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REVIEW ARTICLE

Andean Tubers, Morphological Diversity, and Agronomic Management: A Review

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Abstract

Andean tubers refer to a variety of roots and underground stems cultivated in the Andean region, which spans a significant portion of South America. Among these tubers are *Arracacia xanthorrhiza*, *Tropaeolum tuberosum*, *Oxalis tuberosa*, and *Ullucus tuberosus*. These tubers exhibit resistance to pests, extreme environmental conditions such as drought or frost, and various soil types. It also displays morphological diversity in terms of shape, color, and size, as well as nutritional variation depending on the specific variety grown and the type of propagation employed. While some agronomic requirements are similar for these tubers, others differ due to factors such as crop management, fertilization techniques, plant characteristics, and other influences that contribute to species-level variations. Therefore, it is important to understand the optimal cultivation conditions for achieving high production yields, comprehending the range of tuber variability, and exploring potential applications for these Andean tubers. It is worth noting that there is a lack of up-to-date information on this subject, highlighting the need for further research and exploration. Efforts have been made to classify and differentiate each tuber based on specific physical characteristics, utilizing reported taxonomic data. This classification system assists producers in distinguishing between the various tuber species and their respective varieties.

Keywords

Arracacia xanthorrhiza, *Tropaeolum tuberosum*, *Oxalis tuberosa*, *Ullucus tuberosus*, growing conditions

Introduction

The mountainous Andean region stretches across South America and encompasses various countries, including Ecuador, Colombia, Venezuela, Bolivia, Peru, Chile, and Argentina. This vast area covers approximately 7,000 km, ranging from approximately 10°N to 50°S. This region is characterized by its diverse ecosystems and plant species, with a total number of 14,501 recorded. It experiences topological and climatic variations, ranging from drought-prone areas to frost-prone regions, which significantly influence agronomic practices.

Within this region, agricultural zones can be found at altitudes of up to 4,000 meters above sea level. The production of tubers, cereals, fruits, and vegetables is particularly notable in these areas. These crops are considered marginal species crops and exhibit variations in shape, color, and size (1).

Among the crops cultivated in the Andean zone, Andean tubers such as *Arracacia xanthorrhiza*, *Oxalis tuberosa*, *Ullucus tuberosus*, and *Tropaeolum tuberosum* plays a significant role in the local economy and are of great importance to farmers in the region (2). These crops are known for their resilience to drought, frost, and salinity, as well as their adaptability to diverse agroclimatic conditions. They possess rich nutrient content, including carbohydrates (especially starches), proteins, minerals, vitamins, fatty acids, glycosides, saponins, alkaloids, tannins, oxalates, carotenes, anthocyanins, and betacyanins (3). These compounds present various properties that contribute to the potential utilization and application of these tubers. Some research has explored the therapeutic properties and potential as sources of chemicals in the pharmaceutical industry. However, despite these findings, there is a lack of updated research addressing agronomic management, morphological properties, and the influence of different conditions on the preservation of these globally significant species.

To ensure the conservation of these crops, the agricultural process must be sustainable and economically viable for producers. Therefore, it is crucial to understand the conditions necessary for their optimal production, their morphology, and the potential technological applications of these tubers. This review aims to present information on the agronomic conditions and management practices required for these four crops, elucidate how tuber morphology impacts their nutritional properties, and explore its potential applications in various industries.

Materials and Methods

Bibliometrics is employed to quantify and characterize the global scientific research output, with the aim of analyzing the scientific activity pertaining to a specific research topic.

The procedures followed in this study were based on the PRISMA methodology (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). The methodology encompassed four steps, as depicted in the flow diagram (identification, screening, selection, and inclusion), which were adjusted to suit the requirements of this review. A search was conducted in the scientific databases: Web of Science (WoS) and Scopus, using the following search equation: [(((agronomy OR morphology) AND ("Arracacia xanthorrhiza" OR "Oxalis tuberosa Molina" OR "Tropaeolum tuberosum" OR "Ullucus tuberosus" OR arracacha OR "zanahoria blanca" OR "celio criollo" OR ibia OR ibia OR oca OR cuiba OR mashua OR cubio OR añu OR isañu OR ulluco OR olluco OR ruba OR tiguiño OR melloco OR olluco OR "papa lisa")))]. The data obtained were then processed using the SciMAT (Science Mapping Analysis Tool) software.

The initial results were analyzed by reviewing the titles and abstracts. Articles lacking an abstract or index were excluded from further consideration, and the remaining articles underwent a thorough reading. All articles related to agronomic management and tuber morphology were included in this review, while those deemed irrelevant or not aligned with the research objectives were discarded.

Result and Discussion

Morphology of Andean tubers

Tubers are a type of underground organ, composed mainly of carbohydrates.. It can be stems or roots that present a parenchymatic tissue in which the cells store water and carbohydrates in the form of starch and are a rich source of nutrients for animal and human food (4). Those produced in the Andean region belong to this group, it presents different compounds in their structure, such as fructo-oligosaccharides (5,6), various carotenoids (6), changing nutritional value according to variety, location, type of soil and agricultural management during crop production, as well as morphology since it has different shapes, colors, and sizes, which are often related to the type of propagation, variety, lack of improvement, type of reproduction and adaptation to extreme conditions, so this crop is often confused with each other because it has similar phenotypes according to its taxonomy (7–9) (Table 1).

There are qualitative characteristics that differentiate the cultivars, such as the color of the stems, flowers, leaves and tubers (flesh, skin and appearance), as well as the distribution of the peduncles, which are used as morphological descriptors. The shape of the tuber is a determinant when describing the genotypes of the tubers, being a criterion used by farmers for the selection, determination and identification of varieties (10,11) (Figure 1), since it presents variations in its shape that can be cylindrical, ovoid or spherical between cultivars and species (6) (Figure 2).

Arracacia xanthorrhiza

A. xanthorrhiza belongs to the family Apiaceae and is an herbaceous plant. Approximately 12 species of this genus are known in the Andean region, and reports of species from this genus have been found in Africa and Sri Lanka. This crop can reach heights ranging from 0.5 m to 1 m and has a cylindrical trunk that is branched. It has up to 95 leaflets, with a central underground stem and several lateral stems. The roots of this plant are used for propagation and are also the edible part (12). *A. xanthorrhiza* is characterized by its dense foliage, with leaves that have more than three pinnate leaflets. The leaflets are oval-lanceolate in shape, rounded at the base, and have short petioles and sheaths. The flower of this plant is purple and green. The main organ of *A. xanthorrhiza* is its cylindrical root, which can vary in color between white, yellow, and purple depending on the cultivated variety. It is worth noting that this root has nutritional properties and contains micronutrients such as Vitamin A, niacin, calcium, iron, and is a rich source of polyphenols (2,13).

Table 1. Geographical distribution of tubers species.

Name of the Plant	Geographical distribution	Common name (mention the language also)	Scientific Name	Number of species encountered in South America/ Andes	Family	Reference
Arracacha	Brasil, Colombia, Ecuador, Perú y Bolivia	English name: Arracacha (common), Peruvian Carrot, Peruvian Parsnip, White Carrot Spanish names: Arracacha, Zanahoria blanca y Apio criollo	*Arracacia xanthorrhiza* Bancroft	30 species	Apiaceae	(46, 47)
Oca	Perú, Ecuador, Bolivia, México, Venezuela, Colombia y Nueva Zelanda	Spanish name: Oca, cuiba, quiba, ibia	*Oxalis tuberosa* Molina	50	Oxalidaceae	(11)
Mashua	Peru, Bolivia, Ecuador, Venezuela, Colombia, Mexico, New Zealand, Canada, , United States and England	Spanish name: isa;u, cubio, añu, maswa	*Tropaeolu tuberosu m Ruíz & Pavón*	97 reported	Tropaeolace ae	(48, 49, 35)
Ulluco	Argentina, Bolivia, Chile, Colombia, Ecuador, Peru, and Venezuela	Spanish name: olluco, ulluku, melloco, chigua, ruba, papa lisa o lisas, ulluma, and ulluca	*Ullucus tuberosus Caldas*	50–70	Basellaceae	(35)

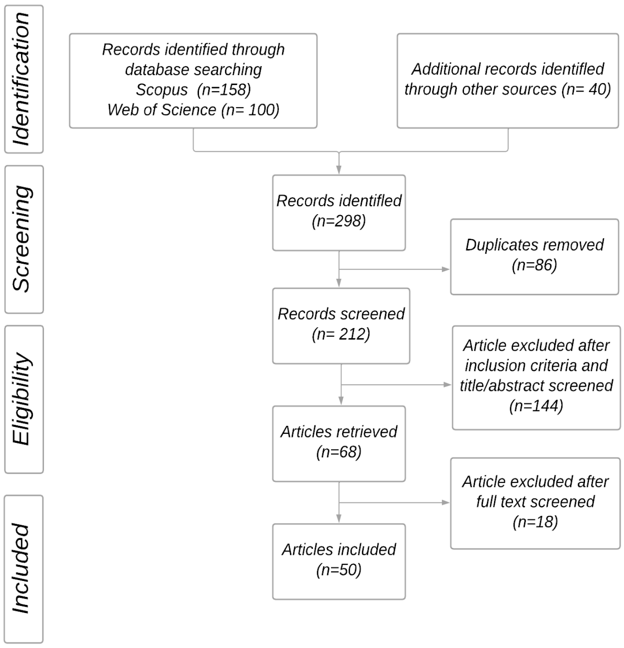

Figure 1. PRISMA methodology adapted for this paper.

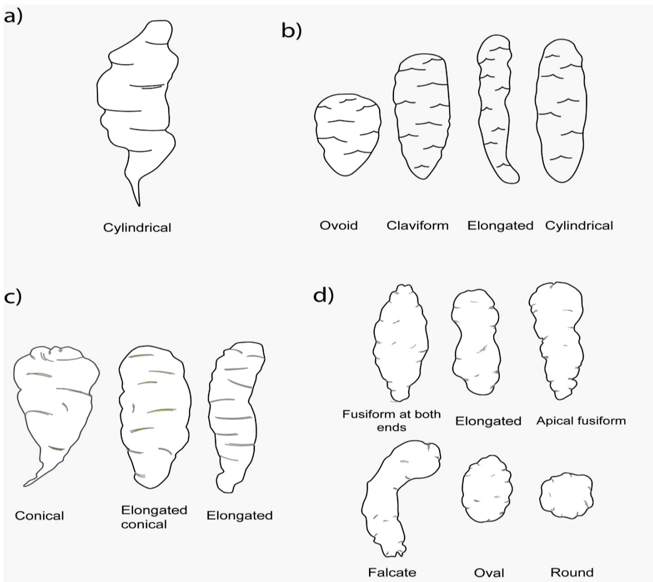

Figure 2. Variation in tuber shape A) Arracacha B) Oca C) Mashua and D) Ullucos.

Oxalis tuberosa

It is an herbaceous, dicotyledonous plant, reaching a height of 0.80 m to 1 m, with some inclination in its second phase of growth. Its stems are cylindrical, and in some cases, it has divisions. It has trifoliate leaves reaching upto a length 9 cm. The inflorescence is present in the upper part of the stem with four to five flowers possessing of yellow petals with some purple pigmentations, conformed by ten stamens. This plant undergoes cross-pollination. These tubers have a sweet taste and a floury consistency, with a smooth texture, sometimes rough, with ellipsoidal, cylindrical shapes, widening towards the apex in some cases. The colour of Oxalis tubers can vary from yellow (light to intense tones), yellow with pink pigments, orange, red, and, with exceptions, white can be found (13–15).

Tropaeolum tuberosum

It is an herbaceous perennial plant. It can grow upto a height between 0.20 and 0.80 m, with cylindrical stems that are 3 to 4 mm thick. In its first phase of development, it has an erect shape, but in the mature stage, it takes on a semi-postulate shape (16). The leaves have a laminated appearance, are wide (5-6 cm), very thick, and dark green in colour, and are separated by nodes (between 1-8 cm) and have petioles with lengths varying between 2 and 30 cm. Flowering occurs on the peduncles (10-15 cm), which are generally intense red in colour. Its tubers are between 5 and 15 cm long, with an elongated conoidal shape and varying degrees of pigmentation. The pulp is commonly yellow regardless of the morphotype, and the skin colour can vary from ivory white to dark purple, from yellow to orange, and different shades of purple. Its texture is sandy (13,17,18).

Ullucus tuberosus

It is an herbaceous plant with stems that can be aerial or creeping, with an approximate length between 40 cm to 1 m. The plant can take the form of a vine or bush, with three edges, and exhibits diversity in its coloring, ranging from light green to purple or a combination of both, as well as entirely yellow. The star-shaped flowers emerge from the axils of the aerial stems, although fruit production is rare. The tubers also vary in shape, which can be cylindrical, ovoid, or spherical, and they have a thin and soft skin layer. Additionally, the tubers come in different colors such as white, yellow (with red spots on occasion), pink, orange, magenta, or red. The nutritional value of the tubers varies depending on the cultivated variety. These tubers are produced underground (14).

Agronomic management of four Andean tubers

The agricultural production in the Andean region displays a remarkable diversity influenced by various factors. These factors include soil conditions, sunlight exposure, temperature variations, humidity, altitude, vegetation, crop types, varieties, and associated practices, which contribute to variations in production levels (19). According to Tapia's report in 1995, the agroecological zones observed in the region encompass maritime and fluvial areas, arid and semi-arid regions, semi-humid zones, areas prone to frost, and pastures for livestock. These distinctions set it apart from other countries in the Andean region (19). Consequently, the conditions allow for year-round production of most tubers, with the highest output occurring during the rainy season from April to September. However, production levels fluctuate depending on seed types, tuber varieties, and the specific crop establishment conditions (21–23) (Table 2).

Arracacia xanthorrhiza, commonly found in Venezuela, southern Bolivia, and northern Ecuador, exhibits excellent adaptability to diverse soil and temperature conditions, including tropical, mountainous, and frost-prone regions. Although the optimal altitude for cultivation is between 1500 and 3000 meters, the specific altitude requirements may vary across different production locations. For instance, in Colombia, it thrives at altitudes of 1800-2500 meters; in Brazil, 1000-2000 meters; in Peru, 1200-3200 meters; in Ecuador, 300-1500 meters; in Bolivia, 1000-3500 meters; and in Venezuela, 1200-3200 meters (24). *A. xanthorrhiza* can withstand temperatures ranging from 15 to 20 °C, and it has been reported to tolerate even lower temperatures (25). It thrives in well-drained soils with high organic matter content and a pH range of 5-6 (24). Planting densities typically involve a spacing of 0.6 to 0.8 meters between plants and 70 cm between rows, with a planting depth of 1 or 2 cm. The production cycle lasts from twelve to sixteen months. Propagation of this crop is commonly done using the colinos (upper part of the root), stems, or occasionally through colinos substitution (replanting). The cultivation process involves activities such as weeding, spraying, and fertilization. On average, 62.5 kg of tubers are planted per hectare (25). Arracacha seedlings are often intercropped with other crops like corn, beans, coffee, and bananas, serving as a dual-purpose strategy that benefits the producer (24).

Oxalis tuberosa , one of the well-known Andean tubers, is cultivated between 2800 to 4000 meters above sea level (masl) in slightly acidic soils with a pH ranging from 5.3 to 7.8. The optimal temperature range for this crop is between 7 and 10 °C, as temperatures exceeding 28 °C can harm the plant. It exhibits resistance to phytosanitary problems and pests, and it readily adapts to various environments. Propagation is achieved through tubers or seeds, contributing to a wide diversity in color and shape(11). The Oca crop yields are high and often require supplementary fertilization. Commonly, the 80-160 -80 formula is applied, along with foliar spraying of

Table 2. Agronomic characteristics for Andean tubers

Tuber	Sowing altitude (masl)	Optimum temperature (°C)	Type of soil	Optimum pH	Annual precipitation	Sowing density	Productiontime In Months	Yield kg ha^{-1}	Reference
Arracacia xanthorrhiza	1500-3000	15-20	Sandy, sandy loamsoils, with great depth,high drainage capacity and abundant organic matter content.	5-6	777.8 mm	50,000-125,000 plants ha-1	8 to 12	2000 a 10.000	(1,5, 56,57)
Oxalis tuberosa	2800-4000	4-17	Dark- coloured soils, with abundant organic matter content andslightly acid soils	5.3-7.8	570 mm to 2,150 mm	25,000 to 50,000 plants ha-1	6 to7	5080 a 5223	(22, 59-60).
Tropaeolum tuberosum	2400-4300	15-22	Sandy loamsoils	5.3-7.5	600-1,200 Mm	>30,000 plants ha-1	6 to 9	7000 a 7500	(60, 61, 3, 11,46,
Ullucus tuberosus	1800-3800	11-13	Loamy, light and loose soils,with a ploughing depth greater than 0.30m, rich in O andwith good water retention capacity.	5.5-6.5	857 mm	35,700 and 41,600 plants ha-1	4- to 12	2000 a 10.000	(44,17).

fertilizer every 15 days at most. The crop is established with row spacing of 70-75 cm and plant spacing of 20-25 cm. Sowing requires up to 750 kg/ha of seed (7,21,25).

Mashua (*Tropaeolum tuberosum*), known as Cubio in Colombia, Mashua in Peru and Ecuador, and Añu or isaño in Bolivia (10), thrives at altitudes ranging from 2400 to 4300 masl. It is typically cultivated in association with other tubers like Oca (*Oxalis tuberosa*), Ulluco (*Ullucus tuberosus*), and potato (*Solanum tuberosum*) (26). Mashua can endure low temperatures and poor soil conditions without the need for inorganic agrochemicals such as fertilizers and pesticides. In fact, its yield can be twice as high as that of potatoes. It requires acidic soils with a pH range of 5 to 6, although it has been reported to tolerate pH levels between 5.3 and 7.5. The cultivation cycle varies between 6 to 9 months (27,28). Due to its strong resistance to insects and pests, pesticides are not necessary for its cultivation (15). Fertilization involves the use of a formula with a ratio of 20-400-20. Plant spacing ranges between 15 and 20 cm, and sowing is typically done from October to November, using up to 1300 kg/ha of seed (22).

Ullucus tuberosus, commonly referred to as Ulluco, possesses various names depending on the country and specific cultivation location (29). It is cultivated within the altitude range of 2800 to 3800 masl, although there have been reports of its ability to withstand lower altitudes. The establishment of this crop involves plowing and furrowing, with a distance of approximately 0.80 m between rows and up to 0.50 m between plants. Typically, 2 to 3 tubers are sown at a depth of 3 to 6 cm, requiring an average of 560 kg/ha for planting. The selection of large tubers for sprouting and greening is carried out from October to December, extending until March depending on irrigation availability (30,31). The recommended fertilization formula for this crop is 50-75-30 (Fertilizer formulation), with half of the fertilization applied at the time of sowing and the remaining portion between 60 and 90 days later (31).

Cultural practices are essential for Andean tubers and include regular weeding every 30 to 60 days, as well as two hilling operations between 80 and 120 days. Crop rotations are commonly employed to maintain soil health and act as a form of biological control against pathogens, thereby reducing the reliance on inorganic fertilizers. Pests commonly found in these crops include *Agrotis* sp., *Copitarsia turbata*, *Cutzo baroteus* spp, *Fusarium* spp, *Alternaria* spp, and *Cladosporium* spp. (30).

Pest and pathogen control strategies

Alternaria spp: This fungal disease typically occurs during the transition from drought to frost, affecting various parts of the plant, including leaves, stems, and tubers, causing spots. To combat this fungus, crop rotations are implemented, ensuring adequate mineral nutrition, and employing fungicides preventively (32).

Agrotis sp: These insects cut and slice the stems and root collar, leading to damage and exposing the crop to fungi. Control measures involve the use of pesticides such as Sevin, Endosulfan, Endrin, Thiodan, as well as irrigation management (32).

Copitarsia turbata: This pest feeds on aerial stems, primarily attacking young plants, and tends to abandon the crop as foliage diminishes. Control methods include highly toxic insecticides like Carbofuran, Methamidophos, and Aldicarb, as well as adjustments in planting times, hilling frequency, and early harvesting (33).

Fusarium spp: This fungus remains in the spore stage on seeds and in the soil. It attacks plants during germination and thrives in temperatures below 10°C, causing wilting and rotting of tubers. Control measures involve the use of disinfected seeds, preventing mechanical damage to the plant, and implementing crop rotation (32).

The Significance of Andean Tubers and Cultivation Prospects

Andean tubers play a crucial socio-economic role as they provide economic support for many individuals in the region. They are an integral part of the staple diet in the communities where they originate and are commonly consumed in soups, salads, or simply cooked. Notably, they hold great importance alongside potatoes, *O. tuberosa* Mol, *U. tuberosus*, and *T. tuberosum* (34,35). In terms of nutritional value, Andean tubers are recognized for their richness in various nutrients, including carbohydrates, with starch being the predominant compound. These are also high in fiber, proteins, minerals, and certain vitamins (34,36) (Table 3). Research conducted so far indicates that the starches found in these tubers exhibit high digestibility (around 90%), showcasing significant potential for industrial applications due to their nutritional and transformative characteristics, low production costs, minimal agrochemical usage, and the ability to be utilized for dual purposes. The attributes make them appealing for chemical, pharmaceutical, and food-related applications (8,22,37). Furthermore, their

Table 3. Nutritional characteristics of tubers

Tuber	Content of Moisture %	Content of Protein%	Content of lipids %	Carbohidrate %	Content of fibre %	Content of %	Minerals	Vitamins	References
Arracacia xanthorrhiza	-	0.7%	0.5%	86%	1.1 %	15%	Calcium	Vitamin A Niacin	(41,42)
Oxalis tuberosa	14%	0.52%	0.15%	90.5%	-	0.24%	Calcium Iron	-	(7,35,43)
Tropaeolum tuberosum	-	4.2%	1.1%	78%	6.8%	0.6%		Vitamin C	(22,41)
Ullucus tuberosus	7.8%	8.5 %	0.1%	64.96%	1.4%	-		Vitamin C	(6,35,39,44,45)

structure contains a substantial amount of fructooligosaccharides with prebiotic activity (5). Andean tubers are a rich source of carotenoids, phenolic acids, anthocyanins (such as malvidin 3-O-glucoside and 3,5-O-diglucoside), petunidin, peonidin, delphinidin (mono- and/ or diglycosides) (38), betalains (such as betanidin- and isobetanidin-5-O-(4'-O-malonyl-β-glucoside)) (39), vitamin C, and have been found to possess anti-inflammatory properties (6). Additionally, glucosinolates have been identified, and research indicates their antifungal, antibacterial, antioxidant, and anticarcinogenic properties (35,40).

Currently, these tubers are cultivated using conventional small-scale production systems and under rustic conditions. However, it is imperative to promote the development of new food products and ensure the sustainability of communities that rely on these dietary traditions (34). To harness the nutritional and techno-functional properties of Andean tubers and leverage their biological potential, it is crucial to explore alternative approaches for their production, application, and commercialization. This includes utilizing them in the development of functional products, thereby offering economic benefits to producers in the Andean region (22,37).

Conclusion

The diversity of Andean tubers, such as *Arracacia xanthorrhiza*, *Oxalis tuberosa*, *Tropaeolum tuberosum*, and *Ullucus tuberosus*, presents significant variations in their nutritional composition, morphological characteristics, and adaptability to different agro-ecological conditions. Factors such as variety, location, soil type, and agricultural management practices influence their nutritional value, phenotypic traits, and overall crop productivity.

The cultivation of Andean tubers in the Andean region requires specific agronomic management practices tailored to each tuber species. Factors such as altitude, temperature, soil pH, planting density, fertilization, and crop rotation play crucial roles in optimizing tuber yield and quality. Additionally, effective pest and pathogen control strategies, including crop rotations, proper mineral nutrition, and judicious use of pesticides, are essential for minimizing yield losses caused by diseases and pests.

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Authors' contributions

SSP is the main author who has done the research work with the help and guidance of MRS, RRH and JFS. All authors collaborated in the drafting, revision and data curation of the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None.

References

1. Pérez-Escobar OA, Zizka A, Bermúdez MA, Meseguer AS, Condamine FL, Hoorn C, et al. The Andes through time: evolution and distribution of Andean floras. Vol. 27, Trends in Plant Science. Elsevier Ltd; 2022. p. 364–78. https://doi.org/10.1016/j.tplants.2021.09.010

2. Barrera VH, Tapia CG, Monteros AR. Raíces y Tubérculos Andinos: Alternativas para la conservación y uso sostenible en el Ecuador. [Internet]. Barrera VH, César G T, Alvaro R M, editors. Vol. 4. 2004. p.3–30 Available from: http://www.asocam.org/sites/default/files/publicaciones/files/f1ce784ad56186d4fbec1a60f9e8e757.pdf

3. Jacobsen SE, Mujica A, Ortiz R. La importancia de los cultivos andinos. Fermentum Revista Venezolana de Sociología y Antropología [Internet]. 2003 Apr [cited 2021 May 19];13(36):14–24. Available from: http://www.redalyc.org/articulo.oa?id=70503603

4. María Bonete , Carlos Urquizo RG y PY. Estudio De Cuatro Tubérculos Y Raíces Tuberosas No Tradicionales De La Sierra Centro De Ecuador Y Su. Escuela de Administración de Empresas Gastronómicas [Internet]. 2016;12:37–67. Available from: https://www.unibe.edu.ec/wp-content/uploads/2017/08/03_12_BONETEetal_RTAs-1.pdf

5. Fabersani E, Grande MV, Coll Aráoz MV, Zannier ML, Sánchez SS, Grau A, et al. Metabolic effects of goat milk yogurt supplemented with yacon flour in rats on high-fat diet. J Funct Foods. 2018;1;49:447–57. https://doi.org/10.1016/j.jff.2018.08.042

6. Heil N, Bravo K, Montoya A, Robledo S, Osorio E. Wound healing activity of Ullucus tuberosus, an Andean tuber crop. Asian Pac J Trop Biomed [Internet]. 2017;7(6):538–43. Available from: http://dx.doi.org/10.1016/j.apjtb.2017.05.007

7. Moscoe LJ, Blas R, Huamán Masi D, Huamán Masi M, Emshwiller E. Genetic basis for folk classification of oca (Oxalis tuberosa Molina; Oxalidaceae): implications for research and conservation of clonally propagated crops. Genet Resour Crop Evol. 2017;;64(5):867–87. https://doi.org/10.1007/s10722-016-0407-y

8. Clavijo Ponce NL. Cultura y conservación in situ de tubérculos andinos marginados en agroecosistemas de Boyacá: un análisis de su persistencia desde la época prehispánica hasta el año 2016. Cuadernos de Desarrollo Rural. 2018;14(80). https://doi.org/10.11144/javeriana.cdr14-80.ccst

9. Basantes Morales ER. Manejo de cultivos andinos del ecuador [Internet]. Andrade Aguirre D, editor. 2015. Available from: www.repositorio.espe.edu.ec.

10. Pissard A, Arbizu C, Ghislain M, Faux AM, Paulet S, Bertin P. Congruence between morphological and molecular markers inferred from the analysis of the intra-morphotype genetic diversity and the spatial structure of Oxalis tuberosa Mol. Genetica. 2008 ;132(1):71–85. https://doi.org/10.1007/s10709-007-9150-9

11. Morillo C. AC, Morillo C. Y, Leguizamo M. MF. Caracterización morfológica y molecular de Oxalis tuberosa Mol. en el departamento de Boyacá. Rev Colomb Biotecnol. 2019;;21(1):18–28. https://doi.org/10.15446/rev.colomb.biote.v21n1.57356

12. Garnica Montaña JP, Villamil Carvajal JE, Atencio Solano LM, Jaramillo Barrios CI. The phenotypic feature of arracacha (Arracacia xanthorrhiza Bancroft.) of three regional cultivars in Tolima, Colombia. Trends in Horticulture. 2022;;5(1):31. http://dx.doi.org/10.24294/th.v5i1.1814

13. Flores HE, Walker TS, Guimarães RL, Vivanco JM. Andean Root and Tuber Crops: Underground Rainbows [Internet]. Vol. 38, 161 HORTSCIENCE. 2003. Available from: www.ars-grin.gov/duke

14. Pickersgill B. Domestication of plants in the Americas: Insights from Mendelian and molecular genetics. Vol. 100, Annals of Botany. 2007. p. 925–40. https://doi.org/10.1093/aob/mcm193

15. Morillo C. ACC, Morillo C. Y, Tovar L. YP. Caracterización molecular de cubios (Tropaeolum tuberosum Ruíz y Pavón) en el departamento de Boyacá. Revista de Ciencias Agrícolas. 2016 Dec 14;33(2):32–42. http://dx.doi.org/10.22267/rcia.163302.50

16. Quilapanta R, Dávila M, Vásquez C, Frutos V. Morphotypes of *Arracacia xanthorrhiza* Bancr. (White carrot) from Ecuador, as a source of germplasm variability. Scientia Agropecuaria. 2018;;9(2):281–6. https://doi.org/10.17268/sci.agropecu.2018.02.13

17. Sanchez Mendoza JC, Sanmartín Rodriguez JP. Estudio de polifenoles totales y actividad antioxidante en extracto de hojas de zanahoria blanca (*Arracacia xanthorrhiza*). [Guayaquil, Ecuador]: Universidad de Guayaquil; 2019. Available from: http://repositorio.ug.edu.ec/handle/redug/43783

18. Rincón Rueda MA, Ruiz Berrio HD, Molano Díaz JM, Alvarez Herrera JG, Pinto Acero YL. Postharvest characterization of seven arracacha cultivars (*Arracacia xanthorrhiza* Bancroft). Rev Fac Nac Agron Medellin [Internet]. 2021;74(3):9745–56. https://doi.org/10.15446/rfnam.v74n3.92658

19. Tapia Núñez ME, Fries AM, Mazar Irela, Rosell Cadmo. Guía de campo de los cultivos andinos. Asociación Nacional de Productores Ecológicos del Perú; 2007. 209 p. Available from: https://www.fao.org/family-farming/detail/es/c/1635590/

20. Barrera V, Espinosa P, Tapia C, Montero A, Valverde F. Caracterización de las Raíces y los Tubérculos Andinos en la Ecoregión Andina del Ecuador. Raíces y Tubérculos Andinos: Alternativas para la conservación y uso sostenible en el Ecuador. 2004;3–30. Available from: http://repositorio.iniap.gob.ec/handle/41000/3261

21. Aguirre Forero SE, Piraneque Gambasica NV, Perez Mojica I. Andean Tuber Production System in Boyacá, Colombia. Cuaderno de Desarrollo Rural [Internet]. 2012;9(69):257–73. Available from: http://www.scielo.org.co/scielo.php?pid=S0122-14502012000200013&script=sci_abstract

22. Pacheco MT, Hernández-Hernández O, Moreno FJ, Villamiel M. Andean tubers grown in Ecuador: New sources of functional ingredients. Food Biosci. 2020;1;35. https://doi.org/10.1016/j.fbio.2020.100601

23. Rojas Sandoval PM. Manejo agronómico de Ullucus tuberosus en Santiago de Chuco,La Libertad. [Trujillo]: Universidad Nacional de Trujillo; 2019. Available from: http://dspace.unitru.edu.pe/handle/UNITRU/13457

24. Lim TK. Arracacia xanthorrhiza. In: Edible Medicinal and Non Medicinal Plants. Springer Netherlands; 2015. p. 361–6. https://doi.org/10.1007/978-94-017-9511-1_7

25. Gutiérrez Malaxechebarría AM. New partnership in production of Arracacha (*Arracacia xanthorrhiza*) in Cajamarca (Colombia). In: Cuaderno de desarrollo rural. Cajamarca ; 2011. p. 205–28. Available from: http://www.scielo.org.co/pdf/cudr/v8n67/v8n67a09.pdf

26. Coloma A, Flores-Mamani E, Quille-Calizaya G, Zaira-Churata A, Apaza-Ticona J, Calsina-Ponce WC, et al. Characterization of Nutritional and Bioactive Compound in Three Genotypes of Mashua (*Tropaeolum tuberosum* Ruiz and Pavón) from Different Agroecological Areas in Puno. Int J Food Sci. 2022;2022. https://doi.org/10.1155/2022/7550987

27. Grau A, Ortega Dueñas R, Nieto Cabrera C, Hermann M. Mashua: *Tropaeolum tuberosum* Ruíz & Pav. Promoting the conservation and use of underutilized and neglected crops. International Plant Genetic Resources Institute [Internet]. 2003;25. Available from: https://www.researchgate.net/publication/245539310

28. Apaza Ticona LN, Tena Pérez V, Bermejo Benito P. Local/traditional uses, secondary metabolites and biological activities of Mashua (*Tropaeolum tuberosum* Ruíz & Pavón). Vol. 247, Journal of Ethnopharmacology. Elsevier Ireland Ltd; 2020. https://doi.org/10.1016/j.jep.2019.112152

29. Bianco M, Sachs C. Growing Oca, Ulluco, and Mashua in the Andes: Socioeconomic differences in cropping practices. Agric Human Values. 1998;15(3):267–80. https://doi.org/10.1023/A:1007572203541

30. Salazar D, Arancibia M, Ocaña I, Rodríguez-Maecker R, Bedón M, López-Caballero ME, et al. Characterization and technological potential of underutilized ancestral andean crop flours from ecuador. Agronomy. 2021 Sep 1;11(9). https://doi.org/10.3390/agronomy11091693

31. Daza, LD, Homez-Jara, A, Solanilla, JF, Váquiro, HA. Effects of temperature, starch concentration, and plasticizer concentration on the physical properties of ulluco (Ullucus tuberosus Caldas)-based edible films. Int J Biol Macromol 2018;120:1834-45. https://doi.org/10.1016/j.ijbiomac.2018.09.211

32. Basantes Morales ER. Manejo de cultivos andinos del ecuador. Andrade Aguirre D, editor. ResearchGate [Internet]. 2015; Available from: https://www.researchgate.net/publication/358595969

33. San Roman C Ortiz A Ayala J P DE. Efecto del imidacloprid en el control de pulgones y en la transmisión de los virus de la amarillez de la remolacha. 1995. https://dialnet.unirioja.es/servlet/articulo?codigo=2135800

34. Velásquez-Barreto FF, Bello-Pérez LA, Nuñez-Santiago C, Yee-Madeira H, Velezmoro Sánchez CE. Relationships among molecular, physicochemical and digestibility characteristics of Andean tuber starches. Int J Biol Macromol [Internet]. 2021;182:472–81. https://doi.org/10.1016/j.ijbiomac.2021.04.039

35. Campos D, Chirinos R, Gálvez Ranilla L, Pedreschi R. Bioactive Potential of Andean Fruits, Seeds, and Tubers. In: Advances in Food and Nutrition Research. Academic Press Inc.; 2018. p. 287–343. https://doi.org/10.1016/bs.afnr.2017.12.005

36. Parra-Quijano M, Panda S, Rodríguez N, Torres E. Diversity of Ullucus tuberosus (Basellaceae) in the Colombian Andes and notes on ulluco domestication based on morphological and molecular data. Genet Resour Crop Evol. 2012;59(1):49–66. https://doi.org/10.1007/s10722-011-9667-8

37. Valle-Parra M, Pomboza-Tamaquiza P, Buenaño-Sánchez M, Guevara-Freire D, Chasi-Vizuete P, Vásquez C, et al. morphology, phenology, nutrients and yield of six accessions of tropaeolum tuberosum ruiz y pav (mashua) 1 [morfología, fenología, nutrientes y rendimiento de seis accesiones de tropaeolum tuberosum ruiz and pav (mashua)]. Vol. 21, Tropical and Subtropical Agroecosystems. 2018. URN: http://www.revista.ccba.uady.mx/urn:ISSN:1870-0462-tsaes.v21i1.2574

38. Alcalde-Eon C, Saavedra G, De Pascual-Teresa S, Rivas-Gonzalo JC. Identification of anthocyanins of pinta boca (Solanum stenotomum) tubers. Food Chem. 2004 ;86(3):441–8. https://doi.org/10.1016/j.foodchem.2003.09.019

39. Mosquera N, Cejudo-Bastante MJ, Heredia FJ, Hurtado N. Identification of New Betalains in Separated Betacyanin and Betaxanthin Fractions from Ulluco (Ullucus tuberosus Caldas) by HPLC-DAD-ESI-MS. Plant Foods for Human Nutrition. 2020;75(3):434–40. https://doi.org/10.1007/s11130-020-00837-9

40. Duque L, Bravo K, Osorio E. A holistic anti-aging approach applied in selected cultivated medicinal plants: A view of photoprotection of the skin by different mechanisms. Ind Crops Prod. 2017 Mar 1;97:431–9. https://doi.org/10.1016/j.indcrop.2016.12.059

41. Leidi EO, Altamirano AM, Mercado G, Rodriguez JP, Ramos A, Alandia G, et al. Andean roots and tubers crops as sources of functional foods. Vol. 51, Journal of Functional Foods. Elsevier Ltd; 2018. p. 86–93. https://doi.org/10.1016/j.jff.2018.10.007

42. Sancho RAS, Souza JDRP, de Lima FA, Pastore GM. Evaluation of oligosaccharide profiles in selected cooked tubers and roots subjected to in vitro digestion. LWT - Food Science and Technology [Internet]. 2017;76:270–7. http://dx.doi.org/10.1016/j.lwt.2016.07.046

43. Hernández-Lauzardo AN, Méndez-Montealvo G, Velázquez Del Valle MG, Solorza-Feria J, Bello-Pérez LA. Isolation and partial characterization of Mexican Oxalis tuberosa starch. Starch/Staerke. 2004 Aug;56(8):357–63. https://doi.org/10.1002/star.200300235

44. Pacheco MT, Moreno FJ, Moreno R, Villamiel M, Hernandez-Hernandez O. Morphological, technological and nutritional properties of flours and starches from mashua (*Tropaeolum tuberosum*) and melloco (*Ullucus tuberosus*) cultivated in Ecuador. Food Chem [Internet]. 2019;301:125268. https://doi.org/10.1016/j.foodchem.2019.125268

45. Velásquez-Barreto FF, Bello-Pérez LA, Yee-Madeira H, Velezmoro Sánchez CE. Esterification and Characterization of Starch From Andean Tubers. Starch/Staerke. 2019 1;71(1–2). https://doi.org/10.1002/star.201800101

46. Siqueira MVBM, do Nascimento WF, Pereira DA, Cruz JG, Vendrame LP de C, Veasey EA. Origin, domestication, and evolution of underground starchy crops of South America. Starchy Crops Morphology, Extraction, Properties and Applications. 2023 (1);17–42. https://doi.org/10.1016/B978-0-323-90058-4.00011-6

47. Lim TK. Arracacia xanthorrhiza. Edible Medicinal and Non Medicinal Plants [Internet]. 2015 [cited 2023 Jun 12];361–6. https://doi.org/10.1007/978-94-017-9511-1_7

48. Apaza Ticona LN, Tena Pérez V, Bermejo Benito P. Local/traditional uses, secondary metabolites and biological activities of Mashua (*Tropaeolum tuberosum* Ruíz & Pavón). J Ethnopharmacol. 2020 ;247:112152. https://doi.org/10.1016/j.jep.2019.112152

49. Guevara-Freire D, Guevara-Freire DA, Valle-Velástegui L, Barros-Rodríguez M, Vásquez C, Zurita-Vásquez H, et al. Nutritional composition and bioactive components of mashua (Tropaeolum tuberosum Ruiz and Pavón). Tropical and Subtropical Agroecosystems [Internet]. 2018 Apr 26 [cited 2023 Jun 12];21(1):53–68. Available from: URN: http://www.revista.ccba.uady.mx/urn:ISSN:1870-0462-tsaes.v21i1.2561

50. Encyclopedia of Food Sciences and Nutrition | ScienceDirect [Internet]. [cited 2023 Jun 12]. Available from: https://www.sciencedirect.com/referencework/9780122270550/encyclopedia-of-food-sciences-and-nutrition