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ORIGINAL ARTICLE

Cubio tuber (*Tropaeolum tuberosum*, Tropaeolaceae) morphological diversity in Colombia and Bolivia

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Abstract

Tropaeolum tuberosum, commonly known as cubio, mashua, or isaño, is an underutilized crop belonging to the group of Andean tubers. Cubios harbor ample genetic and morphological variability, with tubers exhibiting the most variation. Morphological characterization is a fundamental approach for assessing cubio genetic diversity and is the crucial first step in germplasm classification. It is also a determinant for *in-situ* conservation practices carried out by farmers. Therefore, this study aimed to explore the morphological diversity of 15 cubio tuber accessions from Colombia and Bolivia, and to validate the findings by comparing them with previously published accessions. Based on tuber morphological descriptors, we calculated the diversity index and conducted PCA and clustering analyses on two datasets, consisting of (i) Colombian and Bolivian morphotypes and (ii) the latter plus previously published cubio data. Similarities were found in both the morphological diversity index and morphotype clustering between datasets, reinforcing the validity of the proposed morphological traits despite the limited sample sizes and inherent subjectivity in characterization. All accessions were successfully classified as distinct morphotypes, underscoring the considerable morphological variation present in cubios. This morphological variation reflects the wide underlying genetic variability in this species and highlights its adaptability to changing environmental conditions.

Keywords: Andean tubers; crop morphotypes; cubio; diversity; mashua; isaño.

1. Introduction

Tropaeolum tuberosum Ruiz & Pavón, also known as cubio, mashua, isaño, or añu, belongs to the Andean tubers group. This group also includes ruba (*Ullucus tuberosus* Caldas), ibia (*Oxalis tuberosa* Molina), and various potato varieties (*Solanum tuberosum* L.). *T. tuberosum* belongs to the family Tropaeolaceae, and its genus (*Tropaeolum*) includes 96 recognized species distributed across the Americas from Mexico to southern Argentina [1, 2]. Cubio is a perennial herbaceous plant with a sprawling habit, cylindrical stems, and solitary flowers. Its aerial stems are erect to decumbent, while the underground parts consist of conical, elongated tubers with marked nodes [3]. Cubio stems exhibit various degrees of pigmentation, as does its foliage, which ranges from yellow-green to dark green. Its morphological diversity primarily lies in tuber color and shape, as well as in the characteristics of their eyes and pulp color. Cubio tuber skin color varies among white, dark purple-violet, orange, red, and pink. The color pattern is also variable, as it can present a single shade or contrasting spots and stripes located under the eyes [4].

Cubios possesses key agroecological features, such as the ability to withstand low temperatures, thrive in nutrient-poor soils, and resist nematodes and pest insects [5]. Despite their several positive attributes, cubios remain unattractive to consumers and, consequently, hold little economic significance compared to other Andean tubers. Their limited appeal is mainly attributed to a strong flavor and bitterness resulting from a high isothiocyanate content derived from glucosinolates. Additionally, factors such as labor-intensive cooking processes and low economic returns further contribute to its limited market presence [6, 7]. Moreover, local varieties maintained by farmers face various pressures, such as population growth, poverty, and climate change [8]. All of this leads to a loss of genetic variability, compromising their adaptability to fluctuating environmental conditions. Therefore, assessing the cubio's current genetic and phenotypic diversity status will help establish its potential and the development of conservation strategies.

Even though Andean tubers play a significant role in the food security of Andean communities, the characterization of their productive systems in countries such as Colombia and Bolivia remains limited. In Colombia, however, Andean tuber production systems have been identified in the departments of Cundinamarca, Boyacá, Cauca, and Nariño. The high Andean plateau known as Altiplano Cundiboyacense, located in Colombia's central region, represents the main production zone of Andean tubers [9]. Previous studies have recognized the municipalities of Turmequé, Ventaquemada, Belén, and Tuta in the Boyacá department as micro centers of diversity for cubios and other Andean tubers [8, 10, 11]. In Bolivia, the Cochabamba department is significant for its diversity and production of Andean roots and tubers [12].

The assessment of genetic diversity in agricultural plants is routinely conducted using various approaches, including morphological characterization, biochemical characterization, and molecular marker analysis. Morphological markers are based on bare-eye identifiable traits, such as flowers, foliage, and tuber characteristics, and do not require costly technologies. Although these markers are susceptible to phenotypic plasticity, they facilitate the assessment of diversity in the presence of environmental variation, which may also modulate genetic variability [13]. Furthermore, morphological characterization remains the empirical approach used by farmers to support *in situ* conservation practices and the persistence of their seed collections. It is also the first step in describing and classifying germplasm. Statistical tools such as principal component analysis (PCA) and hierarchical clustering methods help curate these accessions [14]. The main objective of this study was to characterize the morphological diversity of 15 cubio accessions from Colombia and Bolivia. This initial phenotypic evaluation of cubios contributes to the understanding of native diversity in the Andean regions and, thus, strengthens conservation efforts for this promising species.

2. Material and methods

2.1. Plant material

Colombian cubio morphotypes were first collected by Fonseca and Márquez-Cardona (2024) from farmers in the municipalities of Belén and Ventaquemada in the Boyacá department. Meanwhile, the four Bolivian accessions were collected in the Sacaba municipality, Cochabamba Department. The selection of these collection regions was driven by prior reports highlighting these localities as micro centers of diversity, ensuring representation of regional variability. The exact origin of the samples cannot be fully traced, as these morphotypes result from seed exchange among producers and farmers, complicating the assessment of their precise background. To control environment-driven morphological variation, tubers were planted on 16. July 2021 in a conservation plot at the San Javier farm, located on the Zipaquirá-to-Nemocón road, department of Cundinamarca, Colombia (05º03'37.0" N, 073º56'41.6" W; 2590 m). Thereafter, samples were morphologically characterized using the tuber descriptors proposed by Manrique *et al*. (2014) with some modifications [15].

The nomenclature given for Colombian samples is based on their color. The first letter indicates the predominant surface color: 'A' for yellow, 'M' for purple, and 'B' for white. Some samples may have a second 'S' letter to indicate the presence of pulp secondary color. In contrast, Bolivian morphotypes begin with 'IS,' which stands for "isaño", the common name for cubio in this country. Finally, the number at the end denotes the specific morphotype.

2.2. Morphological characterization

Ordinal and nominal qualitative variables were employed by Manrique and collaborators, with values assigned for the respective clustering analyses. However, assigning values to nominal variables such as colors can lead to bias, as hierarchical clarity among character levels is not provided. For this reason, in this study, the variables related to the distribution of secondary color on the surface and in the pulp were transformed from nominal to ordinal. This transformation was carried out by dividing the descriptor to refer specifically to the color of each tissue or part separately (**Table 1**). The values assigned to each character level of the proposed descriptors are presented in **Table 2**. The color chart from the Royal Horticultural Society Sixth Edition (2015) [16] was used for the evaluations.

2.3. Statistical Analysis

Based on the morphological data matrix available in Supplementary material 1., the Gini Simpson diversity index for each variable was estimated using the following formula [17]:

$$D = 1 - \sum_{i=1}^{k} p_i^2 \tag{1}$$

Where D is the Gini–Simpson diversity index, p_i is the proportion of accessions belonging to level i of the character in the total number of accessions, and k represents the number of levels of the character.

Additionally, a principal component analysis (PCA) and hierarchical clustering analyses were conducted using the `FactoMineR` (v. 2.9) [18] and `stats` (v. 4.2.3) packages in RStudio (v. 2023.03.0+386) [19]. In the hierarchical clustering analysis, squared Euclidean distance and the Ward clustering algorithm were used, following the suggestions from Žiberna *et al.* (2004) [20]. To validate the proposed descriptors, we incorporated Manrique *et al.*'s accessions (2014) into the matrix (as shown in Supplementary material 2), thus increasing the sample size and analysis robustness. Although Manrique *et al.* mentioned conducting a clustering analysis, they did not present the results, and a principal component analysis (PCA) was not performed. Therefore, in this study, both the clustering analysis and PCA were conducted using the accessions from Manrique *et al.* along with the proposed tuber descriptors.

Table 1. Proposed qualitative morphological traits with their respective levels.

Character	Character levels
Tuber: Predominant Surface Color (PSC)	Yellowish white; Light yellow; Intense yellow; Orange yellow; Grayish red; Intense grayish red; Brown; Purple; Grayish purple; Black.
Tuber: Secondary Surface Color Distributed in Bands (CB)	Absent; Yellow; Light red; Red; Grayish red.
Tuber: Secondary Surface Color Distributed in Dots (CD)	Absent; Yellow; Light red; Red; Grayish red; Purple; Grayish purple; Black.
Tuber: Secondary Surface Color Distributed in Eyes (CE)	Absent; Light yellow; Yellow; Dark green; Light red; Red; Grayish red; Purple; Black.
Tuber: Predominant Pulp Color (PPC)	White; Yellowish white; Yellow; Yellow-orange; Purple.
Tuber: Secondary Cortex Color (CC)	Absent; Yellow; Light red; Grayish red; Brown; Purple.
Tuber: Secondary Vascular Ring Color (VRC)	Absent; Yellow; Purple.
Tuber: Secondary Pith Color (PC)	Absent; White; Grayish red; Purple.
Tuber: Tuber Shape (TS)	Conical; Fusiform conical; Fusiform cylindrical.
Tuber: Eye Depth (ED)	Slightly deep; Deep; Very deep.

3. Results and Discussion

The qualitative variables with the highest diversity index were the predominant surface color (PSC), secondary surface color distributed in eyes (CE), and principal pulp color (PPC). This trend was consistent in both the studied dataset and the one that included the accessions from Manrique et al. (2014), with indices ranging from 0.75 to 0.72 (**Table 3**). The variables with the lowest diversity index differed between the compared datasets. In the studied dataset, the variable with the lowest diversity was eye depth (ED), while in the inclusion of the accessions from Manrique et al. (2014), the variables related to secondary pulp color showed the lowest diversity: cortex color (CC), vascular ring color (VRC), and pith color (PC). The remaining variables exhibited a medium diversity index, averaging around 0.5.

Table 2. Assigned values to the proposed morphological characters.

Tuber color	Value
Absent	0
White	1
Yellowish white	2
Light yellow	3
Yellow	4
Intense yellow	5
Yellow orange	6
Orange yellow	7
Dark green	8
Light red	9
Red	10
Grayish red	11
Intense grayish red	12
Brown	13
Purple	14
Grayish purple	15
Black	16
Eye depth of the tuber	**Value**
Slightly deep	1
Deep	2
Very deep	3
Tuber shape	**Value**
Conical	1
Fusiform conical	2
Fusiform cylindrical	3

The principal component analysis (PCA) revealed that the first two dimensions explained most of the variance in the studied dataset, accounting for 60.8 % of the total variance (**Fig. 1**). In contrast, this share dropped to 46.1 % when including the accessions from Manrique *et al.* (2014) (**Fig. 2**). Furthermore, 9 and 10 dimensions were needed to account for 100 % of the variance in the studied dataset and when incorporating the accessions from Manrique *et al.* (2014), respectively. On the other hand, the variables that contributed the most to the first two dimensions in both datasets were cortex color (CC), secondary vascular ring color (VRC), and predominant surface color (PSC) (Fig. 2). However, they differ in that eye depth (ED) was one of the variables with the highest contribution for the studied dataset, while it was one of the least discriminative when including the accessions from Manrique *et al.* (2014).

Table 3. Simpson diversity indices for the cubio traits within the studied dataset plus accessions from Manrique *et al.* (2014).

Qualitative character	Morphological Diversity Index[1]	Morphological Diversity Index[2]
Tuber: Predominant Surface Color (PSC)	0.75	0.74
Tuber: Secondary Surface Color Distributed in Bands (CB)	0.56	0.49
Tuber: Secondary Surface Color Distributed in Dots (CD)	0.60	0.54
Tuber: Secondary Surface Color Distributed in Eyes (CE)	0.74	0.75
Tuber: Predominant Pulp Color (PPC)	0.68	0.72
Tuber: Secondary Cortex Color (CC)	0.56	0.27
Tuber: Secondary Vascular Ring Color (VRC)	0.50	0.32
Tuber: Secondary Pith Color (PC)	0.52	0.15
Tuber: Tuber Shape (TS)	0.60	0.55
Tuber: Eye Depth (ED)	0.24	0.53

[1] Studied dataset: 15 cubio accessions from Colombia and Bolivia.
[2] Studied dataset including cubio accessions from Manrique *et al.* (2014).

Conversely, predominant pulp color (PPC) was among the most discriminative variables for the dataset that included the accessions from Manrique *et al.* (2014), whereas it ranked sixth in importance for the studied dataset. In both cases, tuber shape was a variable with a lower contribution to both dimensions. Further details are provided in Supplementary material 3.

The results of PCA analysis of the 15 cubio accessions from Colombia and Bolivia, identifying three distinct clusters (Fig. 1). The first cluster is characterized by individuals with surface and pulp colors ranging from yellowish white to orange yellow, with no secondary color present in the pulp. The second cluster includes individuals with a surface color from yellowish white to light yellow, pulp exhibiting shades of grayish red to purple, and eyes varying from purple to black. Finally, the third cluster comprises individuals with surface colors ranging from purple to black, pulp with shades of grayish red to purple, red bands, a predominant pulp color of white, slightly deep eyes, and a fusiform conical shape.

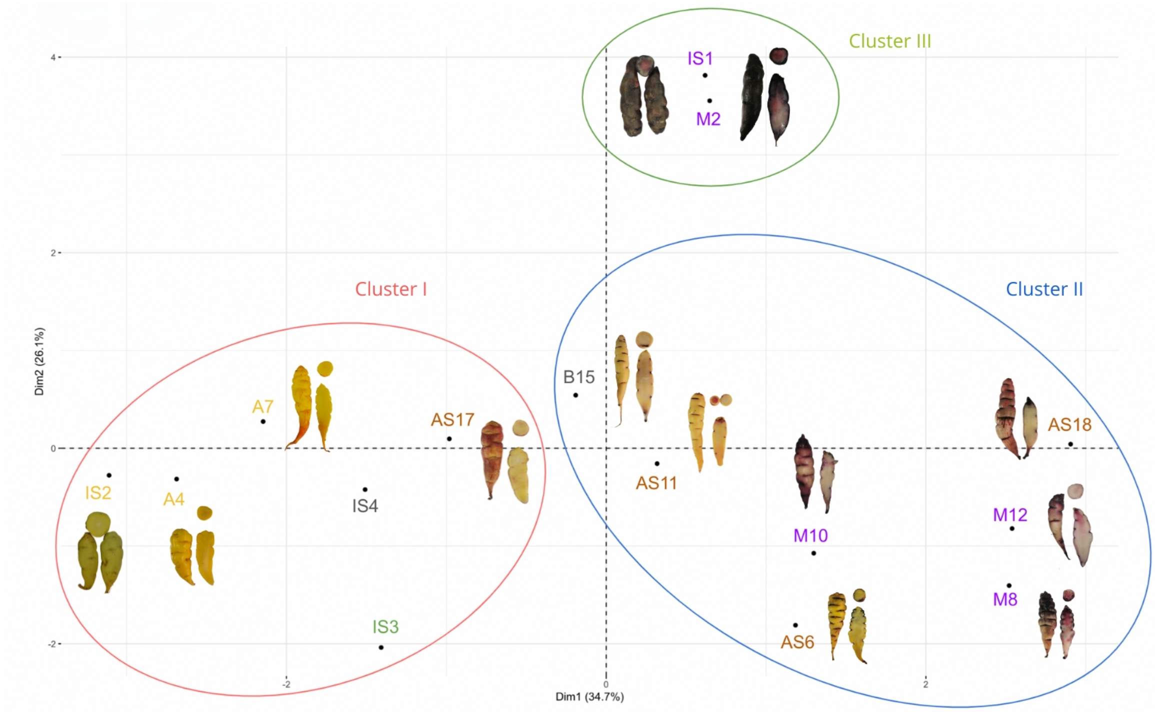

Figure 1. Principal Component Analysis (PCA) based on the morphological characterization of the tubers from the 15 cubio accessions under study, originating from Colombia and Bolivia.

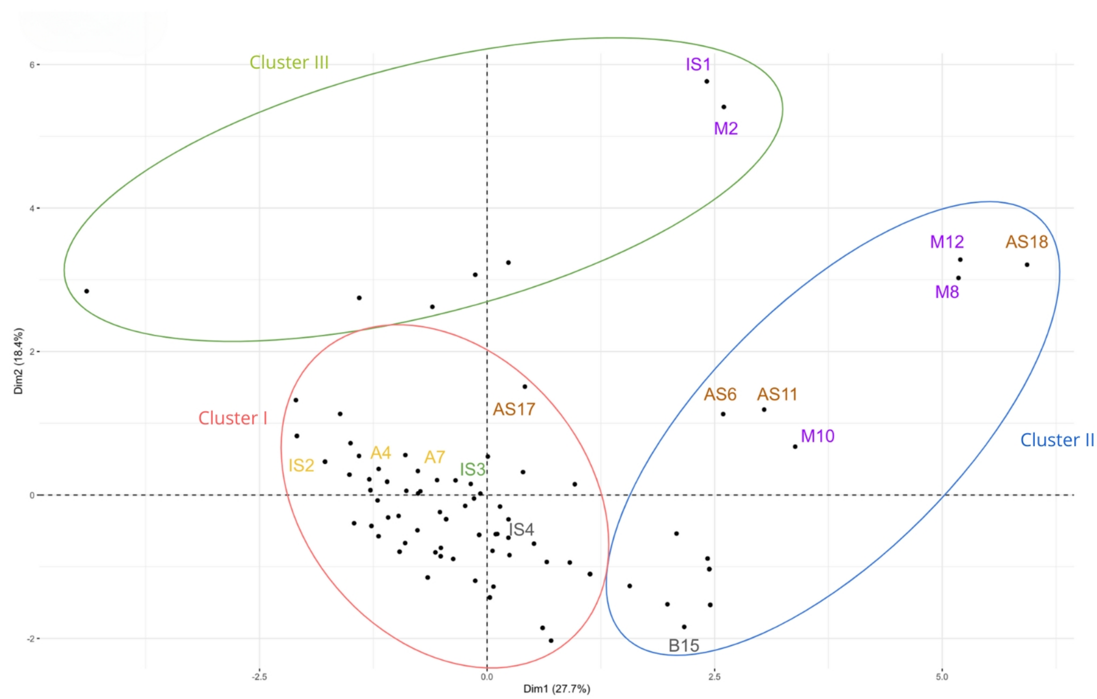

Figure 2. Principal Component Analysis (PCA) based on the morphological characterization 15 cubio accessions under study, originating from Colombia and Bolivia, plus 107 accessions from Manrique *et al.* (2014).

By including the accessions from Manrique *et al*. (2014), for a total of 122 analyzed accessions, three clusters very similar to those previously mentioned are identified, resulting in a consistent grouping of the accessions under study (Fig. 2). In the first cluster, morphotypes with a predominant surface color ranging from yellowish white to orange-yellow with no secondary color in the pulp are found. The second cluster grouped cubios with a predominant surface color ranging from yellowish white to light yellow, featuring secondary vascular ring colors in purple tones and eye colors varying from black to light red. Finally, the third cluster consisted of morphotypes with a predominant surface color ranging from black to grayish red, with no secondary color on the surface distributed in dots.

On the other hand, the hierarchical clustering analysis placed the 15 accessions into different morphotypes, identifying four distinct clusters (**Fig. 3**). The morphotypes in the first cluster exhibited a primary surface color ranging from yellowish white to light yellow. These accessions had grayish and purple-to-black eyes and spots, while the cortex and vascular ring had a purple hue, and their shape was fusiform-conical. The second cluster included individuals with surface colors ranging from purple to black, with red bands.

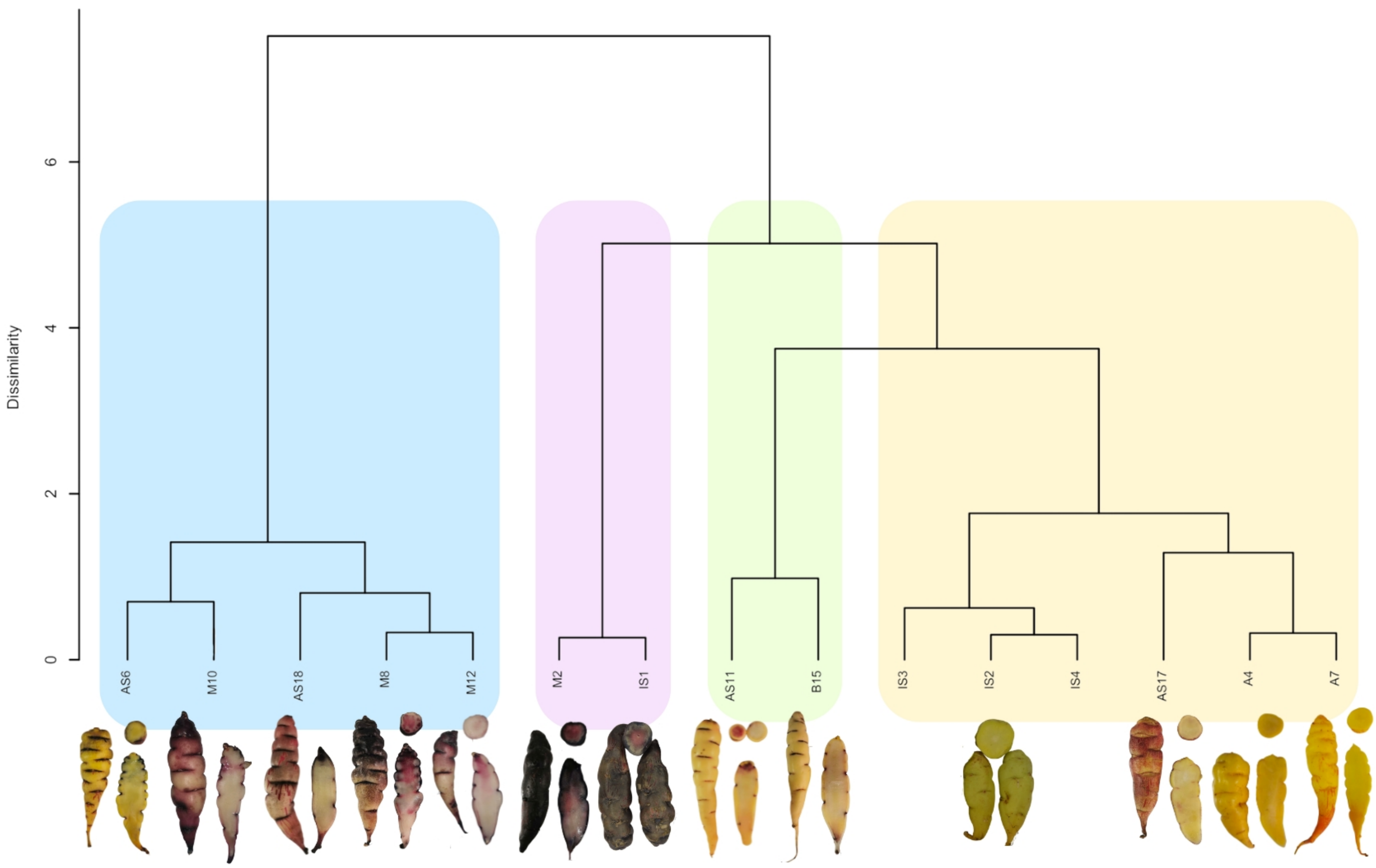

Figure 3. Hierarchical clustering analysis based on the morphological characterization of the tubers from the 15 cubio accessions under study, originating from Colombia and Bolivia. The ward clustering method and squared Euclidean distance were used.

The primary pulp color was white, while the secondary color varied between grayish-red and purple. These individuals had slightly deep eyes and a fusiform conical shape. The third cluster contained cubios showing a primary surface color ranging from yellowish white to light yellow, without spots or secondary band coloration. Their eyes were purple, the primary pulp color was white, and both the cortex and vascular ring exhibited a purple tone. The fourth cluster included morphotypes with primary surface colors varying from a yellowish-white to an orange-yellow hue and without a secondary pulp color. This grouping was consistent with the PCA-derived clusters; cluster I aligned with cluster II of the PCA, except for morphotypes B15 and AS11, which are included in cluster III. Additionally, clusters II and IV corresponded to clusters III and I of the PCA, respectively.

Following the inclusion of Manrique *et al*. (2014) accessions, the hierarchical clustering analysis differentiated six clusters (**Fig. 4**). The first cluster encompassed cubio accessions with a primary surface color ranging from intense yellow to black, while their pulp exhibited a primary tone from yellowish white to yellow-orange, with a secondary cortex hue ranging from light red to purple. The second cluster grouped morphotypes with yellowish-white to yellow-orange primary surface colors, no secondary pulp hues, deep eyed and a fusiform conical tuber shape.

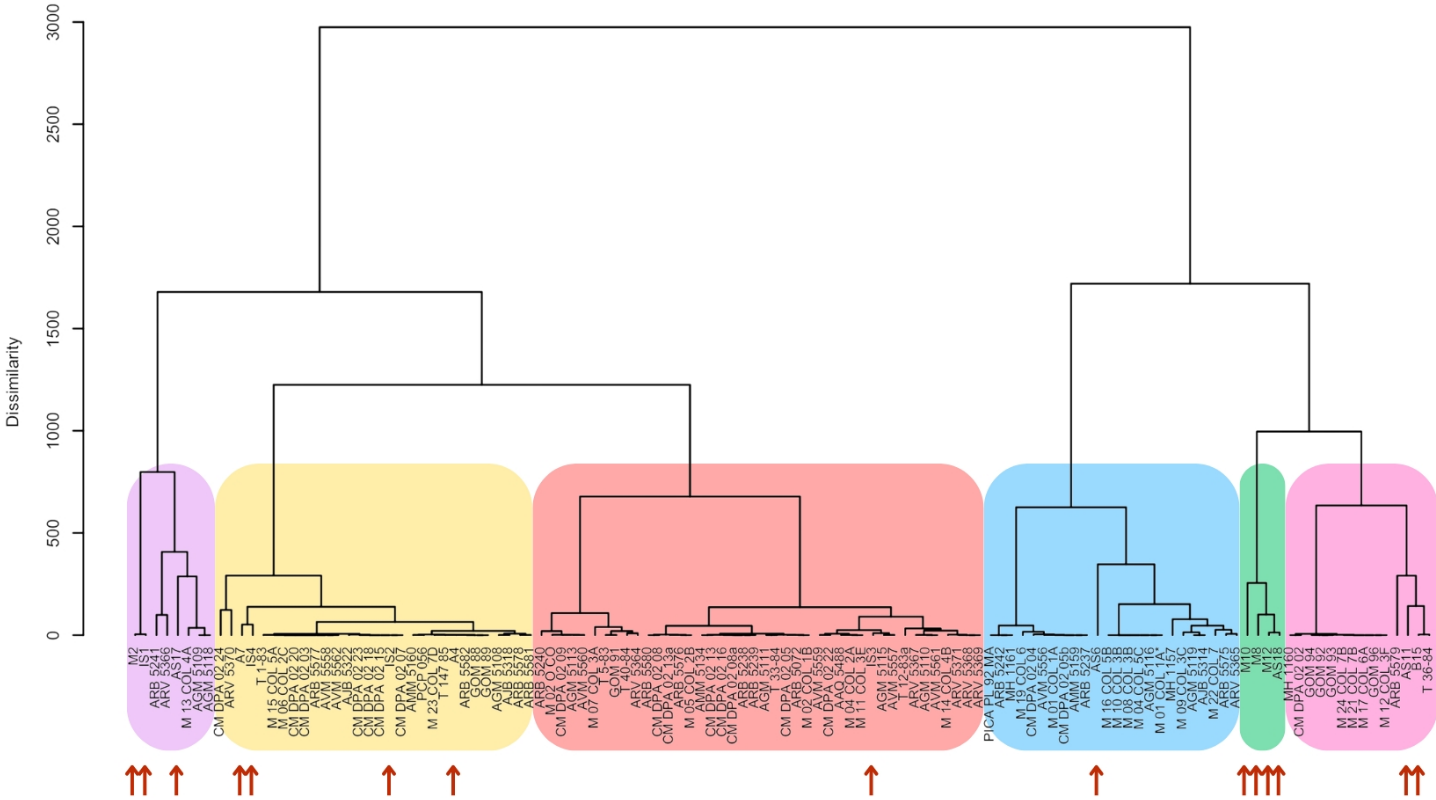

Figure 4. Hierarchical clustering analysis based on the morphological characterization of the tubers from the 15 cubio accessions under study, originating from Colombia and Bolivia (marked with red arrows) plus the accessions from Manrique *et al*. (2014). Ward clustering method and squared Euclidean distance were employed.

The accessions in the third cluster exhibited light-yellow to yellow-orange primary surface hues, eyes in dark green, red, or purple tones, and primary pulp colors ranging from white to yellow-orange without secondary pulp hues. The fourth cluster included accessions with primary surface colors from intense yellow to light yellow, featuring bands, spots, and eyes in tones from red to black and primary pulp colors from yellowish-white to yellow without secondary hues. The fifth cluster included yellowish-white cubios with purple to grayish-purple spots and eyes, primary pulp colors from white to yellowish-white, and a purple cortex and pith. Similar to the previous case, the identified clusters agreed with those from the PCA. Cluster I correspond to Cluster III of the PCA, but it includes morphotype AS17. Clusters II and III, which encompass morphotypes with yellow surface coloration and no secondary color, correspond to Cluster I of the PCA, excluding morphotype AS17. Finally, Clusters IV, V, and VI, which present yellow coloration with secondary pulp color, correspond to Cluster II of the PCA.

Our work revealed notable similarities among the outcomes of the diversity index, PCA analyses, and hierarchical clustering of the accessions from our collection, as well as the entire dataset obtained by adding the accessions analyzed by Manrique *et al.* (2014). This agreement reinforces the validity of the proposed morphological traits and the values assigned to each character level for conducting the corresponding statistical analyses. This is true despite the limited sample size of Colombia and Bolivia morphotypes and the inherent subjectivity in characterization that may be linked to the evaluator. Thus, the consistency observed between the studied dataset and the accessions of Manrique *et al.* (2014) supports the robustness of our findings. Furthermore, the morphological traits initially proposed by Manrique *et al.*, along with the suggested modifications in this study, may be particularly advantageous for landrace characterization by local farmers, as they do not require specialized knowledge for their implementation. This accessibility can encourage the adoption of these traits in practices and agricultural settings. As previously noted, assessing morphological diversity can provide valuable insights into genetic diversity, which is essential for breeding programs and *in-situ* conservation initiatives led by farmers.

All cubio accessions from Colombia and Bolivia were successfully differentiated as distinct morphotypes using solely tuber-related traits. This result suggests their usefulness in *T. tuberosum* morphological diversity analyses, which aligns with previous studies that support the idea that qualitative variables of tubers are better for characterizing varieties than quantitative and qualitative data related to foliage and stems, which are relatively homogeneous among morphotypes [21, 22]. Among the most discriminating qualitative traits of the tuber in this study are cortex color (CC), secondary color of the vascular ring (VRC), primary surface color (PSC), primary pulp color (PPC), and eye depth (ED). This result is partially supported by the work of Fonseca-Hernández and Márquez-Cardona (2024), who suggest that qualitative tuber traits, such as eye depth, predominant surface color, and secondary surface color, explain 74 % of the variation [11]. It is also observed that tuber shape (F) is one of the least discriminating traits in both this and previous studies (Fonseca-Hernández and Márquez-Cardona, 2024).

Having determined that each accession is a distinct morphotype also underscores ample morphological diversity present in the tubers within the species. This observation aligns with reported high morphological variability in cubios [7, 11, 21], as evidenced by the low number of duplicated morphotypes following hierarchical clustering on morphological traits. Likewise, most morphotypes correspond to yellow-orange shades, a finding also observed in studies conducted by Quispe *et al.* (2021) [21]. These shades tend to vary less among themselves compared to morphotypes with darker coloration. This pattern suggests ongoing selection for yellow-orange varieties likely exerted by communities due to consumption preferences. These varieties exhibit more acceptable organoleptic properties, with less bitter flavors due to their lower polyphenol content, compared to varieties with darker shades [23, 24]. However, this aspect has not yet been the subject of study, making it an interesting opportunity for research.

The notable phenotypic variability in terms of morphological characteristics reflects adaptations to different environmental conditions, evolutionary histories, or genetic influences. Given the uncertain traceability of the morphotypes under study, it was not possible to relate the morphological diversity of the samples to their original environmental conditions. However, exploring this relationship could be a valuable approach for future studies. Previous findings have reported adaptive morphological and metabolic traits in cubios in response to different environmental settings. For instance, Valle-Parra *et al.* (2020) carried out a morphological and metabolic characterization of six ecotypes of cubios, successfully differentiating between them [22]. This suggests that the adaptation of a population to a specific region entails changes in metabolic profile and morphological appearance. Similarly, studies on potatoes (*S. tuberosum*, Solanaceae) have reported differences in tuber morphological characteristics between plants exposed to different environmental conditions, highlighting the influence of environment variables in some morphological traits within a given accession. Although this source of variability has been controlled in our study, it highlights the evolutionary dimension of these morphological traits in terms of adaptation and phenotypic plasticity. For instance, Wurr *et al.* (2001) observed that cooler and wetter conditions in the early days before tuber growth were associated with potatoes that were longer, heavier, and had a greater number of buds [25]. Moreover, according to Edriss *et al.* (2020), soil compaction has a negative correlation with tuber width, length, and thickness [26]. Additionally, adaptive traits to altitude, along with increased ultraviolet radiation, are associated with higher levels of phenolic compounds while also resulting in a decrease in yield in potato species (*Solanum kurtzianum*, Solanaceae) from elevated altitudes [27].

Cubios generally exhibit intermediate to high genetic diversity [8, 11, 28]. This high genetic variability can be attributed to several factors, such as its ability to produce abundant seeds, hybridization processes among varieties, the presence of wild subspecies, the various uses of the tuber, and its conservation by peasant communities. As expected, greater genetic diversity can lead to increased morphological diversity. This variation in morphology may manifest in different traits such as size, shape, and color, which can enhance a population's adaptability to fluctuating environmental conditions. In potatoes (*S. tuberosum*, Solanaceae), several quantitative trait loci (QTLs) are associated with specific morphological traits, such as flesh color and tuber shape [29, 30]. This provides evidence of how genetic variability translates into phenotypic differences.

4. Conclusions

This study revealed notable agreement between the outcomes of the morphological diversity index and clustering analyses on the morphological traits of 15 cubio accessions (*T. tuberosum*) from Colombia and Bolivia and from a larger dataset resulting from adding accessions from Manrique *et al*. (2014). This similarity is particularly significant given the limited sample size, which validates these regions as microcenters of diversity for this tuber species. Such agreement reinforces the validity of the proposed morphological traits and the values assigned to each character level for conducting the corresponding statistical analyses.

Each cubio accession was discriminated as a distinct morphotype based solely on tuber-related traits, highlighting their practical use for initial germplasm or seed classification and promoting in-situ conservation strategies for this orphan crop. This finding also emphasizes the broad morphological diversity of cubios, suggesting their adaptability to fluctuating environmental conditions and genetic influences, as supported by previous research on the subject.

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6. Conflict of Interest

The authors declare no conflicts of interest with respect to research, authorship, and/or publication of this article.

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Diversidad morfológica del tubérculo de cubio (*Tropaeolum tuberosum*, Tropaeolaceae) en Colombia y Bolivia

Resumen: *Tropaeolum tuberosum*, conocido comúnmente como cubio, mashua o isaño, es un cultivo subutilizado que forma parte del grupo de los tubérculos andinos. Los cubios presentan una amplia variabilidad genética y morfológica, siendo los tubérculos el órgano con mayor diversidad observable. La caracterización morfológica es una herramienta fundamental para evaluar la diversidad genética del cubio y representa el primer paso crucial en la clasificación del germoplasma. Además, cumple un papel determinante en las prácticas de conservación *in situ* llevadas a cabo por las comunidades campesinas. Por ello, el objetivo de este estudio fue explorar la diversidad morfológica de 15 accesiones de tubérculos de cubio provenientes de Colombia y Bolivia, y validar los hallazgos comparándolos con accesiones previamente publicadas. Con base en descriptores morfológicos del tubérculo, calculamos el índice de diversidad y realizamos análisis de componentes principales (ACP) y de agrupamiento sobre dos conjuntos de datos: (i) un conjunto compuesto por morfotipos de cubios provenientes de Colombia y Bolivia, y (ii) un conjunto ampliado que incluye esos mismos morfotipos junto con datos de cubios previamente reportados en la literatura. Se encontraron similitudes tanto en el índice de diversidad morfológica como en el agrupamiento de morfotipos entre ambos conjuntos de datos, lo que refuerza la validez de los rasgos morfológicos propuestos, a pesar del tamaño limitado de las muestras y de la subjetividad inherente a la caracterización. Todas las accesiones fueron clasificadas exitosamente como morfotipos distintos, lo que evidencia la amplia variación morfológica existente en los cubios. Esta variación refleja una amplia diversidad genética subyacente en la especie y resalta su capacidad de adaptación a condiciones ambientales cambiantes.

Palabras Clave: Cubio; diversidad; isaño; mashua; morfotipos de cultivos; tubérculos andinos.

Diversidade morfológica do tubérculo de cubio (*Tropaeolum tuberosum*, Tropaeolaceae) na Colômbia e na Bolívia

Resumo: *Tropaeolum tuberosum*, conhecido popularmente como cubio, mashua ou isaño, é uma cultura subutilizada que faz parte do grupo dos tubérculos andinos. Os cubios apresentam ampla variabilidade genética e morfológica, sendo os tubérculos os órgãos com maior diversidade observável. A caracterização morfológica é uma ferramenta fundamental para avaliar a diversidade genética do cubio e representa a primeira etapa crucial na classificação de germoplasma. Além disso, desempenha um papel determinante nas práticas de conservação *in situ* realizadas pelas comunidades agrícolas. Neste contexto, o objetivo deste estudo foi investigar a diversidade morfológica de 15 acessos de tubérculos de cubio originários da Colômbia e da Bolívia, e validar os resultados comparando-os com acessos previamente publicados. Com base em descritores morfológicos dos tubérculos, calculamos o índice de diversidade e realizamos análises de componentes principais (PCA) e de agrupamento em dois conjuntos de dados: (i) um conjunto composto por morfotipos de cubios da Colômbia e da Bolívia, e (ii) um conjunto ampliado que inclui esses mesmos morfotipos junto com dados de cubios previamente relatados na literatura. Foram observadas semelhanças tanto no índice de diversidade morfológica quanto na formação dos grupos de morfotipos entre os dois conjuntos, o que reforça a validade dos descritores morfológicos propostos, apesar do número limitado de amostras e da subjetividade inerente à caracterização. Todos os acessos foram classificados com sucesso como morfotipos diferentes, evidenciando a ampla variação morfológica existente entre os cubios. Essa variação reflete uma grande diversidade genética subjacente à especie e destaca sua capacidade de adaptação a diferentes condições ambientais.

Palavras-chave: Cubio; diversidade; isaño; mashua; morfotipos de cultivos; tubérculos andinos.

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