the substrate were: pH=6.65; CE=1.21; $CaCO_3$=1.60; MO=15.72; P=99.6 ppm; and K=78 ppm. Average temperature fluctuated between 11.18°C and 2.06°C, with a maximum of 20.3°C and minimum of 2.06°C. The treatments were continuous irrigation (CI) and restricted irrigation (RI); which were started when the plants reached a general average of 40 cm, such that, at the same time, the sliding roof was closed. Three plants of each morphotype were watered every 1–2 days (CI) and another three of the same clone, were watered with the same amount of water per pot every 5-6 days, when they showed symptoms of drought stress (RI). Seven cycles of CI and RI were performed until the senescence of the plants is triggered. During the treatment period, humidity of available samples in the pots were conducted and volumetric humidity percentage of substrate was recorded. Between 60 and 70 days after commencement of treatments, when majority of the plants were in a phonological state of full growth, random samples of morphotypes were investigated and the plants' height, internode length, stem thickness, leaf index, and terminal leaflet index were recorded. In pre-harvest, the foliage was separated and the dry weight was recorded, whereas at harvest, which was carried 120 days after transplantation, weight and number of tubers were recorded. In each characteristic, the morphotypes were classified according to the magnitude of differences, due to the effect of CI and RI. Morphotypes that showed lower values under RI conditions are considered susceptible, and tolerant to those whose averages were similar or higher under RI. Statistical tests were done by using a descriptive and exploratory analysis of the data (Cobo et al., 2007). Subsequently, in each characteristic, paired student´s t test was performed on paired samples to compare differences due to the treatments effect (Clifford & Taylor, 2008; Gutiérrez & De la Vara, 2008). Finally, Pearson correlation was done between the characteristics under CI and RI.

Results and Discussion

From the beginning of treatments and until senescence of the plants is reached, seven cycles of continuous and restricted irrigation were applied. In total, each plant with CI received 21 liters, while, in this same period, each plant with RI (drought) received 7 liters.

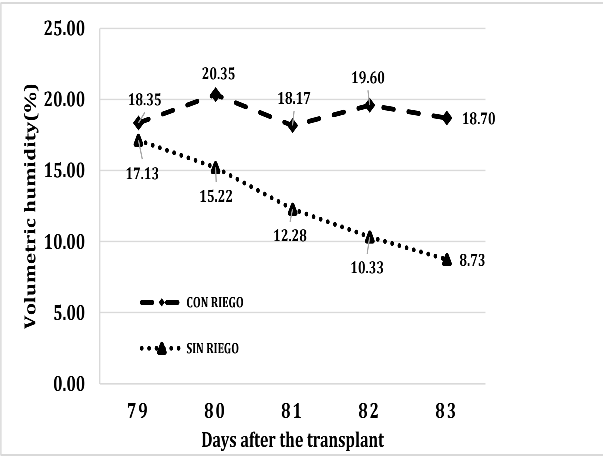

Figure 1: Variation of volumetric humidity of substrate during the fourth cycle of humidity control

The volumetric humidity in substrate of plants under CI varied between 18 and 20% and remained within this range, which corresponds to its field capacity. The substrate of plants RI varied between 8 and 17% indicating that the availability of water was reduced (Figure 1).

Effects on plant characteristics

Generally, the conditions of available moisture deficit are expected to affect the physiological functions of plants and reduce the values of morphological characteristics. According to the obtained results (Table 1), when comparing the averages of characteristics of all the native morphotypes, humidity stress reduced the thickness of stems and dry weight of the plants. The results show statistically non-significant effects on plant size, internode length, leaf index, and terminal leaflet index, indicating that drought did not modify these characteristics; however, among the morphotypes, different responses were attributed to genetic differences, such that 45.4, 22.2, 44.4, 44.0, 51.8, and 28.1% of low RI morphotypes yielded plants with higher averages of plant height, stem thickness, internode length, leaf index, terminal leaflet index, and dry weight of foliage, respectively.

Pearson's correlation coefficients between all the characteristics of the plants under CI (Table 2) and RI (Table 3) were highly significant between height and stem thickness and between number of tubers and weight of tubers. According to the results, it is possible to affirm that the significant relationship between plants with greater size and thicker stems are due to morphological adaptations that keep the plant upright. In the same way, due to the wide variation in the characteristics present within the total morphotypes, it is possible to affirm that

Table 1. Averages and statistical significance of the differences in characteristics of native potato plants grown in continuous irrigation (CI) and restricted irrigation (RI) conditions

Characteristics	Morphotypes	n	Averages CI[1]	Averages RI[2]	Significance
Plants height (cm)	All	44	55.06	54.24	ns
	Susceptibles	16	61.59	55.15	**
	Tolerants	20	51.08	54.43	**
Stem thickness (cm)	All	27	0.74	0.69	**
	Susceptibles	21	0.75	0.67	**
	Tolerants	6	0.72	0.77	*
Internode length (cm)	All	27	5.85	5.66	ns
	Susceptibles	15	6.27	5.57	**
	Tolerants	12	5.31	5.77	**
Leaf index	All	25	2.03	2.03	ns
	Susceptibles	14	2.15	1.99	**
	Tolerants	11	1.89	2.11	**
Terminal leaflet index	All	27	2.13	2.14	ns
	Susceptibles	13	2.23	2.06	**
	Tolerants	14	2.05	2.22	**
Foliage dry weight (g)	All	64	30.10	26.28	**
	Susceptibles	27	37.25	22.73	**
	Tolerants	18	24.57	30.85	**

([1]) CI =Continuous irrigation ([2]) RI = Restricted irrigation ns = non-significant correlations

Table 2: Correlations between characteristics of morphotypes under Continuous Irrigation (CI)

	Plants height	Stem thickness	Internode length	Leaf index	Terminal Leaflet index	Foliage dry weight	Tuber weight
Stem thickness	0.55 (**)						
Internode length	0.25 (ns)	0.48 (*)					
Leaf index	- 0.10 (ns)	0.13 (ns)	0.01 (ns)				
Terminal Leaflet index.	0.19 (ns)	- 0.30 (ns)	- 0.32 (ns)	- 0.26 (ns)			
Foliage dry weight	0.29 (ns)	- 0.12 (ns)	- 0.04 (ns)	- 0.11 (ns)	- 0.08 (ns)		
Tuber weight	0.16 (ns)	0.26 (ns)	0.27 (ns)	- 0.06 (ns)	- 0.21 (ns)	- 0.34 (ns)	
N° of tubers	0.14 (ns)	0.06 (ns)	0.20 (ns)	- 0.49 (*)	- 0.05 (ns)	- 0.01 (ns)	0.59 (**)

ns = non-significant correlations

Table 3: Correlations between characteristics of morphotypes under Restricted Irrigation (RI)

	Plants height	Stem thickness	Internode length	Leaf index	Terminal Leaflet index	Foliage dry weight	Tuber weight
Stem thickness	0.55 (**)						
Internode length	0.16 (ns)	0.18 (ns)					
Leaf index	- 0.16 (ns)	- 0.28 (ns)	- 0.20 (ns)				
Terminal Leaflet index	- 0.04 (ns)	- 0.17 (ns)	- 0.38 (ns)	- 0.03 (ns)			
Foliage dry weight	- 0.04 (ns)	- 0.19 (ns)	- 0.05 (ns)	0.06 (ns)	- 0.06 (ns)		
Tuber weight	0.06 (ns)	0.34 (ns)	0.16 (ns)	- 0.27 (ns)	- 0.22 (ns)	- 0.32 (ns)	
N° of tubers	0.06 (ns)	0.41 (ns)	0.08 (ns)	- 0.21 (ns)	- 0.05 (ns)	- 0.35 (ns)	0.88 (**)

ns = non-significant correlations

greater size of the plants is not always due to greater length of internodes and that greater size of plants is not always due to higher dry weight of foliage.

The non-significant correlations between the six characteristics of the plants with the two characteristics of the yield (number and weight of tubers), confirm the evidences that suggest that, in conditions of abiotic stresses, the morphological and physiological responses that interpose the foliage of the plants are different from those of tuberization. The stem thickness-internode length and leaf index-number of tubers correlations that were significant only in plants under RC require further biological verification.

By supplying a lower volume of water, a lesser acceleration is expected in the growth and development of the plant, due to a lower rate of division, cell expansion (Martínez, 1988), lower pressure of cell turgor (Taiz & Zeiger, 1998), and changes in stomatal conductance (León, 2019). The tolerance of the morphotypes is attributed to resistance mechanisms of evasion, through which plants interpose a defense barrier, thus reducing stress damage (Sevilla & Holle, 2004; Gonzales, 1999). In addition, given that at the end of an RI cycle, watering of the plants under stress was done, repair and recovery mechanisms would have been expressed as proposed by Ekanayake (1994).

Effects on tuber yield

The average number of tubers per plant of all the morphotypes evaluated under CI and RI conditions (Table 4) indicate non-statistically significant difference; however, morphotypes presented under CI conditions, had a greater number. On the other hand, under RI conditions, the average yield of tubers per plant of all the morphotypes is 25.5% lower as a result of the drought. However, 17 morphotypes (28.3%) showed higher performance under RI compared to their clonal counterparts under CI.

Potato growers recognize that the final yield of the potato crop is highly dependent on water and that the

Table 04. Averages and statistical significance of the differences in number and weight of tubers per plant of native grown potatoes under conditions of continuous irrigation (CI) and restricted irrigation (RI)

Characteristics	Morphotypes	n	Averages		Significance
			CI[1]	RI[2]	
Number of tubers	All	60	11.93	10.39	ns
	Susceptibles	28	15.53	8.77	**
	Tolerants	17	8.06	13.80	**
Tuber weight	All	60	115.18	85.77	**
	Susceptibles	39	143.00	78.30	**
	Tolerants	17	63.5	107.7	**

([1]) CI =Continuous irrigation ([2]) RI = Restricted irrigation ns = non-significant correlations

frequency of irrigation should be shorter compared to those other crops. The sensitivity of the potato plant is explained by the weak nature of the roots that overcome the physical barriers of the soil. Similarly, it is explained by the lower depth and lower absorption efficiency of the deep roots. Potato plant is sensitive to water deficit because its roots unable to overcome small retention tension at lower soil depths compared to the roots of other cultivated plants.

Plants are known to oppose certain reactions in conditions of water deficit and the immediate response is closure of the stomata. Prolonged closure of the stomata reduces the entry of CO_2, thus reducing photosynthetic activity, which ultimately reduces the tuber yield. The adaptation of native potato morphotypes to high Andean pluvial conditions, (a probable susceptibility to excess irrigation water in the morphotypes with lower yield under CI conditions), and physiological compensation mechanisms may explain that some native morphotypes are capable of exhibiting higher performance even under RI.

Among the group of native potato morphotypes considered tolerant for presenting a greater number and weight of tubers under RI conditions, BGR 19 (“Rayhuana”) stands out and also did not reduce size, leaf index, terminal leaflet and, foliage dry weight; BGR 238 (“Muru huayro”) did not reduce its leaf indexes or dry foliage weight; BGR 170 (“Yana utcush”) did not reduce its stem thickness or length of internodes, and BGR 99 (“Yuracc ñahui hualash”), did not reduce its bearing or dry foliage weight.

Conclusions

The comparison of averages in morphotype characteristics that add up to a broad genetic base, demonstrate that the conditions of drought does not affect the bearing of plants, length of internodes, leaf index, terminal leaflet or the number of tubers per plant.

Stem thickness, dry weight of foliage, and fresh weight of tubers can be significantly decreased even when comparisons are done between native morphotypes that add broad genetic base.

In all the characteristics of the plant and tuber yield, it is possible to find native morphotypes that demonstrate a drought stress tolerance reaction.

“Rayhuana”, “Muru huayro”, “Yana utcush” and “Yuracc ñahui hualash” morphotypes, cultivated in the Huánuco region, Peru, presented responses in plants and tubers that identify them as drought tolerant and promising genetic resources for future further studies.

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