

# Effect of Hot Air Drying on Remaining Water Content and Total Phenolic Content of Three Morphotypes of Mashua (*Tropaeolum tuberosum* Ruíz y Pav.)

*Efecto del secado con aire caliente en la humedad libre y el contenido de fenólicos totales de tres morfotipos de mashua (Tropaeolum tuberosum Ruíz y Pav.)*

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## ABSTRACT

*Tropaeolum tuberosum* Ruíz y Pav. (mashua) is a tuber cultivated in Andean zones as Huancavelica, with traditional use in food and functional potential due to its content of bioactive compounds. Due to its short fresh shelf life, its preservation is required. Hot air drying, an alternative to solar drying, can affect the stability of these compounds depending on the temperature applied. Therefore, the objective was to evaluate the effect of temperature (50, 60, 70 and 80 °C) of hot air drying on remaining water content (Y) and total phenolic content (TPC) in three morphotypes of mashua (Zapallo, Sangre de Cristo and Negra). The tubers were washed, disinfected with sodium hypochlorite (50 ppm), cut (2.5 mm), and dried (150 g) for 16 h. Free moisture was determined in the dried samples. They were then ground (particles < 850 µm) and extracts (80% methanol, 50 mg/mL) were prepared for TPC determination. Drying temperature significantly ( $p < 0.05$ ) influenced the TPC as it increased from 50 to 80 °C, and did not influence the Y. TPC ranged from  $1608 \pm 80.22$  to  $2069 \pm 82.01$ ,  $1732 \pm 59.43$  to  $2069 \pm 30.32$  and  $5286 \pm 143.74$  to  $7929 \pm 120.48$  mg gallic acid equivalent/100 g dry mashua for Zapallo, Sangre de Cristo and Negra, respectively. These results indicate that hot air drying at 60 °C can be used to obtain dried mashua of the Sangre de Cristo and Negra varieties with higher TPC, while at 80 °C the TPC for the Zapallo variety is better preserved.

**Keywords:** Phenolics, bioactive compounds, dehydration, andean tuber, Huancavelica.



## RESUMEN

*Tropaeolum tuberosum* Ruiz & Pav. (mashua) es un tubérculo cultivado en zonas altoandinas como Huancavelica, con uso tradicional en la alimentación y potencial funcional por su contenido de compuestos bioactivos. Debido a su corta vida útil en fresco, se requiere su conservación. El secado por aire caliente, alternativa al secado solar, puede afectar la estabilidad de estos compuestos según la temperatura aplicada. Por tanto, el objetivo fue evaluar el efecto de la temperatura (50, 60, 70 y 80 °C) de secado con aire caliente en la humedad libre (Y) y el contenido de fenólicos totales (CFT) en tres morfotipos de mashua (Zapallo, Sangre de Cristo y Negra). Los tubérculos fueron lavados, desinfectados con hipoclorito de sodio (50 ppm), cortados (2,5 mm), y secados (150 g) durante 16 h. La humedad libre se determinó en las muestras secas. Luego, se molieron (partículas < 850 µm) y se prepararon extractos (metanol al 80 %, 50 mg/mL) para la determinación del CFT. La temperatura de secado influyó significativamente ( $p < 0,05$ ) en el CFT, a medida que se incrementó de 50 a 80 °C, y no influyó en la Y. El CFT variaron de  $1608 \pm 80,22$  a  $2069 \pm 82,01$ ,  $1732 \pm 59,43$  a  $2069 \pm 30,32$  y  $5286 \pm 143,74$  a  $7929 \pm 120,48$  mg equivalente de ácido gálico/100 g mashua seca para la Zapallo, Sangre de Cristo y Negra, respectivamente. Estos resultados indican que el secado con aire caliente a 60 °C puede ser usado para obtener mashua seca de la variedad Sangre de Cristo y Negra con mayor CFT, mientras que a 80 °C se preserva mejor el CFT para la variedad Zapallo.

**Palabras clave:** Fenólicos, compuestos bioactivos, deshidratación, tubérculo andino, Huancavelica.

## INTRODUCTION

*Tropaeolum tuberosum* Ruiz and Pavón, commonly known as mashua, has traditionally been used for both food and medicinal purposes across a broad Andean region extending from Colombia to northwestern Argentina. However, archaeological evidence from present-day Peru indicates that mashua was consumed by pre-Inca populations more than 7,500 years ago, and its presence has been documented in the ceramics of the Nasca and Chimú cultures. Today, this tuber is cultivated in Colombia, Ecuador, Peru, and Bolivia, and exhibits remarkable phenotypic variability, expressed in external colorations such as orange, pale yellow, yellowish orange, deep yellow, grayish purple, dark purple,

and reddish gray. Likewise, the color of the flesh ranges from yellow to orange and violet. It also presents pigmented buds, which sometimes display purple or red streaks (Siqueira *et al.*, 2023; Grau *et al.*, 2025).

Mashua has been widely used in traditional medicine for its digestive, cleansing, wound-healing, and diuretic properties. It is also employed in the treatment of diseases such as diabetes, dengue, malaria-related fever, and various postpartum conditions, particularly in the management of kidney disorders. Additionally, it is attributed preventive effects against pathologies such as prostate hyperplasia, skin ulcers, gonorrhoea, and tonsillitis. Its high glucosinolate content confers antibacterial,

antimutagenic, anticancer, and antifungal properties. Furthermore, its potent antioxidant activity is associated with its high concentration of phenolic compounds (Grau *et al.*, 2025; Luziatelli *et al.*, 2023).

At present, mashua continues to be consumed by rural populations and has begun gaining wider acceptance in urban markets due to its versatility in food preparation and its potential for industrial processing. Its applications include stews, creams, soups, porridges, panna cotta with milk, mashua in walnut sauce, cookies with rocoto caviar and avocado mayonnaise, cocido boyacense, bottled mashua–pineapple juice, black mashua jam, dehydrated mashua, flour production, and second-generation snack development (Grau *et al.*, 2025; Leidi *et al.*, 2018; Luziatelli *et al.*, 2023; Zambrano *et al.*, 2025; Acurio *et al.*, 2023).

Mashua is also notable for its high content of nutrients, phytochemicals, and natural pigments with antioxidant properties (Betalleluz-Pallardel *et al.*, 2012; Campos *et al.*, 2006; Costa *et al.*, 2008; Warnier *et al.*, 2008; Chirinos *et al.*, 2006, 2015; Pacheco *et al.*, 2019; Paucar-Menacho *et al.*, 2020), making it a functional ingredient of high commercial value. However, its high water content (between 74.51 and 92 g/100 g fresh mashua) (Campos *et al.*, 2006; Castañeta *et al.*, 2024; Coloma *et al.*, 2022) limits its shelf life, prompting interest in studying preservation methods and parameters that prolong it while minimizing impacts on bioactive compounds.

Dried mashua has been obtained using hot air at 60 °C for 6 to 24 hours and air velocities of 1.8 to 2 m/s in a convective dryer as part of the production of dried mashua flour, flour for second-generation snacks (Acurio *et al.*, 2023, 2025), or as a pretreatment for mashua characterization

(Aguilar-Gálvez *et al.*, 2022; Salazar *et al.*, 2021).

Drying is one of the most consolidated and widely used methods for food preservation, enabling shelf-life extension and reduction of fresh-product waste (Berk, 2018; Onwude *et al.*, 2022). This process is based on reducing water content to levels that ensure microbiological stability. Drying also inhibits microbial growth and slows undesirable chemical reactions, while reducing storage and transportation costs by decreasing the weight and volume of the final product (Castillo-Zapata *et al.*, 2024).

Industries in developing countries still favor hot-air drying, considered a low-cost and simple operation in which solid foods are directly exposed to hot air in the drying chamber (Castillo-Zapata *et al.*, 2024; Kerr, 2019). However, the total phenolic content (TPC) of foods may be affected by the drying temperature.

Multiple studies have used the colorimetric Folin–Ciocalteu assay to evaluate TPC. Its preference over other methods is often justified by its recognized reliability, long history of use, and broad acceptance within the scientific community. Moreover, it is more economical than alternative analytical techniques, making it accessible for researchers with limited resources. Its simplicity and applicability have made it one of the most commonly used tools for analyzing phenolic compounds in the food industry (Li *et al.*, 2025).

Several studies have reported TPC values in freeze-dried mashua (Behar *et al.*, 2021; Campos *et al.*, 2006; Castañeta *et al.*, 2024; Costa *et al.*, 2008; Campos *et al.*, 2007; Warnier *et al.*, 2008; Chirinos *et al.*, 2006; Rogez *et al.*, 2007; Choquecham-

bi *et al.*, 2019; Coloma *et al.*, 2022; Jacobo-Velázquez *et al.*, 2022; Pacheco *et al.*, 2020) and in hot-air-dried mashua (Acurio *et al.*, 2025; Salazar *et al.*, 2021). However, no studies have reported the effects of drying temperature on mashua of the zapallo, Sangre de Cristo, and negra morphotypes. Therefore, the objective of this study was to evaluate the effect of drying temperature (50, 60, 70, 80, and 90 °C) using hot air on

the free moisture content and total phenolic content of mashua of the zapallo, Sangre de Cristo, and negra morphotypes.

## MATERIALS AND METHODS

### Raw material

Mashua (Figure 1) was obtained from the rural community of Carpapata, Colcabamba district, Tayacaja, Huancavelica, Peru.



**Figure 1.** Whole and sliced mashua morphotypes: a) zapallo, b) Sangre de Cristo, and c) negra.

### Preparation of the raw material

The three mashua morphotypes were washed with potable water and disinfected with a 50 ppm sodium hypochlorite solution. Residual hypochlorite was then removed by rinsing with potable water. Finally, the tubers were cut into slices 2.5 cm thick and placed on drying trays.

### Drying of mashua

Slices of the three mashua morphotypes were dried using a forced-air dehydrator (AISTAN, model ST04, China). Drying temperatures of 50, 60, 70, and 80 °C were evaluated based on previous studies conducted by our research group (Castillo-Zapata *et al.*, 2024). For each condition, approximately 150 g of fresh mashua slices

were placed in the dehydrator and dried for 16 hours at a constant air velocity of 2.5 m/s. Each treatment was performed in triplicate.

### Grinding and sieving of dried mashua

The three morphotypes of mashua, previously dehydrated at different temperatures, were ground individually for 3 minutes using a blade mill. The pulverized material was then sieved using an 850- $\mu$ m mesh. Fractions passing through the sieve were stored in airtight bags until further use.

### Preparation of mashua extracts

Extracts were obtained following the protocol described by Castillo-Zapata *et al.* (2024). Approximately 2 g of finely ground dried mashua were weighed and ex-

tracted with 40 mL of 80% (v/v) methanol. The mixture was homogenized on a magnetic stirrer at 1,000 rpm for 20 minutes at room temperature. It was then centrifuged at 4,500 rpm for 20 minutes, and the supernatant, corresponding to the extract containing solubilized compounds, was collected.

### Determination of total phenolic content

The TPC was determined following the procedure described by Castillo-Zapata *et al.* (2024). In 10-mL test tubes, 1.364 mL of distilled water, 300  $\mu$ L of previously diluted extract, and 136  $\mu$ L of Folin–Ciocalteu reagent were mixed. The mixture was gently agitated and allowed to rest for 8 minutes at room temperature, protected from light. Subsequently, 1.2 mL of a 7.5% (w/v) sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) solution was added, homogenized, and incubated for 2 hours under the same conditions.

Absorbance was measured at 760 nm using a UV-Visible spectrophotometer (Genesys 150, Thermo Scientific, USA). Quantification of TPC was performed using a calibration curve prepared with gallic acid standard solutions at concentrations of 10, 20, 30, 40, 50, and 60  $\mu$ g/mL. Results were expressed as milligrams of gallic acid equivalents (mg GAE) per 100 g of dried mashua.

### Statistical analysis

TPC was evaluated through an analysis of variance (ANOVA), followed by Tukey's multiple comparison test, using a significance level of 5% ( $p < 0.05$ ). Statistical analyses were performed using RStudio (version 2021). Additionally, data related to free moisture and the standard curve were processed using Origin Pro 2025 (SR1, v10.2.0.196).

## RESULTS AND DISCUSSION

### Effect of drying temperature on the free moisture content of mashua

Figure 2 shows the effect of drying temperature on the free moisture content (kg water/kg dry solid) of the three mashua morphotypes: zapallo, Sangre de Cristo, and negra. Free moisture values ranged from 0.0228 to 0.0042, 0.0216 to 0.0066, and 0.0217 to 0.0076 kg water/kg dried mashua for zapallo, Sangre de Cristo, and negra, respectively, across the temperature range of 50 to 80 °C.

At 80 °C and 16 hours, the zapallo morphotype exhibited the lowest free moisture content (0.0042 kg water/kg dry solid), followed by Sangre de Cristo (0.0066 kg water/kg dry solid) and negra (0.0076 kg water/kg dry solid). At 60 and 70 °C, the three morphotypes showed similar behavior, whereas at 50 °C, zapallo showed a slightly higher value than the other two morphotypes (Figure 2).

It is important to note that in all cases, the final free moisture remained below the maximum limit allowed for dry products processed into flour (15%, equivalent to 0.1765 kg water/kg dry solid), as established by the Codex Alimentarius (1985).

For a 200g load of fresh mashua cut into 2.5 cm slices, a drying time of 16 hours and an air velocity of 2.5 m/s were sufficient to reduce free moisture in all three morphotypes to levels compatible with dehydrated products, according to microbiological stability and reduced degradation reaction criteria (Ibarz & Ribas, 2005). This also contributes to lowering storage and transportation costs (Bahnasawy & Shenana, 2004).

Other studies have reported similar values. Acurio *et al.* (2025) observed a free moisture content of 0.064 kg water/kg dry solid in mashua slices (2 cm thick) dried at 60 °C for 24 hours with an air velocity of 2 m/s, comparable to results from this study under similar conditions. Differences likely relate to initial moisture content and morphotype.

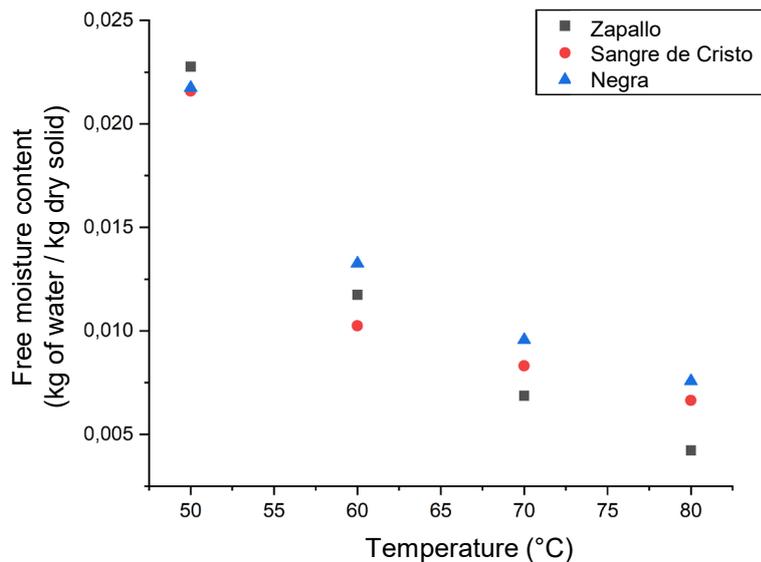
In contrast, Salazar *et al.* (2021) reported a higher value (0.2326 kg water/kg dry solid, equivalent to 18.87% moisture) for 3 cm slices dried at 60 °C for 6 hours, suggesting that slice thickness and drying time influenced moisture retention, and likely the air velocity also affected the drying process.

Fresh mashua moisture values were recorded as 88 ± 0.5% for zapallo and 90 ± 0.5% for Sangre de Cristo and negra. These values are slightly higher than those reported by Coloma *et al.* (2022) for purple mashua (74.51–89.72%), yellow mashua

(82.86–87.81%), and yellow-purple mashua (76.11–83.48%); by Castañeta *et al.* (2024) for santo jonk'ori (81.5%), Achakani (83%), and ch'iyara (80.3%); and by Campos *et al.* (2006) for yellow–yellow (87–92%), purple–yellow (85–89%), purple–purple (87%), and yellow–purple–purple (86%). This confirms that moisture content in fresh mashua is influenced by morphotype, genotype, and ecological conditions of cultivation.

### Effect of drying temperature on the total phenolic content of mashua

Table 1 shows the TPC results for zapallo, Sangre de Cristo, and negra mashua morphotypes dried at 50, 60, 70, and 80 °C. In the zapallo morphotype, TPC ranged from 1,523 ± 61.83 to 2,069 ± 82.01 mg GAE/100 g dried mashua. For Sangre de Cristo, values ranged from 1,732 ± 59.43 to 2,069 ± 30.32 mg GAE/100 g. The negra morphotype showed the highest values, ranging from 5,286 ± 143.74 to 7,929



**Figure 1.** Effect of Drying Temperature on the Free Moisture Content (kg of water/kg of dry solid) of Zapallo, Sangre de Cristo, and Negra

± 120.48 mg GAE/100 g depending on drying temperature (Table 1), mainly due to the anthocyanins found in black mashua (Coloma *et al.*, 2022).

Significant differences ( $p < 0.05$ ) were observed in TPC among the different mashua morphotypes. However, no significant differences were observed between Sangre de Cristo and zapallo morphotypes at 50 and 80 °C.

Regarding temperature influence, significant differences ( $p < 0.05$ ) were observed in TPC among drying temperatures of 50, 60, 70, and 80 °C. For the negra morphotype, no significant differences were found between 60 and 70 °C, although differences were observed between 50, 60, or

70 °C compared to 80 °C. For Sangre de Cristo, there was a significant difference between 50 and 60 °C, but no differences among 60, 70, and 80 °C, nor between 50, 70, and 80 °C. In zapallo, significant differences ( $p < 0.05$ ) were found among temperatures, except between 50 and 70 °C, and between 60 and 70 °C, where no differences were detected.

In the negra and Sangre de Cristo morphotypes, an increase in TPC was observed as drying temperature increased from 50 to 60 °C, likely due to a higher concentration of phenolic compounds resulting from water loss. Moreover, increasing temperature may break covalent bonds, facilitating the release of bound phenolics from the cellular matrix (Onwude *et al.*, 2022).

**Table 1.**  
*Relevant Factors That Impacted Progress or Setbacks in Food Security*

Mashua Morphotypes	Temperature (°C)	TPC (mgGAE/100g dried mashua)*
Zapallo	50	1792.4 ± 6.9 <sup>B;b</sup>
	60	1523.3 ± 61.8 <sup>C;c</sup>
	70	1607.6 ± 80.2 <sup>C;bc</sup>
	80	2069.5 ± 82.0 <sup>B;a</sup>
Sangre de Cristo	50	1732.1 ± 59.4 <sup>B;b</sup>
	60	2069.5 ± 30.3 <sup>B;a</sup>
	70	1932.9 ± 96.6 <sup>B;ab</sup>
	80	1932.9 ± 18.4 <sup>B;ab</sup>
Negra	50	5286.3 ± 143.7 <sup>A;c</sup>
	60	7928.9 ± 120.5 <sup>A;a</sup>
	70	7768.3 ± 283.2 <sup>A;a</sup>
	80	6543.4 ± 150.9 <sup>A;b</sup>

The data are presented as mean ± standard deviation. Identical superscript letters indicate that no significant differences exist ( $p < 0.05$ ) according to Tukey's test.

However, at higher temperatures (70 and 80 °C), a slight reduction in TPC was observed in Sangre de Cristo and a more pronounced reduction in negra. This reduction is likely associated with thermal degradation of thermolabile phenolic compounds, particularly anthocyanins in the negra morphotype.

In contrast, the zapallo morphotype showed a decrease in TPC from 50 to 60 °C, which may be related to polyphenol oxidase activity, a thermostable enzyme that remains active up to temperatures close to 60 °C. This enzyme catalyzes oxidation of phenolics, reducing their concentration (Onwude *et al.*, 2022). Once the enzyme is inactivated at temperatures above 60 °C, an increase in TPC was observed at 70 and 80 °C, likely due to the release of phenolic compounds not degraded by enzymatic action and the concentration of thermoresistant phenolics.

Compared with the results obtained in the present study at 60 °C (Table 1), lower TPC values have been reported for mashua dried at 60 °C for 24 h with an air velocity of 2 m/s (450 mg GAE/100 g) (Acurio *et al.*, 2025), and for mashua dried at the same temperature for 6 h (6.8 mg GAE/100 g) (Salazar *et al.*, 2021). These differences reflect not only the influence of drying conditions on the retention or degradation of phenolic compounds, but also the impact of the crop's origin and production characteristics. In particular, for the lowest reported value, factors such as the final moisture content of the product, air-flow velocity, and extraction method may have contributed to the reduction in TPC.

On the other hand, different TPC values have been reported for freeze-dried mashua compared with those obtained in

this study. Jacobo-Velázquez *et al.* (2022) indicated that TPC in twenty-seven morphotypes of Peruvian mashua ranged from 162.54 mg GAE/100 g (MAC 090 – white, Apurímac region) to 1,316.16 mg GAE/100 g (MAC 092 – black, Ayacucho region).

Similarly, Coloma *et al.* (2022) reported that TPC in purple mashua ranged from 385 to 1,143 mg GAE/100 g dry matter; in yellow mashua, from 182 to 405 mg/100 g dry matter; and in yellow mashua with purple eyes, from 116 to 225 mg/100 g dry matter.

Behar *et al.* (2021) reported TPC values in six fresh mashua accessions ranging from 77.48 to 220.83 mg GAE/100 g, with Tt-19 (skin/flesh: yellow/yellow) and Tt-23 (skin/flesh: purple/purple) being the extreme accessions.

Likewise, Castañeta *et al.* (2024) reported TPC values of 260, 200, and 1,170 µmol GAE/100 g fresh sample for the Santo Jonk'ori, Achakani, and Ch'iyara varieties, respectively.

Additionally, Choquechambi *et al.* (2019) reported the following TPC values, expressed as mg of chlorogenic acid equivalents (CAE)/100 g dry matter: Kellu (yellow), 790 mg; Chejchi (yellow, black eyes), 1,190 mg; Chiar (black), 2,230 mg; Kellu (yellow), 1,280 mg; Keni Kellu (yellow-purple), 1,310 mg; Jachir (yellow, red stripes), 970 mg; and Asuthi (yellow, purple stripes), 800 mg, for mashua samples from Peru and Bolivia.

Different TPC values have also been reported for freeze-dried mashua compared with those obtained in the present study. Campos *et al.* (2006) found that TPC in eleven fresh mashua genotypes ranged from 92 to 337 mg GAE/100 g, with genotypes

ARB-5241 (337 mg GAE/100 g), DP-0224 (305 mg GAE/100 g), and AGM-5109 (275 mg GAE/100 g) presenting the highest values.

Similarly, Chirinos *et al.* (2006) reported TPC values for genotypes ARB-5241 (374.4 mg GAE/100 g), DP-0224 (131.9 mg GAE/100 g), and AGM-5109 (45.5 mg GAE/100 g), all expressed on a fresh-weight basis. Rogez *et al.* (2007) reported maximum TPC values on a dry-weight basis for ARB-5241 (2,200 mg GAE/100 g) and DP-0224 (1,710 mg GAE/100 g).

Likewise, Campos *et al.* (2007) reported TPC values ranging from 1,400 to 2,400 mg GAE/100 g dry matter for cultivars ARB-5241, DP-0224, and AGM-5109. Later, Costa *et al.* (2008) reported TPC values in fresh mashua for genotypes ARB-5241 (skin/flesh, purple/yellow) with 395 mg GAE/100 g, DP-0224 (skin/flesh, purple/purple) with 262 mg GAE/100 g, and ARB-5576 (skin/flesh, yellow/yellow) with 52.2 mg GAE/100 g.

Additionally, Warnier *et al.* (2008) reported the following TPC values in fresh mashua: ARB-5241 (323 mg GAE/100 g; 83.4% moisture), DP-0224 (205 mg GAE/100 g; 84.2% moisture), AGM-5109 (166 mg GAE/100 g; 87.0% moisture), and ARB-5576 (56.3 mg GAE/100 g; 87.1% moisture).

Finally, Campos *et al.* (2018) analyzed eighty-four mashua genotypes and found TPC values on a dry-weight basis ranging from 550 to 1,670 mg GAE/100 g.

Overall, the results obtained in this study, as well as those reported by other authors, demonstrate that mashua morphotypes with black, purple, or dark pigmentation tend to show higher TPC values than

those with yellow or lighter bicolorations. Likewise, the cultivation area exerts a significant influence on TPC, as demonstrated in mashua samples from different agroecological zones in the Puno region (Coloma *et al.*, 2022). Furthermore, TPC values depend on factors such as genotype, solvent type, pH level, solvent-to-water ratio, and extraction time (Rogez *et al.*, 2007).

Compared with other plant species, the black mashua morphotype exhibits a TPC within the range of values reported for maqui (*Aristotelia chilensis*) (3,190 mg/100 g dry matter) (Quispe-Fuentes *et al.*, 2018), aronia (*Aronia melanocarpa*) (2,190 mg GAE/100 g fresh fruit and 9,400 mg GAE/100 g dried fruit) (Kaloudi *et al.*, 2022), and camu camu (12,798.80 mg GAE/100 g fresh fruit) (García-Chacón *et al.*, 2023), species widely recognized for their high antioxidant capacity and classified as superfoods.

The black mashua used in this study exhibits morphological characteristics similar in shape to the black mashua from the AGM-5118 collection (Lingán Grande, Chota, Cajamarca) and in color to the mashua yana ojo from the CM DPA 02 24 collection (Socorro, Ninacaca, Pasco). It is possible that this mashua represents a new collection, which aligns with the statement by Campos *et al.* (2018), who suggest that many more likely exist, given the considerable genotypic variability in shape and color, variability that appears to correlate with the content of bioactive compounds.

## CONCLUSIONS

Drying mashua at temperatures between 50 and 80 °C for 16 h with an air velocity of 2.5 m/s reduced the free moisture content of the zapallo, Sangre de Cristo, and black morphotypes to levels below

those established by the Codex Alimentarius (0.1765 kg water/kg dry solid). The zapallo morphotype exhibited the lowest remaining water content (0.0042 kg/kg). The differences observed between morphotypes and in comparison with previous studies can be attributed to variables such as slice thickness, drying time and air velocity, as well as the tuber's initial moisture content. Likewise, it was confirmed that moisture in fresh mashua is conditioned by morphotype, genotype, and agroecological conditions, factors that must be considered when optimizing industrial drying processes.

Furthermore, TPC showed significant variations according to morphotype and drying temperature. The black morphotype exhibited the highest TPC values, attributable to its elevated anthocyanin

content. The drying temperature of 60 °C favored the concentration of phenolic compounds in most morphotypes, whereas higher temperatures led to partial degradation of thermolabile compounds. The behavior of TPC was influenced by enzymatic activity, particularly polyphenol oxidase, and by the dehydration of the plant matrix.

Discrepancies with previous studies can be explained by variations in genotype, origin, drying conditions, and extraction methods. These results underscore the potential of the black morphotype as a rich source of phenolic compounds, with levels comparable to recognized superfoods, highlighting the importance of continued research on mashua for potential applications in nutraceuticals or functional food ingredients.

## REFERENCES

- Acurio, L., Salazar, D., Castillo, B., Santiana, C., Martínez-Monzó, J., AMD Igual, M. (2023). Characterization of Second-Generation Snacks Manufactured from Andean Tubers and Tuberous Root Flours. *Foods*, 13(1), 51. <https://doi.org/10.3390/FOODS13010051>
- Acurio, L., Salazar, D., Guanoquiza, I., García-Segovia, P., Martínez-Monzó, J., y Igual, M. (2025). Ecuadorian roots flours: Bioactive compounds and processing properties. *Journal of Agriculture and Food Research*, 19, 101740. <https://doi.org/10.1016/J.JAFR.2025.101740>
- Aguilar-Galvez, A., García-Ríos, D., Lindo, J., Ramírez-Guzmán, D., Chirinos, R., Pedreschi, R., y Campos, D. (2022). Impact of cold storage followed by drying of mashua tuber (*Tropaeolum tuberosum*) on the glucosinolate content and their transformation products. *International Journal of Food Science & Technology*, 57(12), 7797–7805. <https://doi.org/10.1111/ijfs.16088>
- Bahnasawy, A. H., y Shenana, M. E. (2004). A mathematical model of direct sun and solar drying of some fermented dairy products (Kishk). *Journal of Food Engineering*, 61(3), 309–319. [https://doi.org/10.1016/S0260-8774\(03\)00134-1](https://doi.org/10.1016/S0260-8774(03)00134-1)
- Behar, H., Reategui, O., Liviach, D., Arcos, J., y Best, I. (2021). Phenolic compounds and in vitro antioxidant activity of six accessions of mashua (*Tropaeolum tuberosum* R. & P.) from Puno Region, Peru. *Revista Facultad Nacional de Agronomía Medellín*, 74(3), 9707–9714. <https://doi.org/10.15446/rfnam.v74n3.93020>

- Berk, Z. (2018). Dehydration. *Food Process Engineering and Technology*, 513–566. <https://doi.org/10.1016/B978-0-12-812018-7.00022-1>
- Betalleluz-Pallardel, I., Chirinos, R., Rogez, H., Pedreschi, R., y Campos, D. (2012). Phenolic compounds from Andean mashua (*Tropaeolum tuberosum*) tubers display protection against soybean oil oxidation. *Food Science and Technology International*, 18(3), 271–280. <https://doi.org/10.1177/1082013211427794>
- Campos, D., Chirinos, R., Gálvez Ranilla, L., y Pedreschi, R. (2018). Bioactive Potential of Andean Fruits, Seeds, and Tubers. *Advances in Food and Nutrition Research*, 84, 287–343. <https://doi.org/10.1016/BS.AFNR.2017.12.005>
- Campos, D., Noratto, G., Chirinos, R., Arbizu, C., Roca, W., y Cisneros-Zevallos, L. (2006). Antioxidant capacity and secondary metabolites in four species of Andean tuber crops: native potato (*Solanum sp.*), mashua (*Tropaeolum tuberosum* Ruiz & Pavón), Oca (*Oxalis tuberosa* Molina) and ulluco (*Ullucus tuberosus* Caldas). *Journal of the Science of Food and Agriculture*, 86(10), 1481–1488. <https://doi.org/10.1002/jsfa.2529>
- Castañeta, G., Miranda-Flores, D., Bascopé, M., y Peñarrieta, J. M. (2024). Characterization of carotenoids, proximal analysis, phenolic compounds, anthocyanidins and antioxidant capacity of an underutilized tuber (*Tropaeolum tuberosum*) from Bolivia. *Discover Food*, 4(1), 1–12. <https://doi.org/10.1007/S44187-024-00078-8/FIGURES/4>
- Castillo-Zapata, K. C., Reyes-Díaz, J. D., Cornelio-Santiago, H. P., Espinoza-Espinoza, L. A., Valdiviezo-Marcelo, J., y Ruiz-Flores, L. A. (2024). Efecto del secado con aire caliente en el contenido de fenólicos totales y capacidad antioxidante de la cáscara de pitahaya roja (*Hylocereus guatemalensis*). *Revista de Investigaciones de La Universidad Le Cordon Bleu*, 11(2), 97–106. <https://doi.org/10.36955/RIUL-CB.2024v11n2.009>
- Chirinos, R., Campos, D., Arbizu, C., Rogez, H., Rees, J., Larondelle, Y., Noratto, G., y Cisneros-Zevallos, L. (2007). Effect of genotype, maturity stage and post-harvest storage on phenolic compounds, carotenoid content and antioxidant capacity, of Andean mashua tubers (*Tropaeolum tuberosum* Ruiz & Pavón). *Journal of the Science of Food and Agriculture*, 87(3), 437–446. <https://doi.org/10.1002/jsfa.2719>
- Chirinos, R., Campos, D., Betalleluz, I., Giusti, M. M., Schwartz, S. J., Tian, Q., Pedreschi, R., y Larondelle, Y. (2006). High-Performance Liquid Chromatography with Photodiode Array Detection (HPLC–DAD)/HPLC–Mass Spectrometry (MS) Profiling of Anthocyanins from Andean Mashua Tubers (*Tropaeolum tuberosum* Ruiz and Pavón) and Their Contribution to the Overall Antioxidant Activity. *Journal of Agricultural and Food Chemistry*, 54(19), 7089–7097. <https://doi.org/10.1021/jf0614140>

- Chirinos, R., Campos, D., Costa, N., Arbizu, C., Pedreschi, R., y Larondelle, Y. (2008). Phenolic profiles of andean mashua (*Tropaeolum tuberosum* Ruíz & Pavón) tubers: Identification by HPLC-DAD and evaluation of their antioxidant activity. *Food Chemistry*, 106(3), 1285–1298. <https://doi.org/10.1016/J.FOODCHEM.2007.07.024>
- Chirinos, R., Campos, D., Warnier, M., Pedreschi, R., Rees, J. F., y Larondelle, Y. (2008). Antioxidant properties of mashua (*Tropaeolum tuberosum*) phenolic extracts against oxidative damage using biological in vitro assays. *Food Chemistry*, 111(1), 98–105. <https://doi.org/10.1016/J.FOODCHEM.2008.03.038>
- Chirinos, R., Pedreschi, R., Cedano, I., y Campos, D. (2015). Antioxidants from Mashua (*Tropaeolum tuberosum*) Control Lipid Oxidation in Sacha Inchi (*Plukenetia volubilis* L.) Oil and Raw Ground Pork Meat. *Journal of Food Processing and Preservation*, 39(6), 2612–2619. <https://doi.org/10.1111/JFPP.12511>;WGROU:STRIN-G:PUBLICATION
- Chirinos, R., Rogez, H., Campos, D., Pedreschi, R., y Larondelle, Y. (2007). Optimization of extraction conditions of antioxidant phenolic compounds from mashua (*Tropaeolum tuberosum* Ruíz & Pavón) tubers. *Separation and Purification Technology*, 55(2), 217–225. <https://doi.org/10.1016/J.SEPPUR.2006.12.005>
- Choquechambi, L. A., Callisaya, I. R., Ramos, A., Bosque, H., Mújica, A., Jacobsen, S. E., Sørensen, M., y Leidi, E. O. (2019). Assessing the Nutritional Value of Root and Tuber Crops from Bolivia and Peru. *Foods*, 8(11), 526. <https://doi.org/10.3390/FOODS8110526>
- Coloma, A., Flores-Mamani, E., Quille-Calizaya, G., Zaira-Churata, A., Apaza-Ticona, J., Calsina-Ponce, W. C., Huata-Panca, P., Inquilla-Mamani, J., y Huanca-Rojas, F. (2022). Characterization of Nutritional and Bioactive Compound in Three Genotypes of Mashua (*Tropaeolum tuberosum* Ruiz and Pavón) from Different Agroecological Areas in Puno. *International Journal of Food Science*, (1), 7550987. <https://doi.org/10.1155/2022/7550987>
- García-Chacón, J. M., Marín-Loaiza, J. C., y Osorio, C. (2023). Camu Camu (*Myrciaria dubia* (Kunth) McVaugh): An Amazonian Fruit with Biofunctional Properties-A Review. *ACS Omega*, 8(6), 5169–5183. <https://doi.org/10.1021/ACSOMEGA.2C07245>/ASSET/IMAGES/LARGE/AO2C07245\_0003.JPEG
- Grau, A., Andrade, N. J. P., y Sørensen, M. (2025). Traditional uses, processes, and markets: the case of Mashua (*Tropaeolum tuberosum* Ruíz & Pav.). *Traditional Products and Their Processes*, 269–278. <https://doi.org/10.1016/B978-0-323-90844-3.00009-3>
- Jacobo-Velázquez, D. A., Peña-Rojas, G., Paredes-Avila, L. E., Andía-Ayme, V., Torres-Contreras, A. M., y Herrera-Calderon, O. (2022). Phytochemical Characterization of Twenty-Seven Peruvian Mashua (*Tropaeolum tuberosum* Ruíz & Pavón) Morphotypes and the Effect of Postharvest Methyl Jasmonate Application on the Accumulation of Antioxidants. *Horticulturae*, 8(6), 471. <https://doi.org/10.3390/HORTICULTURAE8060471>

- Kaloudi, T., Tsimogiannis, D., y Oreopoulou, V. (2022). Aronia Melanocarpa: Identification and Exploitation of Its Phenolic Components. *Molecules*, 27(14), 4375. <https://doi.org/10.3390/MOLECULES27144375>
- Kerr, W. L. (2019). Food Drying and Evaporation Processing Operations. Editor(s): Myer Kutz (Third Edition) Handbook of Farm, Dairy and Food Machinery Engineering, 353–387. <https://doi.org/10.1016/B978-0-12-814803-7.00014-2>
- Leidi, E. O., Altamirano, A. M., Mercado, G., Rodriguez, J. P., Ramos, A., Alandia, G., Sørensen, M., y Jacobsen, S. E. (2018). Andean roots and tubers crops as sources of functional foods. *Journal of Functional Foods*, 51, 86–93. <https://doi.org/10.1016/J.JFF.2018.10.007>
- Li, H., Nunekpeku, X., Adade, S. Y.-S. S., Sheng, W., Kwadzokpui, B. A., Ahlivia, E. B., y Chen, Q. (2025). Phenolic compounds detection and quantification in whole grains: A comprehensive review of recent advancements in analytical methods. *TrAC Trends in Analytical Chemistry*, 187, 118215. <https://doi.org/10.1016/J.TRAC.2025.118215>
- Luziatelli, G., Alandia, G., Rodríguez, J. P., Manrique, I., Jacobsen, S. E., y Sørensen, M. (2023). Ethnobotany of Andean minor tuber crops: tradition and innovation—Oca (*Oxalis tuberosa* Molina—Oxalidaceae), Mashua (*Tropaeolum tuberosum* Ruiz & Pav.—Tropaeoleaceae) and Ulluco (*Ullucus tuberosus* Caldas—Basellaceae). Varieties and Landraces: Cultural Practices and Traditional Uses: Volume 2: Underground Starchy Crops of South American Origin: Production, Processing, Utilization and Economic Perspectives, 2, 79–100. <https://doi.org/10.1016/B978-0-323-90057-7.00009-7>
- Onwude, D. I., Iranshahi, K., Rubinetti, D., Schudel, S., Schemminger, J., Martynenko, A., y Defraeye, T. (2022). How much do process parameters affect the residual quality attributes of dried fruits and vegetables for convective drying? *Food and Bioproducts Processing*, 131, 176–190. <https://doi.org/10.1016/J.FBP.2021.11.005>
- Pacheco, M. T., Escribano-Bailón, M. T., Moreno, F. J., Villamiel, M., y Dueñas, M. (2019). Determination by HPLC-DAD-ESI/MSn of phenolic compounds in Andean tubers grown in Ecuador. *Journal of Food Composition and Analysis*, 84, 103258. <https://doi.org/10.1016/J.JFCA.2019.103258>
- Pacheco, M. T., Hernández-Hernández, O., Moreno, F. J., y Villamiel, M. (2020). Andean tubers grown in Ecuador: New sources of functional ingredients. *Food Bioscience*, 35, 100601. <https://doi.org/10.1016/J.FBIO.2020.100601>
- Paucar-Menacho, L. M., Peñas, E., Hernandez-Ledesma, B., Frias, J., & Martínez-Villaluenga, C. (2020). A comparative study on the phenolic bioaccessibility, antioxidant and inhibitory effects on carbohydrate-digesting enzymes of maca and mashua powders. *LWT*, 131, 109798. <https://doi.org/10.1016/J.LWT.2020.109798>

- Quispe-Fuentes, I., Vega-Gálvez, A., & Aranda, M. (2018). Evaluation of phenolic profiles and antioxidant capacity of maqui (*Aristotelia chilensis*) berries and their relationships to drying methods. *Journal of the Science of Food and Agriculture*, 98(11), 4168–4176. <https://doi.org/10.1002/JSFA.8938>;WGROU:STRING:PUBLICACION
- Salazar, D., Arancibia, M., Ocaña, I., Rodríguez-Maecker, R., Bedón, M., López-Caballero, M. E., y Montero, M. P. (2021). Characterization and Technological Potential of Underutilized Ancestral Andean Crop Flours from Ecuador, *Agronomy* 11(9), 1693. <https://doi.org/10.3390/AGRONOMY11091693>
- Siqueira, M. V. B. M., do Nascimento, W. F., Pereira, D. A., Cruz, J. G., Vendrame, L. P. de C., y Veasey, E. A. (2023). Origin, domestication, and evolution of underground starchy crops of South America. *Starchy Crops Morphology, Extraction, Properties and Applications: Vol 1: Underground Starchy Crops of South American Origin: Production, Processing, Utilization and Economic Perspectives*, 1, 17–42. <https://doi.org/10.1016/B978-0-323-90058-4.00011-6>
- Zambrano, J. L. A., de Oliveira Paulino, F., y da Cruz, D. D. (2025). Roots and tubers in Colombia's culinary and food traditions. *Traditional Starch Food Products: Application and Processing*, 4(4), 113–127. <https://doi.org/10.1016/B978-0-323-90844-3.00012-3>

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- Cornelio-Santiago H. P.: Conceptualization; writing; statistical analysis; review and editing.
- Gutiérrez-Valverde K. S.: Conceptualization; review and editing.

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