MORPHOLOGY, PHENOLOGY, NUTRIENTS AND YIELD OF SIX ACCESSIONS OF *Tropaeolum tuberosum* Ruiz y Pav (MASHUA)[1]

[MORFOLOGÍA, FENOLOGÍA, NUTRIENTES Y RENDIMIENTO DE SEIS ACCESIONES DE *Tropaeolum tuberosum* Ruiz and Pav (MASHUA)]

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SUMMARY

The aim of this work was to characterize the morphology, phenology, main nutrients and yield, of six accessions of mashua (*Tropaeolum tuberosum* Ruiz y Pav) from the central region of Ecuador. The trial was carried out in Cevallos-Ecuador, at 2865 m.a.s.l, single parcels were installed at each accession. The morphological characteristics observed were related to foliage, leaf, stem, flower and tuber. Also, the duration of the four phenological phases were registered; the yield; and the macronutrients of the tuber were analyzed. Analysis were carried out regarding the main components, the variance and conglomerates. The results reveal that the variables associated with the flower and tuber were the most useful for identifying the accessions. The accession Poza Rondador registered the longest duration of the cultivation cycle (282 days), the highest usage of water (Kc 1.1) and the highest content of nutrients (protein 18.25%, phosphorus 0.73% and potassium 2.3%), whilst the Amarilla registered the shortest cultivation cycle (169 days) and the lowest amount of nutrients (protein 11.19%, phosphorus 0.42% and potassium 0.99%). The rest of the accessions varied between these ranges. The results suggest the need to promote the cultivation of accessions with higher content of nutrients. On the other hand, they also reveal the need to study secondary metabolites, and to identify accessions with potential to create nutraceutical foods.

Keywords: mashua, phenology, morphology, Andean tubers, nutrients, crop coefficient

RESUMEN

El objetivo del trabajo fue caracterizar la morfología, la fenología, los principales nutrientes y el rendimiento, en seis accesiones de mashua (*Tropaeolum tuberosum* Ruiz y Pav) provenientes de la región central del Ecuador. El ensayo se realizó en Cevallos-Ecuador a 2865 msnm, se instalaron parcelas únicas de cada accesión. Las características morfológicas observadas se relacionaron con el follaje, hoja, tallo, flor y tubérculo. Además, se registró la duración de cuatro fases fenológicas; el rendimiento; y se analizaron los macronutrientes del tubérculo. Se efectuaron análisis de componentes principales, de varianza y de conglomerados. Los resultados revelan que las variables asociadas con la flor y el tubérculo, fueron más útiles para identificar las accesiones. La accesión Poza Rondador registro la mayor duración del ciclo de cultivo (282 días), el mayor consumo de agua (Kc 1.1) y el mayor contenido de nutrientes (proteína 18.25%, fósforo 0.73% y potasio 2.3%), en cambio la Amarilla registró el menor ciclo de cultivo (169 días) y la menor cantidad de nutrientes (proteína 11.19%, fósforo 0.42% y potasio 0.99%). Las demás accesiones variaron entre estos rangos. Los resultados sugieren promover el cultivo de las accesiones con mayor contenido de nutrientes. Por otro lado, también revela la necesidad de estudiar el contenido de metabolitos secundarios e identificar accesiones con potencial, para elaborar alimentos nutraceuticos.

Palabras clave: mashua; fenología, morfología, tubérculos andinos, nutrientes, coeficiente de cultivo

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INTRODUCTION

Mashua is an ancestral Andean crop, with high genetic diversity, used with increasingly less frequency in food and known amongst farmers for its effectiveness in treating illnesses of the urinary tract and prostate. This crop is found throughout several Andean countries (Bolivia, Peru, Ecuador and Columbia) and has many local names like Isaño, Añu, Mashua and Cubio, amongst others. The tubers can present many colors such as Amarilla, Blanca, and Morada, and they are cooked after being left out in the sun to improve their flavor.

Preliminary investigations report that mashua is an edible tuber originating in the Andes, and was domesticated by native peoples since pre-Incan times (Barrera *et al.*, 2004). Mashua is an annual species cultivated in elevated zones of the Andean region, in dry lands associated with typical crops like ocas (*Oxalis tuberosa* Mol) and potatoes, forming part of agricultural farming systems (Grau et al., 2003). In Bolivia mashua is cultivated between April and June, the cultivation cycle lasts around 7 to 8 months (Gonzales et al., 2003).

In relation to genetic diversity, mashua presents an ample genetic variability that responds to the ecologic and cultural characteristics of the region (Malice y Baudoin, 2009). However, there are reports of genetic erosion, on average a loss of 46.5% of genetic variability is estimated. In Ecuador, the province of Cañar has the highest values of 61.1% (Tapia y Estrella, 2001). In Chimborazo, in 2002 70 ecotypes of mashua where found in local fairs in the community of Huanconas (Tapia et al., 2003). On the other hand, INIAP has characterized 100 samples by morphology and 80 by agronomical characteristics (Tapia y Estrella, 2001). However, cultivations in some provinces of Ecuador diminish, and among the causes is the change in food habits, the presence of monoculture, deficient support and technical assistance to the autochthonous crops and the ignorance regarding ancestral practices (Tapia et al., 2003). Also, the low demand of mashua in markets demotivates the producers who are seen force into planting more cost effective crops (Espinosa, 2004).
Regarding nutrition the crop played in important role in the communities of the region (Roca y Manrique, 2005). Currently, in rural areas it is still used as food (Quispe et al., 2015). On the other hand, in mashua accessions in the bank of germoplasm of INIAP the energetic content is reported to be between 4.19 and 4.64 Kcal/g, protein between 7.22 and 13.99, starch between 20.01 y 79.46 and total sugars between 6.77 y 55.23 (Espín et al., 2003). These values coincide with another report: humidity 88.7%, ash 4.81%, proteins 9.17%, fiber 5.86%, phosphorous 0.32%, potassium 1.99% and energy 440 Kcl/100g (Villacrés et al., 2016). These properties are attributed also to the content of carbohydrates, fiber, ascorbic acid, vitamin A and C, and calories (Manrique et al., 2014; Roca y Manrique, 2005). These nutritional characteristics reflect the importance in rural nourishment.

Regarding medicinal use, mashua tubers possess bioactive substances that, when ingested, influence cellular activity and physiological mechanisms. Likewise, it contains phytochemicals (Glucosinolates, anthocyanins and carotenoids) that protect the crops from plagues and illnesses (Grau et al., 2003), among these the main phenolic compounds identified are the anthocyanins (Chirinos et al,. 2008). On the other hand, glucosinolates have medicinal properties, which are used by farmers in traditional medicine (Flores, 2011). When these are hydrolyzed they become isothiocyanates, sulfuranes, nitriles, and thiocyanates by the action of the enzyme myrosinase (Rincón, 2014), these have antibiotic, insecticide, nematicide, anticarcinogenic, and diuretic properties (Manrique et al., 2014). Furthermore, they effectively control prostate hyperplasia (Aire et al., 2013), and reduce sperm mobility without causing toxicity (Vásquez et al., 2012). Thus, it can be seen that mashua is a species with many studies. However, in the accessions of the central zone of Ecuador the existing ecotypes and their characteristics are unknown. In this context the investigation had the objective of characterizing six mashua accessions in their morphology, phenology, nutrients and yield.

MATERIALS AND METHODS

The investigation was carried out in the Experimental Farm Querochaca (Cevallos - Ecuador) at an altitude of 2865 m.a.s.l. The average annual temperature registered over the last five years was 13.6°C; the average yearly rainfall 465mm; environmental humidity 75.15% and wind velocity 1.7 m/s (INAMHI, 2016).

The mashua accessions were collected: In the province of Tungurahua, Amarilla (A) and Morada (M); In Cotopaxi, Blanca (B): and in Chimborazo Milicia roja (MR), Verde amarilla (VA) and Poza Rondador (PR) (vulgar name as peasant know the accessions of Mashua in the Andean region of Ecuador). These materials where planted between May 2016 and February 2017, in single parcels (15 x 3.2 m), two tubers per point, with 0.6 m between plants and 0.8 m between grooves. The fertilization was done using guinea pig manure.

The morphological characterization was completed with qualitative parameters related to the color of vegetative and reproductive structures, using the atlas of vegetable colors as recommended by Kuppers

(1979). These parameters where referenced in the leaf (color of the midrib, underside and veins); in the stalk; in the flower (pedicel, sepals, underside of the sepals, petals and spur); in the predominant color of the surface of the tuber (Cpst); in the secondary color of the surface of the tuber (Csst); in the predominant color of the pulp of the tuber (Cppt); and in the secondary color of the pulp of the tuber (Cspt) (Manrique et al., 2014) .

Quantitative variables were also registered, such as: plant height (Ap) length (Ls) and width of the sepals (As), length (Lpe) and width of the petals (Ape), length (Le) and width of the spur (Ae), length (Lf) and width of the flower (Af), length (Lh) and width of the leaf (Ah), length (Lfr) and width of the fruit (Afr), length of the axils (La), length of the petiole (Lp), diameter of the stalk (Dt), diameter of the tuber (Dtu), length of the tuber (Ltu), weight of 10 tubers (P 10 tu) and indent of the eye of the tuber (Hotu) according to the descriptors proposed by Manrique et al. (2014). The quantitative and qualitative data were registered in the flowering phase with the exception of the data related to the tubers which were collected at harvest. On the other hand, the yield (R) was calculated based on production.

The phenological phases were determined according to the duration of the four stages established by the FAO which are: initial, development, intermediate and final. The crop coefficient (Kc) was calculated, with data from the Abacus and formulas for initial, intermediate and final Kc, as propose by Allen et al. (2006). The nutritional analysis of the tubers, was carried out after harvest. For nitrogen (N) the Dumas method was used, as was the elemental analyzer CHN 628 of Leco brand; for phosphorus (P_2O_5), the colorimetric vanadate molybdate method and the UV spectrophotometer GENESYS 20 brand were used; for K, Ca, Mg, Zn the method of atomic absorption spectroscopy and atomic absorption spectrophotometer Perkin Elmer 100 brand were used, the gravimetric method and an OHAUS brand analytic balance, and for energy the thermochemical method with an IKA C 6000 brand isoperibolic calorimeter.

RESULTS

Morphological characterization

In the qualitative variables that were evaluated, differences were found between the accessions, predominant and secondary color of the surface of the tuber and in the primary and secondary color of the pulp of the tuber (Table 1). The Blanca and Verde amarilla accessions showed similarity in the predominant color of the surface of the tuber. According to the atlas of colors by Kuppers (1979) the corresponding nomenclature is N00A50M10 and N10A99M00, but they differ in the coloration of the point of the tuber in the Verde amarilla variety. On the other hand, the Amarilla and Milicia Roja accessions were similar in the predominant coloration of the surface of the tuber (A99M50C00 and A99M50C10). However, the Milicia Roja presented scores around the indent of the eye, and the surface of the tuber. The tone of the predominant color of the surface of the Morada and Poza Rondador accessions were similar (N00C00A60 and N00A90M00), they differed in the indent of the eye. Regarding the color of the flower (Cf), variation in the intensity was observed between the analyzed accessions.

Table 1. Nomenclature of the color of the tubers of the accessions

Ac	B	A	M	MR	PR	VA
Cpst	N00A50M10	A99M50C00	N00C00A60	A99M50C10	N00A90M00	N10A99M00
Csst	N00A50M00	A99M60C10	N60A60M90	N10A50M80	N00A50M60	N00C10A99
Cppt	A10M00C00	A90M30C00	N00A10M00	N00A60M00	N00A50M00	N00A40M00
Cspt	A60M00C00	A50M00C00	N40A50M50	N10A60M00	N00A40M00	N00A60M00
Cf	A60M90C00	A60M90C10	A99M90C20	A70M99C20	A50M99C80	A99M90C30
Photo						

Caption: Ac= Accession; B= Blanca; A= Amarilla; M= Morada; MR= Milicia Roja; PR=Poza Rondador; VA= Verde amarilla

In regard to the quantitative variables, only 10 out of 21 presented significant difference between the accessions. The tallest registered plant was the Verde amarilla accession, followed by the Poza Rondador, while the smallest were Blanca and Amarilla. Regarding the size of the spur of the flower, the Verde amarilla variety had the longest length, while the Morada and Poza Rondador varieties presented the lowest value. On the other hand, the Poza Rondador accession exhibited higher values for the length and width of the leaf, diameter of the stalk and yield. However. The lowest values were observed in the Amarilla (length of the leaf), Morada (width of the leaf and diameter of the stalk) and Verde amarilla (yield). Also, the Blanca accession present the highest value of eye indentation and weight of 10 tubers. Meanwhile, the lowest value was seen in the Morada and Verde amarilla accessions (eye indentation of the tuber) and Verde amarilla (weight per 10 tubers) (Table 2).

Table 2. Morphological descriptors of the accusations of Mashua

	B	A	M	MR	PR	VA
Ap (cm)	41.3a	57.91b	64.23b	63.72b	80.66c	87.44c
Ls (cm)	1.33bc	1.46c	1.24ab	1.45c	1.15a	1.32abc
As (cm)	0.48a	0.49a	0.44a	0.58ab	0.68b	0.48a
Lpe (cm)	1.50b	1.6b	1.2a	1.62b	1.23a	1.18a
Ape (cm)	0.78ab	0.83ab	0.69a	0.81ab	0.89b	0.93b
Le (cm)	1.84ab	1.97bc	1.72a	1.96bc	1.72a	2.11c
Ae (cm)	0.31a	0.34ab	0.35ab	0.45c	0.37b	0.38b
Lf (cm)	1.58ab	1.72b	1.44a	1.75b	1.47a	1.7b
Af (cm)	0.9b	0.97bc	0.74a	1.11c	1.01bc	0.95b
Lh (cm)	4.36abc	3.88a	4.03ab	4.79c	5.39d	4.45bc
Ah (cm)	5.13b	4.49a	4.67ab	5.92c	6.61d	5.93c
Lfr (cm)	0.87b	0.9bc	0.9bc	0.95bc	0.73a	1.02c
Afr (cm)	1.52b	1.45b	1.36b	1,.5b	1.05b	1.59a
La (cm)	0.30a	0.28a	0.31a	0.32a	0.30a	0.26a
Lp (cm)	14.14ab	13.93ab	12.76a	15.43ab	16.66ab	17.38b
Dt (cm)	0.54bc	0.44ab	0.40a	0.5abc	0.57c	0.53bc
Dtu (cm)	3.8b	3.24a	3.05a	3.92b	2.84a	2.88a
Ltu (cm)	11.38a	12.84a	12.09a	12.03a	11.74a	12.01a
Hotu (cm)	0.37d	0.3bc	0.20a	0.33cd	0.24ab	0.2a
P 10 tu (Kg)	0.85d	0.50a	0.6b	0.7c	0.5a	0.49a
R (Tn/Ha)	42.70bc	33.33ab	35.35b	23.85a	47.92c	24.79a

Hight of the plant (Ap), length (Ls) and width of the sepals (As), length (Lpe) and width of the petals (Ape), length (Le) and width of the spur (Ae), length (Lf) and width of the flower (Af), length (Lh) and width of the leaf (Ah), length (Lfr) and width of the fruit (Afr), length of the axils (La), length of the petiole (Lp), diameter of the stem (Dt), diameter of the tuber (Dtu), length of the tuber (Ltu), weight per 10 tubers (P 10 tu), indent of the eye of the tuber (Hotu) yield (R). The letters a, b, c, and d indicate significant difference according to the probability $p<0.05$

According to the analysis of main components the variables that best explain the differences are: flower width (Af), indent of the eye of the tuber (Hotu), spur width (Ae) and weight per 10 tubers (P 10 tu), which allowed the identification of four varieties. The Amarilla and Milicia Roja accessions apparently are the same variety, and also the Blanca and Morada accessions seem to be another variety (Figure 1).

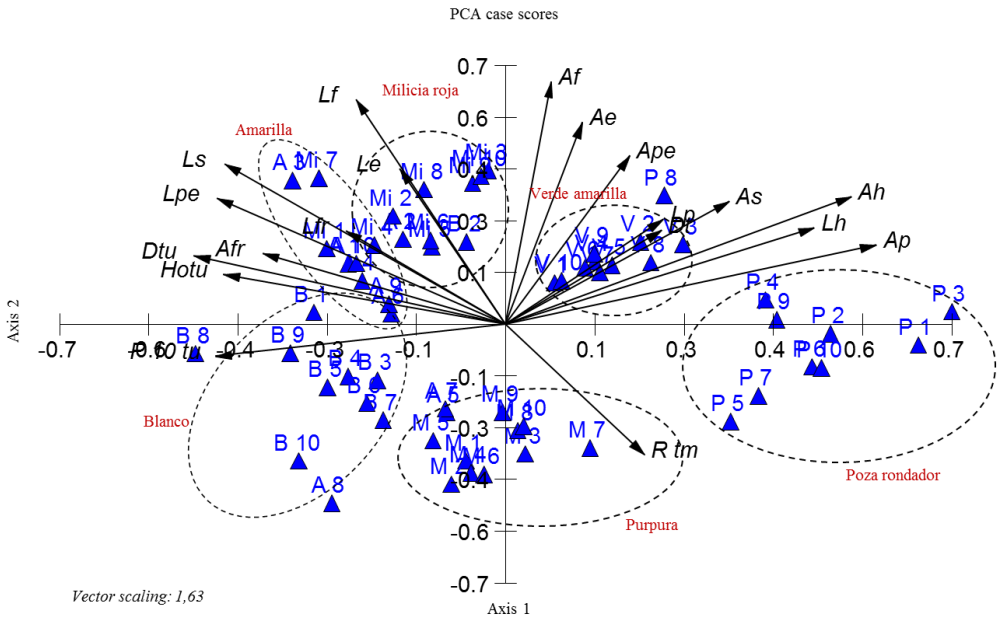

Figure 1. Analysis of main components based on quantitative variables of mashua accessions. (Blanca, Amarilla, Milícia Roja, Verde Amarrilla, Poza Rondador and Morada, vulgar name as peasant know the accessions of Mashua in the Andean region of Ecuador)

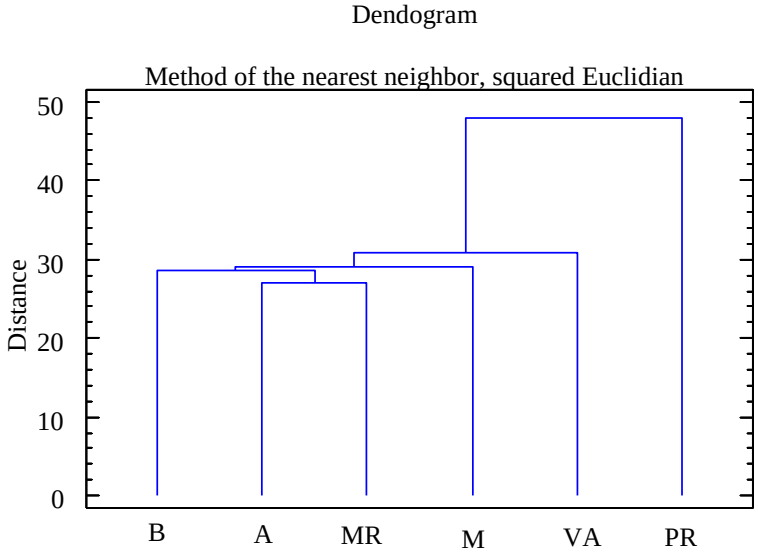

Figure 2. Analysis of the conglomerates based on the quantitative variables of mashua accessions. B=Blanca; A= Amarilla; M= Morada; MR= Milicia roja; PR=Poza Rondador; VA= Verde amarilla

In the analysis of conglomerates two groups were observed, the first formed by the Blanca, Amarilla, Morada, Milicia Roja and Verde amarilla accessions. Meanwhile the second contains the Poza Rondador accession (Figure 2).

Phenology

In the initial phase, the Morada accession registered the higher number of days between the sowing and germination (28), while the Milicia Roja presented the lowest number of days (16). In the development phase, the Poza Rondador accession showed the higher number of days from germination to tuberization (143), conversely the Blanca accession showed the least number of days (63). In the intermediate phase, the Poza Rondador accession took longer between the tuberization and flowering (18 days). Meanwhile the Morada, Milicia Roja and Verde amarilla accessions, reached this phase within

10 days. And in the final phase, between flowering and harvest, the Milicia Roja accession took longer (188 days), conversely the Amarilla accession took 70 days. In this manner, the Poza Rondador accession possessed the longest cultivation cycle (282 days) while the Amarilla accession was the shortest with 169 days (Figure 3)

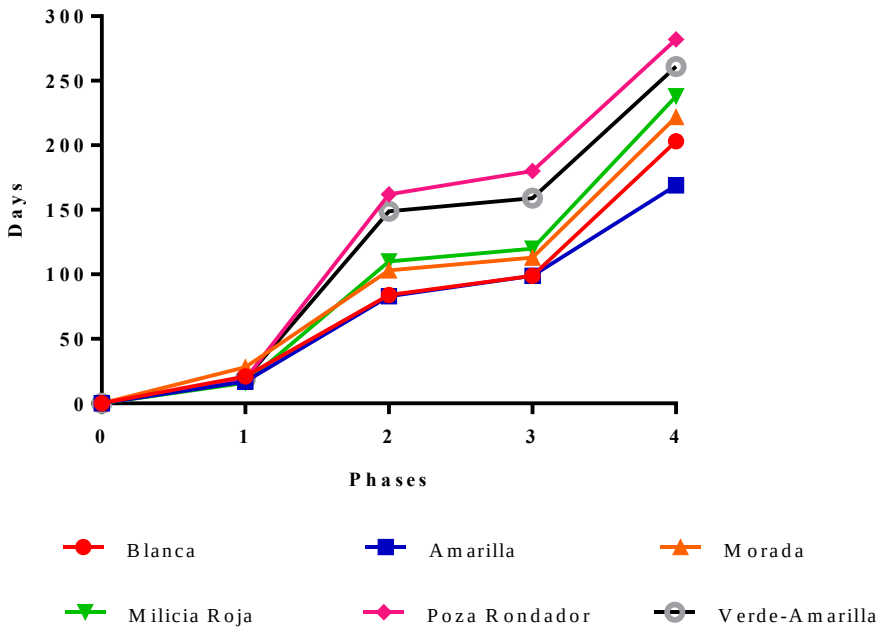

Figure 3. Duration (in days) of the phenological phases in each mashua accession. Blanco, Amarillo, Milícia Roja, Verde Amarrilla, Poza Rondador y Purpura, is the vulgar name as peasant know the accessions of Mashua in the Andean region of Ecuador.

Relating to the value of the crop coefficient (Kc), no differences were detected in the initial Kc (0.51) between the six accessions. However, differences were detected in the middle and fj al Kc (Figure 4). The mean Kc value was 1.02 in White accession, 1,0 for Amarilla, Morada, and Milicia Roja accessions, 1.1 in Poza Rondador and 0.96 in Verde amarilla. The final Kc reported values of 0.73 in Blanca; 0.58 in Amarilla; 0.71 in Morada, Milicia Roja and Poza Rondador and 0.7 in Verde amarilla.

Chemical analysis of nutrients

The chemical compositions of the accessions, showed variable results in the evaluated elements. The higher values of energy were exhibited in the Milicia Roja accession and Blanca the lowest value. Regarding the content of phosphorus and calcium, the Verde amarilla accession showed high values, while the Amarilla accession had the lowest value of phosphorous and the Morada had the lowest amount of calcium. Finally, the lowest values of magnesium were detected in the Verde amarilla accession and the higher in the Morada and Milicia Roja accessions. In the latter, high values of zinc were found, and low values were found in the Verde amarilla accessions (Table 3).

DISCUSSION

The morphological characterization of the phytogenic resources, consist in determining a set of characteristics (qualitative and quantitative) that function as descriptors, that enable the taxonomical differentiation of the species (Hernández, 2013). In this, study (Province of Tungurahua), the qualitative descriptors that most helped in the identification of the differences between the mashua accessions, were related with the flower and the tuber. Also, Quispe et al. (2015) reported that the qualitative morphological characteristics related to the flower and the tuber, were of most use in the characterization of mashua accessions.

The analysis of the variance of the quantitative characteristics, revealed significant statistical differences in plant height, sepal length, spur length, flower width, length and width of the leaf, diameter of the stalk, indent of the eye of the tuber, weight per 10 tubers, and yield. In contrast, with the reports of

Malice y Baudoin (2009), in Cochabamba-Bolivia, who reported significant differences only in plant height and leaf width. The accessions studied in Tungurahua, presented similar values to those obtained in Bolivia.

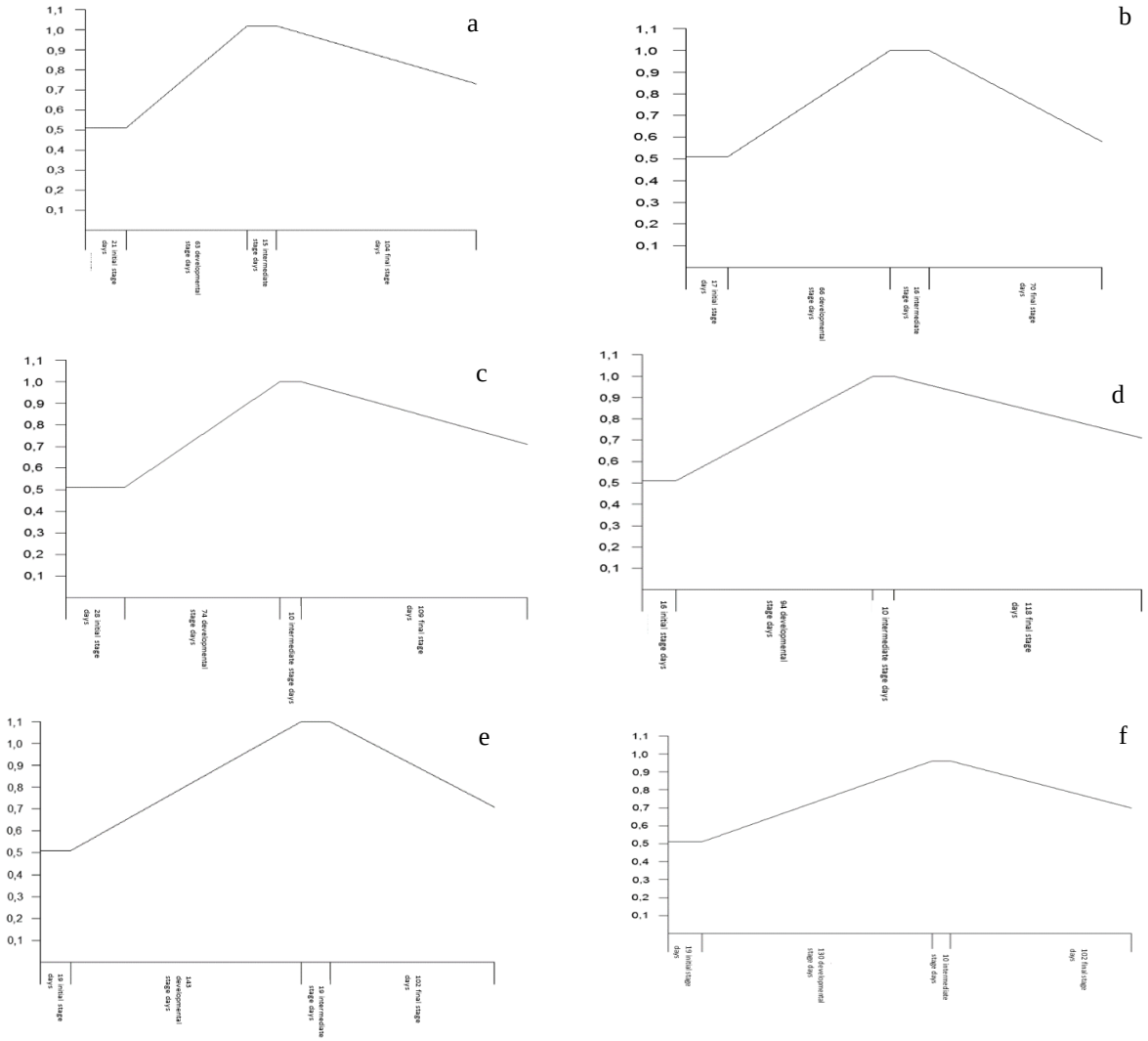

Figure 4. Values of Kc in the accessions: Blanca (a), Amarilla (b), Morada (c), Milicia roja (d), Poza Rondador (e), Verde amarilla (f) of mashua cultivated in Querochaca, Province of Tungurahua.

In so far as foliar morphology, one group of accessions (Blanca, Amarilla, Milicia Roja and Poza Rondador), were found to present both tribulated and pentalob leaves in an estimated 50% in each accession. Conversely, in the Bolivia accessions tribulate and pentalob plants were observed in 100% of the leaves (Malice and Baudoin, 2009). The analysis of main components indicated that of the 21qualitative characteristics analyzed four contributed significantly, two related to the flower and two with the tuber. However, Quispe et al. (2015), found that out of the 44 characteristics studied, 25 of them were of greater contribution to the total variance. These were related to the flower, the tuber, the leaf and the stem. Regarding the phenology, four phases were identified: emergence, tuberization, flowering and harvest, The Amarilla accession registered the lowest number of days in the cultivation cycle. Meanwhile, the Poza Rondador turned out to be the most belated, with an estimated difference of 113 days. These results suggest that the cultivation cycle is related to the genetic characteristics of the accession. Also, in the behavior of the accessions regarding the phenological phases, differences between the accessions in the second and fourth phase were found (Figure 3).

However, in previous works seven phenological phases were cited in this species: emergence,

formation of stolons, tuberization, budding, flowering, fructification, ripening (Yzarra and López, 2011; Fries and Tapia, 2007). In the case study, four phenological phases are considered in accordance with the methodology proposed by Allen (FAO, 2006) who also facilitated the calculation of the crop coefficient (Kc). Regarding the crop coefficient, it was observed that in the first phase all the accessions had similar values, variance was found in the second, third and fourth stages of the cultivation. Regarding this, Valverde (1998) mentions that the crop coefficient (Kc) depends on anatomic, morphologic and physiologic characteristics of the plant. This determines the volume of water that the plant absorbs, in relation to the vegetative state. These values can be useful for the planning of irrigation in each accession to achieve a more efficient irrigation.

Table 3. Content of nutrients of the Mashua accessions

Nutrients	B	A	M	MR	PR	VA
H (%)	82.73ab	78.04a	87.76cd	90.25cd	92.18d	86.61bc
E (Kcal/g)	3.66b	3.67b	3.94a	3.94a	3.9a	3.91a
P (%)	10.06b	11.19a	12.56b	16.25d	18.25e	14.13c
P2O5 (%)	0.55ab	0.42a	0.56abc	0.69bc	0.73bc	0.77c
K (%)	0.62a	0.99a	0.82a	0.66a	2.33b	1.26a
Ca (%)	0.08a	0.1a	0.025a	0.03a	0.65b	1.43c
Mg (%)	0.12b	0.11b	0.14b	0.14b	0.13b	0.03a
Zn (ppm)	9.6a	9.63a	17.0b	27.13c	8.33a	5.0a

Caption: humidity (H), energy (E), protein (P), phosphorous (P2O5), potassium (K), calcio (Ca), magnesium (Mg), zinc (Zn). The letters a, b, c, d, and e, indicate significant differences according to the probability $p<0.05$. B; Blanca, A; Amarilla, M; Morada, MR; Milicia roja, PR; Poza rondador, VA; Verde amarilla

Respecting the content of nutrients, it was observed that the Poza Rondador accession has the highest content of humidity, nitrogen and potassium. Meanwhile, the Blanca accession had the lowest content of nitrogen and potassium. This indicates a relationship between the accessions and the nutritional content. These values were similar to those reported by Espín et al (2003) and Villacrés et al. (2016). Furthermore, all the accession presented high calorie content. In relation to this, Ayala (2004) sustains that for each 100g of tuber contains 50 Kcal and 84.1% humidity. The characteristics of some accessions make mashua an alternative for the improvement of the nutrition of rural populations.

CONCLUSIONS

Regarding the morphology, the six accessions presented differences relating to the variables associated with the flower and tuber. In like manner, in the phenology (cultivation cycle) differences between all the accessions were observed, the Poza Rondador accession with 282 days and Amarilla accession with 169 days stood out. In relation to the Kc, differences were found in the second, third and fourth phase. In function of the cultivation cycle the Poza Rondador variety demanded the highest amount of water. Finally, the accessions that showcased the higher quantity of nutrients (N, humidity, P and K) were the Poza Rondador and Verde amarilla. Meanwhile, the accessions with the lowest quantity were the Amarilla and Blanca. The information that was found reveals the presence of a few accessions that have good potential for commercial and food production.

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