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Agromorphological Characterization of Native Potato Cultivars (*Solanum tuberosum* L.) in Puno

Caracterización agromorfológica de cultivares de papas nativas (*Solanum tuberosum* L.) en Puno

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Abstract

Potato (*Solanum tuberosum* L.) is the third most important food crop worldwide and a primary staple food. Its high global production justifies the present study. The objective was to perform an agromorphological characterization of native potato cultivars to identify essential phenotypic patterns for the preservation of agrobiodiversity and genetic improvement. A total of 125 native potato cultivars were evaluated using 21 standardized qualitative and quantitative descriptors established by Bioversity International, including growth habit, leaf morphology, floral traits, and tuber characteristics. Four distinct phenotypic groups were identified: Group I (32%) with erect growth habit; Group II (54%) with semi-erect habit; Group III (13%) with decumbent habit; and Group IV (1%) with semi-rosette habit. Stem pigmentation was green (58%), green with pigmented spots (28%), and fully pigmented (14%). Floral morphology was rotate (42%), pentagonal (38%), and semi-star-shaped (20%). Petal coloration was lilac/purple (48%), light blue/white (36%), and pinkish red (16%). Tuber shape was round (31%), ovate (27%), and compressed (18%). Flesh color was white (44%), yellow (32%), and purple (24%). Finally, a phylogenetic tree and principal component analysis (PCA) were developed, revealing high homogeneity within the native potato cultivars (Group 1) and divergent outlier values (Groups 2, 3, and 4), highlighting the need for integrated analyses to explore genetic diversity.

Keywords: agromorphological, genetic diversity, ovate, pigmented.

Resumen

La papa (*Solanum tuberosum* L.) es el tercer cultivo alimenticio más importante del planeta y un producto básico esencial; su alta producción global justifica el presente estudio. El objetivo fue caracterizar agromorfológicamente cultivares de papas nativas, con la finalidad de detectar patrones fenotípicos esenciales para la preservación de la agrobiodiversidad y el mejoramiento genético. Se evaluaron 125 cultivares de papas nativas mediante 21 descriptores cualitativos y cuantitativos estandarizados por Bioversity International, que incluyeron el hábito de crecimiento, la morfología foliar y floral, y las características de los tubérculos. Se identificaron cuatro grupos fenotípicos distintos: grupo I (32 %) con hábito de crecimiento erecto; grupo II (54 %) con hábito semierecto; grupo III (13 %) con hábito decumbente; y grupo IV (1 %) con crecimiento semirrosetado. La pigmentación del tallo fue verde (58 %), verde con manchas pigmentadas (28 %) y totalmente pigmentada (14 %). La morfología floral fue rotada (42 %), pentagonal (38 %) y semiestrellada (20 %). La coloración de pétalos fue lila/morado (48 %), celeste/blanco (36 %) y rojo rosado (16 %). La forma de los tubérculos fue redonda (31 %), ovalada (27 %) y comprimida (18 %). El color de la pulpa fue blanco (44 %), amarillo (32 %) y morado (24 %). Finalmente, se desarrolló un árbol filogenético y un PCA que revelaron alta homogeneidad en el grupo 1 y valores atípicos divergentes (grupos 2, 3 y 4), lo que destaca la necesidad de análisis integrados para explorar la diversidad genética.

Palabras clave: agromorfológica, diversidad genética, ovalada, pigmentadas.

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Introduction

Potato (*Solanum tuberosum* L.) is the third most important food crop worldwide, after rice and wheat, with an estimated global production of 376 million tons (FAO, 2022). In South America, Peru is recognized as the center of origin and diversification of the potato, playing a key role in global food security. The country is the largest potato producer in Latin America, with an annual production of approximately 5.6 million tons (FAO, 2022; MINAGRI, 2023). Additionally, Peru hosts one of the greatest genetic diversities of native potatoes, with over 3,000 cataloged varieties, many cultivated in the Andean regions at altitudes above 3,800 meters above sea level (Zimmerer *et al*., 2019).

In the Puno region, located in the Peruvian highlands, potato is a fundamental crop for the subsistence of rural communities, accounting for approximately 15% of the national production (INEI, 2023). This region is notable for its native potato production, with over 400 identified varieties adapted to extreme climatic conditions such as frost and drought (Lüttringhaus *et al*., 2021). However, despite its importance, the average productivity in Puno is relatively low, ranging between 10 and 12 tons per

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hectare, compared to the national average of 14 to 16 tons per hectare. This situation is attributed to factors such as soil degradation, low adoption of agricultural technologies, proliferation of pests and diseases, and the impacts of climate change (MINAGRI, 2023).

Recent studies highlight that native potatoes from Puno possess high nutritional value, with elevated levels of anthocyanins, iron, and zinc, making them a strategic resource to combat malnutrition in rural areas (Bellumori *et al*., 2020). Additionally, their cultivation is associated with traditional agricultural systems, such as crop rotation, which contribute to environmental sustainability.

Despite their importance, native potatoes face several challenges, such as replacement by commercial varieties in urban areas, only 5% of consumption corresponds to native potatoes (INEI, 2023); loss of genetic diversity due to the disappearance of local varieties (Zimmerer *et al*., 2019), and impacts of climate change, including altered precipitation patterns and increased pest incidence. In this context, the agronomic characterization of native potatoes is essential for: (1) Identify varieties with the highest productive and nutritional potential. (2) Strengthen in situ and ex situ conservation strategies. (3) Promote public policies that encourage their cultivation and commercialization.

This study aims to contribute to the scientific knowledge of these varieties by providing updated data to support genetic improvement programs, conservation efforts, and the valorization of Andean agrobiodiversity.

Table 1

Native potato cultivars collected in the Ayapata district of the Puno region, 2025.

CODE	COMMON NAME	CODE	COMMON NAME	CODE	COMMON NAME
SIA001	Peruanita	**SIA045**	Enanito	**SIA108**	NN
SIA002	Cucasally	**SIA047**	Loccma	**SIA109**	NN
SIA005	Yawar wantacha	**SIA048**	Color unkhuña	**SIA110**	NN
SIA007	Puka Phjintikiña	SIA049	Hunu papa	**SIA111**	NN
SIA008	Lengua	SIA059	Alcca pumamaqui	**SIA112**	NN
SIA009	Yana Saly	SIA064	Alcca eqwello	**SIA113**	NN
SIA010	Puca Ch’upa	SIA066	Señora	SIA114	NN
SIA011	Puma Maqui	SIA067	Sumac sipas	SIA116	NN
SIA012	Yana Thoccocho	SIA068	Mactha lomo	SIA120	NN
SIA013	Yarac Chupa	SIA069	Ch’upa	SIA121	NN
SIA014	Kilhuana	SIA070	Rosascha	SIA123	NN
SIA016	Sali	SIA071	Thaclla	SIA128	K´anchalle
SIA017	Arroz Saly	SIA072	Khakaña	SIA130	Turkolomo
SIA018	Cuchillo Phaqui	SIA073	Pantipanti	SIA134	Yana tarma 2
SIA019	Khusi	SIA074	Saywa Chupa	SIA136	Puka jawilomo
SIA020	Mochoro	SIA076	Khuchi aka	SIA137	Q’osko papa
SIA021	Puka Chocllo	SIA077	Papa waycho	SIA139	K’usi
SIA022	Yurac Lomo	SIA078	Khausi lomo	SIA140	Ch’ucho lomo
SIA023	Ñawi Papa	SIA081	Kiysa	SIA144	Alka imilla
SIA024	Puka Ccolyllorkhi	SIA085	Soly	SIA145	Uma senk’a
SIA025	Añas silllo	SIA086	Chilcay warmi	SIA146	Yuraj chillka
SIA026	Puka Huallata	SIA087	Toccra Señora	SIA152	Yana huayro
SIA027	Oqhe Sacsa	SIA088	Ninfa	SIA155	Uank’usullu alka
SIA028	Algodón	**SIA089**	Achachi	SIA157	Yana t’umana
SIA029	Boly	**SIA090**	Jamankhay	SIA158	Yana ch’aki
SIA030	Puka Lontusa	**SIA091**	Alcca lacla	SIA160	Yana ukukiri
SIA031	Puca alcca phitikiña	**SIA092**	Qhosela	SIA161	Alk’a wayro
SIA032	Qheccorani	**SIA093**	Yurac lomo	SIA163	Arrusale
SIA033	Condor Mayllani	**SIA094**	Yurac chocllo	SIA164	Ucha lomo
SIA034	Suri Lomo	**SIA095**	Leqhe ronto	SIA165	Yana huanq’usullu
SIA035	Ccoyllorkhi	**SIA096**	Ñawi papa	SIA166	Mojre
SIA036	Suwa Machachi	**SIA097**	NN	SIA167	Yana Tajllachi
SIA037	Thomana	**SIA098**	NN	SIA168	Yana bola
SIA038	Mata Cura	**SIA099**	NN	SIA169	Yuraj wayro
SIA039	Puca alcca Kilhuana	**SIA100**	NN	**SIA170**	Zanahoria lomo
SIA040	Yana huallata	**SIA101**	NN	**SIA173**	Kajawiri
SIA041	Chiqhchi Lomo	**SIA102**	NN	**SIA175**	Alka thumana
SIA042	Puka alcca Eqhwello	**SIA103**	NN	**SIA176**	Jamank’ay
SIA043	Alcca tarma	**SIA104**	NN	**Agata**	Agata
SIA044	Yurac Phitikiña	**SIA105**	NN	**Varonesa**	Varonesa

Materials and Methods

This study employed a qualitative and quantitative approach with an explanatory scope, aiming to agromorphologically characterize native cultivars of *Solanum tuberosum* L. grown in the Puno Region. A total of 125 native cultivars were monitored under controlled conditions. The methodology was structured into three main stages: (1) sample collection, (2) agro-morphological evaluation, and (3) phylogenetic characterization (Ignacio-Cárdenas et al., 2022; *Lü*ttringhaus et al., 2021).

Plant material collection

The collection of native potato cultivars was conducted in the communities of Taype and Hanac Ayllu, located in the Ayapata district, Puno region (Table 1), based on criteria of diversity and cultural relevance. The identification and coding of the cultivars followed the protocol established by Bioversity International (BI). Subsequently, these cultivars were propagated under controlled conditions (greenhouse).

The alphanumeric codes assigned to the potato cultivars were established following a standardized identification system, in accordance with the international standards set by Bioversity International. These codes were generated within the framework of the study using the prefix "SIA": "SI" refers to *Solanum tuberosum* subsp. *andigenum* (native potato), "A" corresponds to the collection site, and the number indicates the sequential order within the study.

Agromorphological characterization

The evaluated traits of the 125 native potato cultivars included tuber skin shape and color, flesh color, number of eyes, growth habit, flower color, and leaf type. Observations were conducted under greenhouse conditions, following the standardized descriptors established by Bioversity International (2007) (Tables 2 and 3), throughout the plant's full phenological cycle.

Table 2
Selection of descriptors (Standardization protocols for the characterization of phylogenetic resources) for Solanum tuberosum

Category	Descriptor	Code IPGRI	States or Modalities
A. Plant Descriptors	Growth habit	HAB	Erect (30°), Semi-erect (45–60°), Decumbent (>60°), Semi-rosetted
	Main stem color	COL_STEM	Green, Green with pigmentation, Fully purple
	Leaf type	LF_TYPE	Elliptic, Lanceolate, Broadly elliptic, Ovate
B. floral Descriptors	Corolla shape	COR_SHAPE	Rotate, Pentagonal, Semi-stellate
	Primary flower color	FL_COL	Lilac, Purple, Light blue, White, Pinkish red
	Color distribution	FL_COL_DIST	Band on both sides, Star-shaped, Absent
C. Tuber Descriptors	Shape	TUB_SHAPE	Round, Ovate-oblong, Compressed, Oblong, Elliptic
	Eye depth	EYE_DEPTH	Shallow, Intermediate, Deep, Very deep
	Skin color	TUB_SKIN_COL	Red, Purple, Yellow, White-cream, Blackish
	Flesh color	TUB_FLESH_COL	White, Yellow, Cream, Purple, Red

Source: (Bioversity International, 2007)

Table 3
Evaluation Protocols for Solanum tuberosum

Stage	Activity	Description/Procedure
Stage 1: Material Preparation	Sampling	Five plants per cultivar were evaluated to reduce intra-specific variability.
	Controlled Conditions	Greenhouse: • Day temperature: 18–22°C • Night temperature: 12–15°C • Photoperiod: 12–14 h light
Stage 2: Trait Measurement	Growth habit	The insertion angle of the main stem was measured using a protractor (3 measurements per plant).
	Organ coloration	The Royal Horticultural Society (RHS) Color Chart was used to standardize descriptions.
	Tuber evaluation	Three mature tubers per plant were analyzed.
Stage 3: Rating Scales	Eye depth	An ordinal scale was used with the following parameters: 1 = Shallow (≤1 mm) 3 = Intermediate (1–3 mm) 5 = Deep (>3 mm)

Source: (Bioversity International, 2007)

Data Analysis

This study employed descriptive statistics. The collected data were stored in MS Excel spreadsheets and analyzed for the agromorphological characterization of potato cultivars.

Results and Discussion

Agromorphological Analysis of Potato Cultivars

According to the analysis, in terms of clustering and genetic diversity, the cultivars were characterized into four (4) groups (Table 4): Group I (Erect), Group II (Semi-erect), Group III (Decumbent), and Group IV (Semi-rosette). Among the 125 cultivars, frequencies based on growth habit (F3) showed a predominance of the semi-erect habit (54 %), followed by erect (32 %), decumbent (13 %), and semi-rosette (1 %). Zimmerer *et al.* (2019), in a previous study, also observed a predominance of semi-erect varieties (45–60°) at 56%, noting that semi-erect cultivars exhibit greater versatility in traditional cropping systems, which aligns with the findings of this study. Additionally, Ignacio-Cárdenas (2022) and Lüttringhaus *et al.* (2021) suggest that this selection is driven by human intervention due to the phenotypic plasticity of these varieties. The Ayapata district, where the samples were collected, offers favorable conditions for the cultivation and adaptation of these varieties, including high altitudes, presence of frost and drought, as well as low production costs.

Likewise, Ochoa (1999) and Ignacio-Cárdenas (2022) indicate that erect varieties (<45°), representing 30%, are susceptible to strong winds, which limits their cultivation in high-altitude areas. In contrast, decumbent varieties (>60°) and semi-rosette (<2%) exhibit typical traits of abiotic stress resistance. Muñoz *et al.* (2016), in a morphological study, reported similar results for erect varieties (31%), while Arcos *et al.* (2024) documented an erect habit of 29%, figures consistent with those found in the present study, suggesting that these varieties follow recurrent morphological patterns in the Andes. However, Alor *et al.* (2015) note that growth habit in potato crops does not always accurately reflect environmental adaptation, as varieties with similar morphologies may respond differently to stress. Additionally, Muñoz *et al.* (2016) mention that certain erect varieties in high-altitude areas show reduced frost resistance, calling into question the correlation between erect habit and performance across different altitudes.

Regarding nutraceutical value, Group 2, which includes tubers with yellow flesh, is associated with health benefits, as proposed by Alor *et al.* (2015). However, White *et al.* (2017) suggest that classification based solely on flesh color is broad and that other factors, such as biofortification and antioxidant content, should be considered. Concerning the purple potatoes in Group 3, Wegener and Jansen (2013) highlight their antioxidant properties; however, they also note that their susceptibility to water stress limits their commercial viability in certain high Andean regions.

In the analysis of stem color (CT^5), green predominated at 58 %, with the presence of dark pigmentation or spots in some genotypes, such as varieties SIA008 and SIA025. Additionally, green stems with pigmentation accounted for 28 %, and fully pigmented stems for 14 %, mainly observed in erect and decumbent groups, displaying purple pigmentation (Table 4). Brown (2005) and Stushnoff *et al.* (2008) associated this pigmentation with traits specific to native potatoes, while Navarre *et al.* (2010) reported variations in anthocyanin content, noting that these are not always visible in green stems.

Regarding flower shape (FF6), 42 % of the cultivars exhibited rotate corollas, which are mainly associated with insect pollination, predominantly found in semi-erect varieties such as SIA030. Pentagonal corollas accounted for 38 %, more frequent in erect varieties, while semi-star-shaped corollas made up 20 %. In terms of flower color, lilac/purple predominated (48 %), followed by sky blue/white (36 %) and pinkish red (16 %), with varying intensities from intermediate to pale. The high prevalence of lilac/purple tones is linked to anthocyanins, antioxidant compounds induced by UV radiation, as noted by Shahidi *et al.* (2006). Sky blue and white tones, common in areas with moderate UV stress, represented 36 %, whereas pinkish red tones, associated with lycopene and responsible for antioxidant protection, accounted for 16 %, as reported by Reátegui *et a*l. (2019). These biochemical and morphological patterns reflect the adaptation of native potatoes to the ecological gradients of the Andes and highlight the importance of pollination and bioactive compounds in the evolution and conservation of these species, as emphasized by Wu *et al.* (2004).

Regarding tubers (FT8), in terms of shape, round tubers predominated (31 %), mainly in erect varieties, followed by ovate-rounded (27 %) in semi-erect types, and compressed (18%). Regarding flesh color, white (44%) with low antioxidant content, yellow (32%) rich in carotenoids, and purple (24%) rich in anthocyanins were the most common. Most tubers exhibited medium eye depth (45%) across all groups. The tuber shapes varied, with round and ovate-rounded forms dominating, consistent with Alor *et al.* (2015), but contrasting with Bautista (2023), who reported elongated tubers as most common in Andean varieties. Flesh colors included yellow, linked to carotenoids (32%), and purple, rich in anthocyanins (24%), as noted by Stushnoff *et al.*

Table 4

Summary Table of the Agromorphological Classification of Native Potato Genotypes Based on Data from 125 Cultivars (Bioversity International, 2007).

G[1]	H[2]	F[3]	CULTIVARS[4]	CT[5]	FF[6]	CF[7]	FT[8]	CP[9]
1	Erect (<45°)	32% (40)	SIA002, SIA005, SIA008, SIA011, SIA014, SIA022, SIA024, SIA027, SIA028, SIA045, SIA066, SIA067, SIA068, SIA069, SIA070, SIA071, SIA072, SIA073, SIA078, SIA085, SIA092, SIA094, SIA095, SIA124, SIA134, SIA144, SIA163, SIA164, SIA165, SIA170, SIA173, SIA175, SIA176	Green (58%)	Pentagonal 38%	Lilac/Purple 48%	Round 31%	White 35%
2	Semi-Erect (45-60°)	54% (68)	SIA001, SIA007, SIA009, SIA012, SIA013, SIA016, SIA017, SIA018, SIA019, SIA021, SIA023, SIA026, SIA029, SIA030, SIA032, SIA033, SIA034, SIA035, SIA036, SIA037, SIA038, SIA039, SIA041, SIA042, SIA043, SIA047, SIA048, SIA059, SIA064, SIA074, SIA076, SIA077, SIA081, SIA086, SIA087, SIA088, SIA089, SIA090, SIA091, SIA097, SIA098, SIA099, SIA101, SIA103, SIA105, SIA109, SIA110, SIA113, SIA114, SIA123, SIA130, SIA136, SIA137, SIA139, SIA140, SIA145, SIA152, SIA155, SIA157, SIA158, SIA161, SIA166, SIA168, SIA169, AGATHA, VARONESA	Green with pigmentation (28%)	Rotate 42%	Light blue/ White 36%	Ovate-oblong 27%	Yellow 32%
3	Decumbent (>60°)	13% (16)	SIA010, SIA020, SIA025, SIA031, SIA040, SIA044, SIA049, SIA093, SIA096, SIA100, SIA102, SIA104, SIA108, SIA111, SIA112, SIA120, SIA121, SIA128, SIA146	Fully pigmented (14%)	Semi-stellate 20%	Pinkish red 16%	Compressed 18%	Purple 24%
4	Semi-rosetted	1% (2)	SIA116, SIA167	Mostly pigmented	Pentagonal	Purple	Oblong	Cream 9%

Note: Group (G1); Growth habit (H2); Frequency (F3); Cultivars (C4); Stem color (CT5); Flower shape (FF6); Flower color (CF7); Tuber shape (FT8); Flesh color (CP9).

(2008), demonstrating the nutritional diversity of native potatoes. These patterns reflect the influence of ecological adaptation and domestication on potato morphology, with important implications for breeding and conservation strategies.

Phenotypic Patterns

Four main categories have been identified (Table 5), based on the growth habit of native potato. The erect habit (32 %) (Figure 1C) is characterized by rigidly inserted stems and ascending leaves that enhance sunlight capture, associated with pentagonal flowers and round tubers. This group is found in inter-Andean valleys and exhibits high photosynthetic efficiency, although it is susceptible to strong winds. The semi-erect habit (54 %) (Figure 1A) combines efficient light capture with lodging resistance, displaying phenotypic plasticity and notable genetic diversity within the group, making it valuable for breeding programs. The decumbent habit (13 %) (Figure 1D) is distinguished by its prostrate growth, deep roots, and adaptation to steep slopes, maintaining stability under marginal conditions despite low productivity. Finally, the semi-rosette habit (1 %) (Figure 1B) exhibits extremophilic traits and frost tolerance, with significant genetic potential for cold resistance.

According to this analysis, considerable morphological and adaptive variability was revealed in the present study. Erect habit varieties enhance light absorption and are predominant in inter-Andean valleys; the semi-erect habit exhibits broad phenotypic plasticity and intra-group diversity; the decumbent habit shows adaptations to marginal environments with productive stability; and the semi-rosette habit stands out in extreme environments. These observations corroborate the structural variability identified among the different plant forms. The study by Soto *et al*. (2013) in the Central Andes reported low genetic diversity contrasted with

Table 5

Categorization of Phenotypic Patterns of Potato Cultivars According to Their Growth Habit.

Habit	Frecuency	Representative Varieties	Associated Characteristics
Erect (30°)	32% (40)	SIA002, SIA067, SIA144	Leaves are upright. Rigid stems (<45°). Greater sunlight exposure (Huamán *et al*., 2000).
Semi-Erect (45–60°)	54% (68)	SIA030, SIA110, AGATHA	Balance between productive efficiency and wind resistance (CIP, 2021).
Decumbent (>60°)	13% (16)	SIA025, SIA112, SIA128	Adapted to marginal lands. Prostrate stems help prevent water stress (Ochoa, 1999).
Semi-rosetted	1% (2)	SIA113, SIA167	Dense basal leaves, frequent at high altitudes (Andre *et al*., 2007).

Figure 1

Photographs of Potato Cultivars According to Their Growth Habit; A) Semi-erect; B) Semi-rosette; C) Erect; D) Decumbent.

high phenotypic diversity, aligning with our findings of morphophysiological adaptations to environmental gradients. Finally, Remón G*amboa* and Peña Rojas (2018) indicate that due to high levels of polymorphism and provenance diversity, there is a need to characterize genetics and growth habit traits to support conservation and breeding programs.

Stem Pigmentation

Stem pigmentation (Table 6) shows adaptive variations linked to environmental conditions. Green stems (58%) (Figure 1A) predominate in frequency and are associated with reduced anthocyanin production, adapting better to temperate zones where UV radiation and low-temperature stress are moderate. Green stems with pigmentation (28%) (Figure 1B) exhibit purple or reddish streaks, generally linked to increased resistance to solar radiation at high altitudes. Lastly, predominantly pigmented stems (14%) (Figure 1C) display uniform purple or red coloration, associated with high frost tolerance due to the accumulation of anthocyanins as antioxidants. The low frequency of this pigmentation indicates adaptation to extreme cold conditions, typical of areas located above 3,500 meters above sea level.

There are marked differences between the data reported by Bautista (2023), who recorded a higher frequency of green stems with few spots (33.8%), followed by fully green stems and green stems with many spots, both at 19.1%. Lower proportions included reddish stems (5.9%), purple stems (4.4%), and stems heavily pigmented with green (1.5%). These findings suggest that, although the present study observed a higher incidence of pigmentation, Bautista identified a predominance of less pigmented forms, indicating possible environmental or genetic differences between populations. Brown (2005), on the other hand, found 58% green stems and 42% pigmented stems, partially aligning with the current results. This slight discrepancy in pigmented green stems may be due to Brown's inclusion of germplasm bank collections, whereas our research focused on in situ cultivated varieties. Additionally, Navarre *et al.* (2010) and Brown (2005) indicate that genotypes with low anthocyanin synthesis are better adapted to temperate zones.

Table 6

Classification of Potato Cultivars According to Stem Pigmentation.

Color	Frequency	Implications
Green	58% (73)	Reduced anthocyanin synthesis. Predominates in temperate zones (Andre *et al*., 2007).
Green with pigmented spots	28% (35)	With purple/reddish streaks. UV resistant (Brown, 2005).
Fully pigmented	14% (17)	Stems are purple/red. High frost tolerance (Navarre *et al*., 2010).

Figure 2

Potato cultivars according to stem pigmentation; A) Green; B) Green with pigmented spots; C) Pigmented with green spots; D) Mostly pigmented.

Fully pigmented stems, exhibiting a uniform purple or red hue, are associated with high frost tolerance due to the accumulation of anthocyanins acting as antioxidants. Molecular studies by authors such as Stushnoff *et al.* (2008) indicate that UV-B radiation exposure on stems and leaves of potato plants can stimulate anthocyanin accumulation in the tubers. This supports the analysis presented in this study, suggesting that stem pigmentation is an environmentally induced response.

Floral Morphology

According to flower morphology (Table 7), various features are observed related to pollination mechanisms and the presence of bioactive compounds. Regarding corolla shape, most cultivars exhibit rotate corollas (42%) (Figure 3C), with characteristics that attract bees. The pentagonal shape (38%) (Figure 3A) is linked to anemophilous pollination mechanisms (wind pollination), while semi-star-shaped corollas, with a lower frequency (20%) (Figure 3B), are common in high-Andean cultivars. Bautista (2023) reported similar frequencies for corolla shape: rotate and very rotate (66.2% and 13.2%, respectively), pentagonal (20.6%), and a low frequency of very rotate corollas (13.2%).

Regarding flower coloration, 48% of the flowers exhibit lilac or purple tones, associated with the presence of anthocyanins; 36% display white or sky blue hues, with low pigment content; and the remaining 16% show red or pink shades, linked to lycopene. Zevallos *et al.* (2023), in a study evaluating 80 native potato ecotypes, reported lilac or purple flowers at 51%, white or sky blue at 20%, and red or pink at 25.1%. Bautista (2023), meanwhile, found lilac (38.2%), purple (36.8%), white (11%), and pink (10.3%) colors, showing some differences in results. Regarding corolla shape, some authors, such as Bautista (2023), report a higher percentage of rotate corollas, while other data indicate lower values. There are also discrepancies in the proportions of pentagonal and semi-star-shaped corollas, possibly linked to ecological factors, altitude, categorization methods, or local genetic diversity. Concerning flower coloration, lilac and purple tones predominate, associated with anthocyanins, although percentages vary between studies. For example, Zevallos *et al.* (2023) report 51% lilac or purple flowers, whereas Bautista records 38.2 % lilac and 36.8 % purple flowers. Additionally, white and pink flowers appear in varying proportions, suggesting the influence of environmental conditions and methodologies used for recording. The observed diversity highlights the genetic richness of Andean varieties and underscores the importance of standardizing morphological criteria to facilitate comparative studies and conservation programs.

Table 7

Classification of Potato Cultivars According to Floral Morphology.

BY COROLLA SHAPE			BASED ON COLORATION		
Corolla Shape	**Frecuency**	**Pollination Relationship**	**Primary Color**	**Frequency**	**Compounds**
Rotate	42% (53)	Attracts bees	Lilac/Purple	48% (60)	Anthocyanins Andre *et al.* (2007)
Pentagonal	38% (48)	Wind-assisted pollination	Light Blue/White	36% (45)	Low pigmentation Zhang, *et al*. (2020)
Semi stellate	20% (25)	Intermediate; common in high Andean genotypes	Pinkish Red	16% (20)	Bright red carotenoid Fernandez *et al*. (2013)

Figure 3

Potato Cultivars According to Their Floral Morphology; A) Pentagonal; B) Semi-star-shaped; C) Rotate; D) Star-shaped

Tuber Morphology

The information presented in Table 8 shows a variety of shapes and colors among potato cultivars, which impacts their potential uses and content of bioactive compounds. Regarding shape, round tubers account for 31 % and are ideal for the industrial sector due to their ease of peeling; ovate-rounded tubers (27 %) are preferred for fresh consumption because of their attractive shape; and compressed tubers (18 %) are suitable for processing. Regarding flesh color, 44 % of tubers have white flesh, associated with low antioxidant content; 32 % display yellow flesh, rich in carotenoids; and 24 % show purple flesh, with high levels of anthocyanins, compounds recognized for their antioxidant properties and benefits to human health.

In another study, Bautista (2023) found a higher frequency of elongated tubers (26.5 %), round tubers (19.1 %), and oblong and oblong-elongated tubers (30.8 %). Tubers with compressed shapes (11.8 %) and oval

Table 8

Classification of Potato Cultivars According to Tuber Morphology.

BY SHAPE			BY FLESH COLOR			
Shape	**Frequency**	**Potential use**	**Color**	**n**	**%**	**Compounds**
Round	31% (39)	Industry	White	55	44	Antioxidants Shahidi *et al*., (2000)
Ovate	27% (34)	Fresh consumption	Yellow	40	32	Carotenoids Fernandez *et al*. (2013)
Compressed	18% (23)	Processing	Purple	30	24	Anthocyanins Andre *et al*. (2007)

shapes (8.8 %) were recorded less frequently, while only the samples "puma maki rojo" and "mashua papa" presented obovate tubers. Differences in tuber shape and color reflect a vast morphological diversity influenced by genetic and environmental factors. In the present study, there is a predominance of round, oval, and compressed tubers associated with industrial use or fresh consumption, whereas Bautista (2023) reports a higher percentage of elongated, oblong, and oblong-elongated forms with a low number of oval and compressed shapes, suggesting regional variations in selection criteria.

Principal Component Analysis (PCA)

Identified four distinct morphological groups of native potatoes (Table 9, Figure 4), each adapted to specific environmental conditions within the high Andean ecosystem and characterized by unique agronomic and nutritional attributes.

Group I is characterized by tubers with a round shape and purple skin, exhibiting high productive performance and notable adaptability to environments with elevated solar radiation. Group II comprises tubers with yellow flesh, which possess a high carotenoid content, conferring significant nutraceutical value,

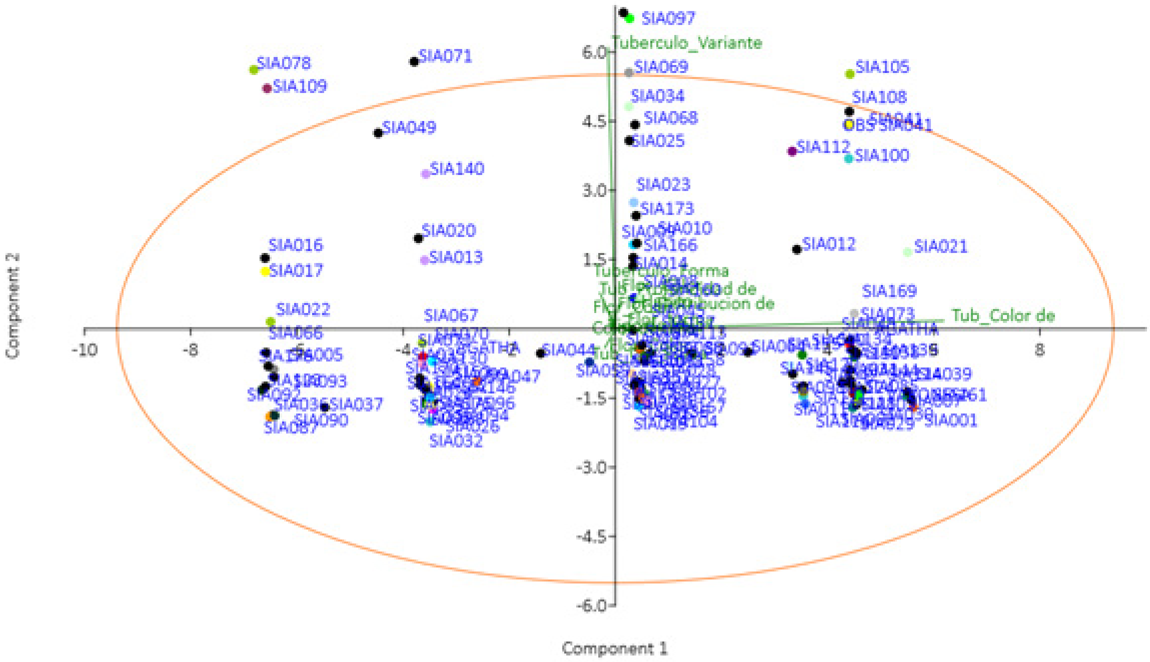
Table 9

Classification of Potato Cultivars into Groups Based on Principal Component Analysis (PCA)

Group	Key Characteristics	Examples	Importance
I	Erect, lilac flower, round/purple tuber	SIA002, SIA144	High productive potential Griffiths, *et al*. (2016)
II	Semi-erect, light blue flower, yellow flesh	SIA030, AGATHA	Valuable for genetic improvement Varshney, *et al*. (2013)
III	Decumbent, white flower, oblong tubers	SIA112, SIA128	Drought stress tolerant Hu & Xiong (2014).
IV	Semi-rosetted, red flower, purple flesh	SIA158, SIA167	Frost resistant Zhang, *et al*. (2020)

Figure 4

Graphical Representation of Variables from Principal Component Analysis (PCA)



particularly in promoting visual health. Group III consists of oblong-shaped tubers with high tolerance to abiotic stress, making them suitable for cultivation in high Andean regions with harsh climatic conditions. Finally, Group IV, defined by tubers with purple flesh, is distinguished by its resistance to low temperatures and frost, efficiently adapting to cold environments.

These morphological groups demonstrate extensive adaptive plasticity and possess essential nutritional properties that contribute both to the sustainability of high Andean agricultural systems and to regional food security.

This result is consistent with previous studies highlighting the extensive genetic and phenotypic variability present in native potato germplasm collections. Varshney *et al.* (2014) and Griffiths *et al.* (2016) emphasized the significant morphological and physiological variability among potato cultivars, noting that such diversity is influenced by both genetic factors and environmental conditions, which aligns with the clustering observed in the PCA analyses.

Similarly, Hu and Xiong (2014), who focused on genetic engineering and the improvement of drought-resistant potato cultivars, recognized the crucial role of morphological diversity in developing stress-resilient varieties, correlating with the differentiation of morphological groups identified in PCA studies.

Collectively, these studies reinforce the validity of morphological group identification in native potatoes, as revealed by PCA (Figure 4), and underscore the importance of such classifications for understanding genetic diversity, adaptation, and the crop improvement potential.

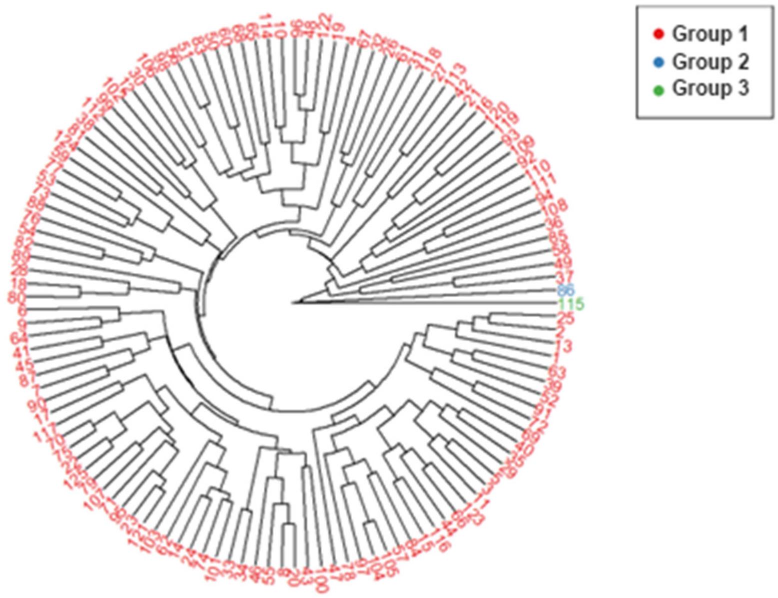
Cluster Analysis of Native Potato Cultivars Based on Morpho-Agronomic Traits

Cluster analysis using Gower's coefficient and the UPGMA method, based on morpho-agronomic traits, identified three main phenotypic groups among the 125 native Solanum tuberosum cultivars (Figure 5). These groups correspond specifically to the UPGMA analysis and should not be confused with the four groups identified through Principal Component Analysis (PCA), since both multivariate approaches use different criteria to summarize and represent phenotypic variation.

UPGMA Group I showed greater phenotypic similarity among its constituent cultivars, reflecting a relatively homogeneous combination of the evaluated morpho-agronomic traits. UPGMA Group II comprised only two cultivars and was clearly differentiated from the remaining groups based on their morphological characteristics. UPGMA Group III included cultivars with intermediate phenotypic characteristics, representing a differentiated cluster within the evaluated germplasm.

Figure 5

UPGMA dendrogram of 125 native potato cultivars based on Gower's coefficient calculated from morpho-agronomic traits.



The identification of three clusters through UPGMA, compared with the four groups distinguished by PCA, does not necessarily represent a contradiction between the analyses. Rather, it reflects methodological differences between the two multivariate approaches. PCA summarizes the contribution of morphological variables through principal components, whereas UPGMA hierarchically groups cultivars according to their overall similarity based on Gower's coefficient. Therefore, the results of both analyses provide complementary perspectives on the phenotypic diversity present among the evaluated native potato cultivars.

Previous studies have also reported substantial diversity within cultivated potato germplasm. Hardigan *et al*. (2017) described differentiation among wild and cultivated potato germplasm, while Spooner *et al*. (2005) examined the origin and relationships of cultivated potatoes. In the present study, however, the groups identified through UPGMA should be interpreted as phenotypic clusters based on morpho-agronomic descriptors rather than as direct evidence of genetic or phylogenetic relationships.

Overall, the clustering pattern highlights the considerable morpho-agronomic diversity present among the evaluated native potato cultivars. This information may contribute to the characterization and conservation of native potato germplasm and support the identification of potentially useful materials for breeding programs.

Conclusion

A total of 125 native potato cultivars were identified and grouped into four standardized categories based on growth habit: Group I (32%) comprising genotypes with erect habit; Group II (54%) with semi-erect habit; Group III (13%) with decumbent habit; and Group IV (1%) with semi-rosette habit.

Similarly, classification based on stem pigmentation showed green (58%), green with pigmented spots (28%), and fully pigmented (14%) types. Regarding floral morphology, rotated (42%), pentagonal (38%), and semi-star-shaped (20%) forms were observed. Lastly, tuber morphology was predominantly round (31%), ovate (27%), and compressed (18%).

References

Alor, N., López-Pardo, R., Barandalla, L., Rios, D., Ritter, E., & Ruiz de Galarreta, J. I. (2015). New sources of resistance to potato pathogens in old varieties of the Canary Islands. Potato Research, 58(2), 135–146. https://doi.org/10.1007/s11540-015-9293-5

Andre, C. M., Oufir, M., Guignard, C., Hoffmann, L., Hausman, J. F., Evers, D., & Larondelle, Y. (2007). Antioxidant profiling of native Andean potato tubers (*Solanum tuberosum* L.). Journal of Agricultural and Food Chemistry, 55(26), 10839–10849. https://doi.org/10.1021/jf0726583

Arcos-Pineda, J. H., del Rio, A. H., Bamberg, J. B., Vega-Semorile, S. E., Palta, J. P., Salas, A., Gomez, R., Roca, W., & Ellis, D. (2024). An international breeding project using a wild potato relative *Solanum commersonii* resulted in two new frost-tolerant native potato cultivars for the Andes and the Altiplano. Frontiers in Plant Science, 15. https://doi.org/10.3389/fpls.2024.1358565

Bautista Condori, M. J. (2023). Descripción morfológica de papas nativas (*Solanum* spp.) cultivadas en la Comunidad Campesina Matipacana, Yauli, Huancavelica. https://hdl.handle.net/20.500.12996/5802

Bellumori, M., Chasquibol Silva, N., Vilca, L., Andrenelli, L., Cecchi, L., Innocenti, M., Balli, D., & Mulinacci, N. (2020). A study on the biodiversity of pigmented Andean potatoes: Nutritional profile and phenolic composition. Molecules, 25(14), 3169. https://doi.org/10.3390/molecules25143169

Brown, C. R. (2005). Antioxidants in potato. American Journal of Potato Research, 82(2), 163–172. https://doi.org/10.1007/BF02853654

FAO (Organización de las Naciones Unidas para la Agricultura y la Alimentación). (2022). FAOSTAT – Crop production data. http://www.fao.org/faostat

Griffiths, C. A., Sagar, R., Geng, Y., Primavesi, L. F., Patel, M. K., Passarelli, M. K., Gilmore, I. S., Steven, R. T., Bunch, J., Paul, M. J., & Davis, B. G. (2016). Chemical intervention in plant sugar signalling increases yield and resilience. Nature, 540(7634), 574–578. https://doi.org/10.1038/nature20591

Hardigan, M. A., Laimbeer, F. P. E., Newton, L., Crisovan, E., Hamilton, J. P., Vaillancourt, B., Wiegert-Rininger, K., Wood, J. C., Douches, D. S., Farré, E. M., Veilleux, R. E., & Buell, C. R. (2017). Genome diversity of tuber-bearing *Solanum* uncovers complex evolutionary history and targets of domestication in the cultivated potato. Proceedings of the National Academy of Sciences, 114(46). https://doi.org/10.1073/pnas.1714380114

Hu, H., & Xiong, L. (2014). Genetic engineering and breeding of drought-resistant crops. Annual Review of Plant Biology, 65(1), 715–741. https://doi.org/10.1146/annurev-arplant-050213-040000

Ignacio-Cárdenas, S., Gonzales-Pariona, F. J., & Jacobo-Salinas, S. S. (2022). Caracterización morfológica de papas nativas (*Solanum tuberosum* L. Grupo Andigenum) de Huánuco. Revista Investigación Agraria, 4(2), 13–25. https://doi.org/10.47840/ReInA.4.2.1394

INEI (Instituto Nacional de Estadística e Informática). (2023). Cinco departamentos concentraron más del 50 % de la producción de papa logrando un crecimiento de 13,3 % en julio. https://m.inei.gob.pe/prensa/noticias/cinco-departamentos-concentraron-mas-del-50-de-la-produccion-de-papa-logrando-un-crecimiento-de-133-en-julio-2023-14574/

Lüttringhaus, S., Pradel, W., Suarez, V., Manrique-Carpintero, N. C., Anglin, N. L., Ellis, D., Hareau, G., Jamora, N., Smale, M., & Gómez, R. (2021). Dynamic guardianship of potato landraces by

Andean communities and the genebank of the International Potato Center. CABI Agriculture and Bioscience, 2(1), 45. https://doi.org/10.1186/s43170-021-00065-4

MINAGRI (Ministerio de Desarrollo Agrario y Riego). (2023). Anuario estadístico agrario. Ministerio de Agricultura del Perú.

Muñoz, M., Folch, C., Rodriguez, F., Kalazich, J., Orena, S., Santos, J., Vargas, R., Fahrenkrog, A., & Puga, A. (2016). Genotype number and allelic diversity overview in the national collection of Chilean potatoes. Potato Research, 59(3), 227–240. https://doi.org/10.1007/s11540-016-9329-5

Navarre, D. A., Shakya, R., Holden, J., & Kumar, S. (2010). The effect of different cooking methods on phenolics and vitamin C in developmentally young potato tubers. American Journal of Potato Research, 87(4), 350–359. https://doi.org/10.1007/s12230-010-9141-8

Ochoa, C. M., & Centro Internacional de la Papa. (1999). Las papas de Sudamérica: Perú (1.ª ed.). Centro Internacional de la Papa.

Reategui, K., Aguirre, N., Oliva, R., & Aguirre, E. (2019). Phenology and yield of four potato varieties in the Peruvian Altiplano. Scientia Agropecuaria, 10(2), 265–274. https://doi.org/10.17268/sci.agropecu.2019.02.12

Remón Gamboa, Y. K., & Peña Rojas, G. (2018). Diversidad genética de papas nativas (*Solanum* spp.) del distrito de Vilcashuamán, Ayacucho-Perú, mediante AFLP. Revista Peruana de Biología, 25(3), 259–266. https://doi.org/10.15381/rpb.v25i3.15209

Shahidi, F. (2000). Antioxidants in food and food antioxidants. Nahrung/Food, 44(3), 158–163. https://doi.org/10.1002/1521-3803(20000501)44:3<158::AID-FOOD158>3.0.CO;2-L

Soto, J., Medina, T., Aquino, Y., & Estrada, R. (2013). Diversidad genética de papas nativas (*Solanum* spp.) conservadas en cultivares nativos del Perú. Revista Peruana de Biología, 20(3), 215–222. https://doi.org/10.15381/rpb.v20i3.5216

Spooner, D. M., McLean, K., Ramsay, G., Waugh, R., & Bryan, G. J. (2005). A single domestication for potato based on multilocus amplified fragment length polymorphism genotyping. Proceedings of the National Academy of Sciences, 102(41), 14694–14699. https://doi.org/10.1073/pnas.0507400102

Varshney, R. K., Terauchi, R., & McCouch, S. R. (2014). Harvesting the promising fruits of genomics: Applying genome sequencing technologies to crop breeding. PLoS Biology, 12(6), e1001883. https://doi.org/10.1371/journal.pbio.1001883

Wegener, C., & Jansen, G. (2013). Antioxidants in different potato genotypes: Effect of drought and wounding stress. Agriculture, 3(1), 131–146. https://doi.org/10.3390/agriculture3010131

White, P. J., Thompson, J. A., Wright, G., & Rasmussen, S. K. (2017). Biofortifying Scottish potatoes with zinc. Plant and Soil, 411(1–2), 151–165. https://doi.org/10.1007/s11104-016-2903-4

Zevallos Arias, E. L., Inga Ortíz, J. H., Marmolejo Gutarra, K. J., Álvarez Rodríguez, F. J., Paitan Gilian, R. K., Rixi Vilca, G. H., Becerra Pozo, D. A., & Neyra Valdez, E. L. (2023). Genetic and phenotypic diversity of native potatoes (*Solanum* spp.) from the Central Andes of Peru. Acta Agronómica, 72(1). https://doi.org/10.15446/acag.v72n1.102549

Zhang, J., Wang, X., Yu, O., Tang, J., Gu, X., Wan, X., & Chen, X. (2020). A natural mutation in the promoter of the NAC transcription factor StNAC103 enhances carotenoid accumulation in potato flesh. Plant Physiology, 183(2), 793–807. https://doi.org/10.1104/pp.20.00268

Zimmerer, K. S., de Haan, S., Jones, A. D., Creed-Kanashiro, H., Tello, M., Carrasco, M., Meza, K., Plasencia Amaya, F., Cruz-Garcia, G. S., Tubbeh, R., & Jiménez Olivencia, Y. (2019). The biodiversity of food and agriculture (agrobiodiversity) in the anthropocene: Research advances and conceptual framework. Anthropocene, 25, 100192. https://doi.org/10.1016/j.ancene.2019.100192