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REVIEW ARTICLE

Andean tubers: Traditional medicine and other applications

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Abstract

Tubers are a staple food in Andean highland communities, valued for their rich carbohydrate content with starch being the predominant component. Additionally their consumption is preferred for various health benefits, including anti-inflammatory effects, pain relief, digestive system improvement, diabetes management and wound healing, among others. Several studies have focused on Andean tubers such as *Oxalis tuberosa*, *Tropaeolum tuberosum*, *Ullucus tuberosus*, *Arracacia xanthorrhiza* and *Smallanthus sonchifolius*, revealing different compounds with pharmacological effects on humans and strengthening the immune system. Therefore, the objective of this review was to compile information from different databases such as Scopus and Web of Science on research conducted in the last decade on these tubers, highlighting their health benefits and potential for technological innovation for the benefit of the Andean communities that produce these crops. These tubers have been little marketed outside their production areas due to a lack of awareness. Although their applications have been limited, they have shown positive results, making them promising sources of health-beneficial phytochemicals. They could be used in technological developments to benefit health, particularly in addressing diseases that cause the most deaths.

Keywords

Andean tubers; *Arracacia xanthorrhiza* ; *Oxalis tuberosa* ; physicochemical; *Smallanthus sonchifolius* ; *Tropaeolum tuberosum* ; *Ullucus tuberosus*

Introduction

For over 3000 years, Andean tubers have been a staple food in the diet of the Inca, Quechua and Aymara peoples, serving as important sources of energy, vitamins and minerals. These tubers are characterized by their high productivity, due to their wide adaptability to diverse climatic and orographic conditions, such as altitudes raFnging from 1800 to 3800 m above sea level, extreme daily temperature variations and low rainfall (300 mm per year). This resilience allows them to be cultivated without using agricultural inputs such as pesticides and fertilizers (Table 1) (3). In the Andes, the main tubers include Oca (*Oxalis tuberosa*), Mashua (*Tropaeolum tuberosum*), Papalisa (*Ullucos tuberosus*), Potato (*Solanum* ssp. L.), Arracacha (*Arracacia xanthorrhiza*) and Yacon (*Smallanthus sonchifolius*). Among these tubers, Potato is the most well-known and widely cultivated, followed by the Oca, which is the only tuber that has been successfully cultivated outside the Andes, found in Mexico and New Zealand. The other tubers remain endemic to the Andean highlands (4).

Table 1. Agronomic performance of Andean tubers.

Tuber	Sowing density	Yield kg ha^{-1}	Reference
Oxalis tuberosa	25000 – 50000 plants ha^{-1}	5080 - 5223	(1)
Tropaeolum tuberosum	> 30000 plants ha^{-1}	7000 - 7500	(1)
Ullucus tuberosus	35700 – 41600 plants ha^{-1}	2000 - 10000	(1)
Arracacia xanthorrhiza	50000-125000 plants ha^{-1}	- 10000	(1)
Smallanthus sonchifolius	12000-26000 plants ha^{-1}	20000 - 50000	(2)

The Andean highlands, as depicted in Fig. 1, span across 7 countries: Venezuela, Colombia, Peru, Ecuador, Bolivia, Argentina and Chile. The Andes form the second-longest mountain range globally, stretching approximately 7000 km, surpassed only by the Himalayas. Peru, Argentina and Ecuador host the highest peaks of this mountain chain. Additionally, the region contains around 183 volcanoes, numerous hot springs and mineral deposits (5, 6). The vegetation at the highest latitude is found in this mountainous region. Rainfall is frequent up to the forest limit (3000 m above sea level), with temperatures ranging approximately from -3 to 7 °C and an average altitude ranging from 3000 to 4500 m above sea level. This ecological zone is referred to as the "altiandino" zone, marking the limit of vegetation (7).

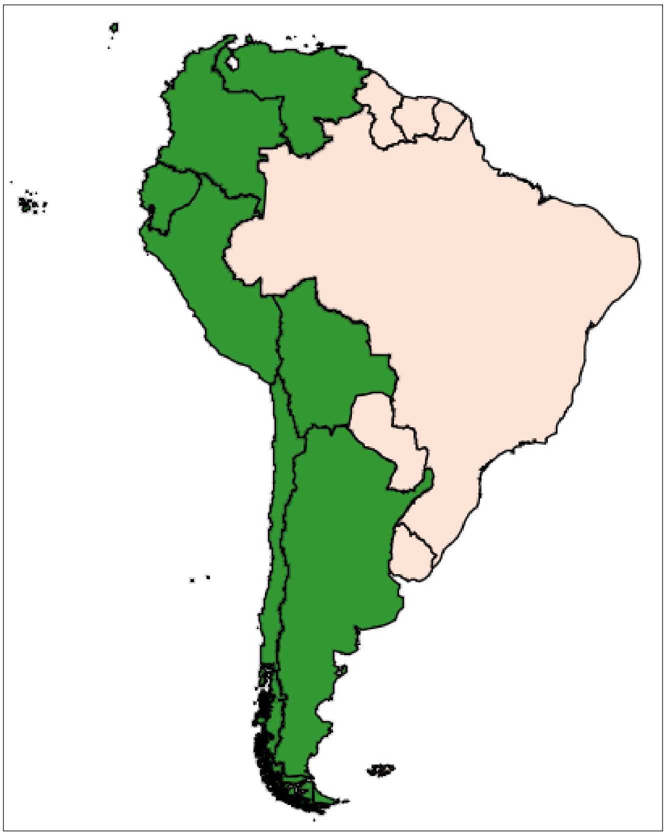

Fig. 1. Map of the Andes region.

These tubers are traditionally consumed by Andean communities and have been used to alleviate digestive problems, inflammation, pain, kidney damage and more. People report feeling better after consuming these tubers in their usual forms, such as infusions, soups, purees, drinks etc. There are also few scientific "*in vivo*" studies that demonstrate why these tubers produce positive health effects, suggesting that the presence of secondary metabolites might be responsible. A previous study has evaluated the biological activity of Oca and Yacon on the intestinal health of a group of rats (8) and obtained good results, probably due to the presence of anthocyanins and fructo-oligosaccharides respectively. Similarly, researchers have investigated the anti-inflammatory activity of alkamides, bioactive compounds in yacon and found a positive anti-inflammatory response on TNF-α and NF-κB (9).

However, the lack of knowledge about the primary and secondary metabolites of Andean tubers (some of these metabolites have been associated with antibiotic, antioxidant, insecticidal, nematocidal, anticancer and diuretic properties) has limited the enhancement of their properties in scientific and technological developments. This limitation hinders the ability to add value to these tubers and thereby support the economic sustainability of Andean communities (10, 11). Based on the above, this review analyses the contributions and systematic information documented in bibliographic databases such as Scopus and Web of Science on the uses of Andean tubers in traditional medicine, their physicochemical composition and recent developments or applications in health. The focus is on 5 Andean Tubers: Oca (*Oxalis tuberosa*), Mashua (*Tropaeolum tuberosum*), Papalisa (*Ullucos tuberous*), Arracacha (*Arracacia xanthorrhiza*) and Yacon (*Smallanthus sonchifolius*).

Materials and Methods

The methodology was based on a systematic and exhaustive review of the scientific literature available in the mentioned databases. Keywords such as tubers, Andeans, *Oxalis tuberosa*, *Tropaelum tuberosum*, *Ullucus tuberosus*, *Arracacia xanthorrhiza*, *Smallanthus sonchifolius*, phytochemicals and medicinal use were used to ensure the relevance and quality of the selected studies, resulting in 497 articles (Fig. 2). Documents with a publication date before 2003, those repeated in both databases and those not primarily focused on Andean tubers and their technological developments were excluded.

In addition, a detailed analysis of the selected studies was conducted, extracting relevant information on the traditional medicinal uses of Andean tubers, their physicochemical composition and recent advances and applications in health. Of the initial selection, 68 articles were analyzed. The synthesis of the information was carried out systematically, reviewing the summary, title, analysis of results and conclusions to ensure high relevance.

This allowed the findings to be organized into thematic categories to facilitate the presentation and understanding of the results.

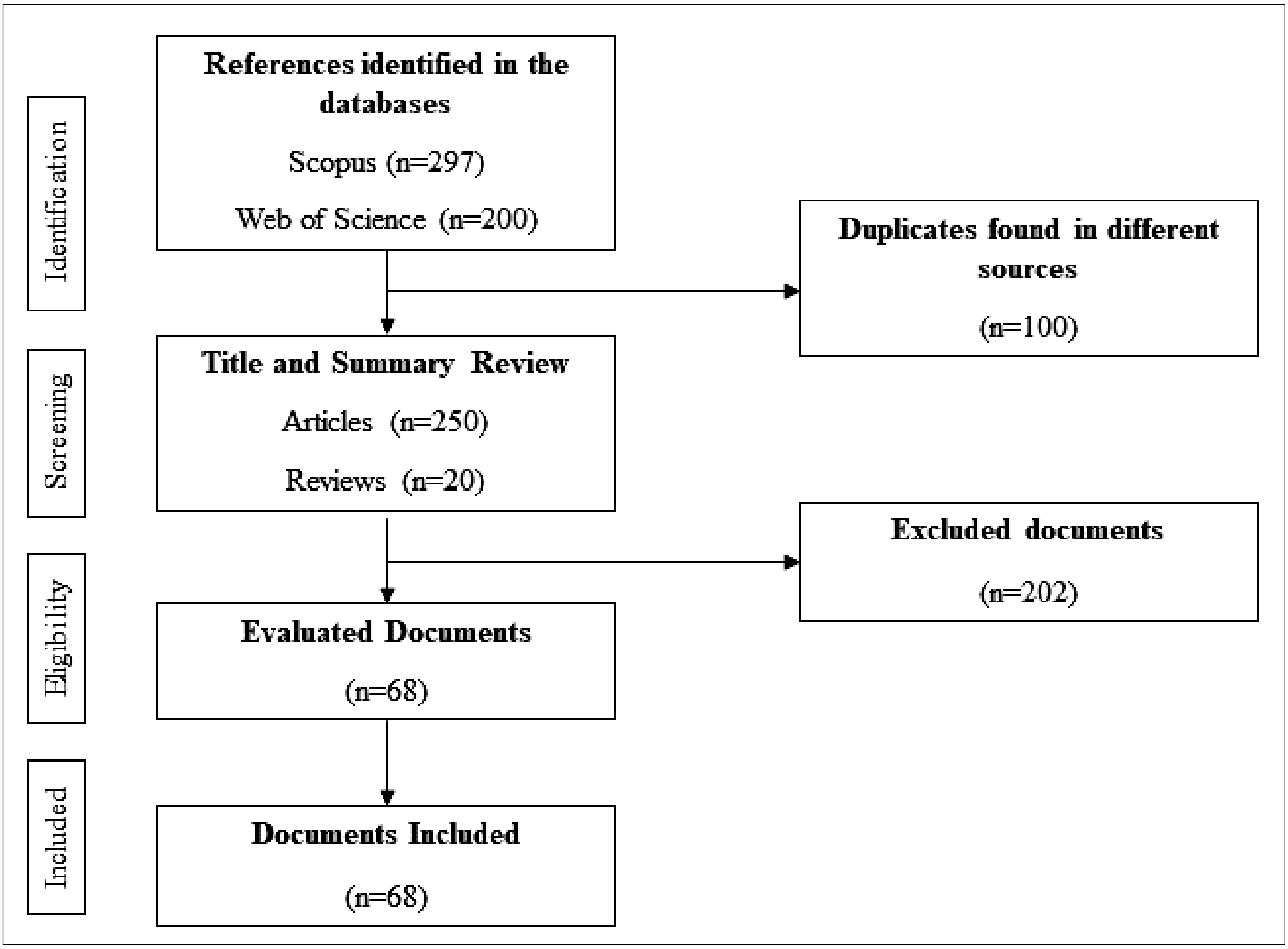

Fig. 2. The methodological process used for the review of Andean tubers.

Results and Discussion

Uses in traditional medicine

Table 2 reports the common names of Andean tubers, their forms of consumption and their applications in traditional medicine by different indigenous communities. These communities have consumed the tubers in different ways according to their traditions and for their health benefits, possibly due to their composition. Each tuber contains secondary metabolites with biological and antioxidant properties that are of interest to the scientific, food and pharmaceutical fields. These properties present opportunities to develop various alternatives and to use resources that have been produced for years but are gradually being lost due to limited knowledge about them. Thus, few scientific studies have demonstrated *in vivo* how the composition of these tubers helps to prevent and/or reduce diseases that can cause death.

Physico-chemical composition

The analysis of the chemical composition of a plant matrix reveals the substances present and their proportions, including proteins, fats, vitamins, minerals, carbohydrates, toxins and bioactive compounds. The latter include primary and secondary metabolites such as polyphenols, carotenoids or phytosterols, vitamins, minerals, glucosinolates and fatty acids. These important biochemical compounds have gradually evolved to protect and promote plant growth and reproduction and have been characterized as being of agroindustrial and food interest (32).

Table 3 describes some secondary metabolites, highlighting their biological activities. For instance, polyphenols accumulate in the outer layers of plant tissues and seeds as a protective mechanism against environmental stressors. These compounds are recognized for their antioxidant activity and various biological benefits, which help protect against oxidative reactions. Consequently, they have garnered attention across scientific areas such as biochemistry, medicine and pharmaceuticals (50). Similarly, fructo-oligosaccharides have been integrated into the food industry because they provide texture to dairy products and moisture to soft baked goods like sucrose, but with fewer calories. In addition to their nutritional properties, they exhibit bioactive characteristics such as prebiotic, hypocholesterolaemic and hypolipidemic properties. These attributes suggest they can reduce the risk of colon cancer, improve cognitive function, have brain-protective effects and reduce blood glucose, phospholipids, serum cholesterol and triglycerides (51). Carotenoids and glucosinolates are also known to have positive health effects due to their biological properties.

Table 2. Medicinal uses and consumption methods of Andean tubers.

Tuber	Common name	Consumption method	Traditional Medicinal Use	Traditional medicine preparation mode	Reference
Oxalis tuberosa	Papa de Oca, Oca, Cuiba, Quiba, Ibia, Apilla, Uncha, Papa extranjera, Agrillo, Oca de la chacra, Oca Rosada, Papa roja.	Soups, stews, sweets, seasoning.	Prostate inflammation, inflammatory diseases, diuretics, gallbladder damage, gastritis, rheumatism, sexual potency, diarrhea, constipation, skin ulcers, postpartum recovery and acne treatment.	Juices, Syrup, Infusions, Tea.	(12-17)
Tropaeolum tuberosum	Mashua, Isaño, Año, Añu, Cubio	Fresh, boiled, fried, baked, stewed, soups, flour.	Treating kidney diseases, bladder and kidney stones, skin ulcers, diuretics, and prostate inflammation.	Juices, Syrup, Infusions, Tea	(4, 18-20)
Ullucus tuberosus	Ulluco, Papa Lisa, Lisa, Melloco, Olluco, Chugua, Ruba	Fresh, cooked, soups, salads.	Treating burns, scar prevention.	Juices, Syrup, Infusions, Tea	(21-24)
Arracacia xanthorrhiza	Arracacha, Zanahoria Peruana, Chirivía Peruana, Zanahoria Blanca	Soups, bread, frying, purees, cakes, flour, sweets, roasted.	Digestive system issues, gastritis.	Juices, Syrup, Infusions, Tea	(25-27)
Smallanthus sonchifolius	Yacon	Infusion, juices, puree, sweets, jams, syrup, flour, cookies, smoothies, wines.	Obesity, diabetes, colon cancer, kidney conditions, skin rejuvenation.	Juices, Syrup, Infusions, Tea	(29-31)

Table 3. Characteristics of secondary metabolites found in plant matrices.

Secondary metabolites	Type	Characteristics	
Polyphenols	Phenolic acid	Modulate the digestion of food and the absorption of nutrients, due to its ability to unleash and inhibit enzymes of digestion and intestinal transport (33).	*O. tuberosa* (13) *Rhizophora mucronate* (41) *Dioscorea* spp (42)
	Flavonoid	Antioxidant, anti-inflammatory, antitumoral, cardiovascular protection, antidiabetic and immunomodulatory activities. It exerts its antidiabetic effect by stimulating the secretion of insulin, inhibiting the absorption of glucose, reducing the production of free radicals and improving antioxidant activity (34).	*O. tuberosa* (13) *Sedum rubens* (43)
	Lignan	Exhibits pharmacological effects such as hepatoprotective, anti-inflammatory, antioxidant, antitumor and antipathological effects (35).	*Linum usitatissimum* (44)
	Estilbenes	Provides benefits for human health, such as protection against cancer, inflammation, cardiovascular diseases and diabetes, thanks to resveratrol as a fundamental component (36).	
Carotenoids	Carotene	Natural coloring with antioxidant activities and provitamin A, which is susceptible to oxidation and easy isomerization under conditions of light, heat or acids. Therefore, it is not directly used in food and medicine (37).	*A. xanthorrhiza* (26) Sweet potato (45)
	Xanthophylls	Lutein, zeaxanthin and β-cryptoxanthin are xanthophylls that are important for brain and eye development and for stimulating the immune and antioxidant systems (38).	*Zea mays* (46)
Glucosinolates		The properties of this substance include antioxidant and immune-strengthening effects. It also inhibits the production of carcinogens, which can cause damage to DNA and cells, leading to tumor growth (39).	*Tropaeolum tuberosum* (47) *Raphanus sativus* (48)
Fructooligosaccharides		The non-digestible bifidogenic oligosaccharide is fermented by intestinal microbes that produce short-chain fatty acids, hydrogen gas derived from intestinal microbes and other metabolites. It does not increase blood glucose levels, stimulates insulin secretion, suppresses adipose tissue accumulation and has a beneficial effect on glucose homeostasis (40).	*Smallanthus sonchifolius* (47) *Allium cepa* (49)

Oxalis tuberosa

Ibia (*Oxalis tuberosa*), also known as Oca, is a tuber with a color range from white/cream, yellow, orange, pink, red and violet, with firm white to peach flesh and buds all over its surface. Its average size is 66.22 mm long and 18.04 mm in diameter (12, 51) (Fig. 3). Its potential uses include weed control and soil fertility enhancement. Its nutritional composition is approximately 1.1-9 % protein, 13.2 % carbohydrates, with starch (60-50 %), sugars such as sucrose and glucose (21 % and 3.6 % respectively), 0.6 % fat, 1-5.1 % fiber, minerals and organic acids as major components, thus allowing its use in industrial processes such as baking, dehydration and alcohol extraction by fermentation (35). The *in vitro* digestibility of starch has been reported to be around 91.78 %. Additionally, its phytochemical composition includes anthocyanins such as 3, 5-O-diglucosides of petunidin, peonidin, malvidin, 3-O-diglucosides of delphinidin, petunidin as well as 3, 5-O-diglucoside of malvidin (13, 52, 53).

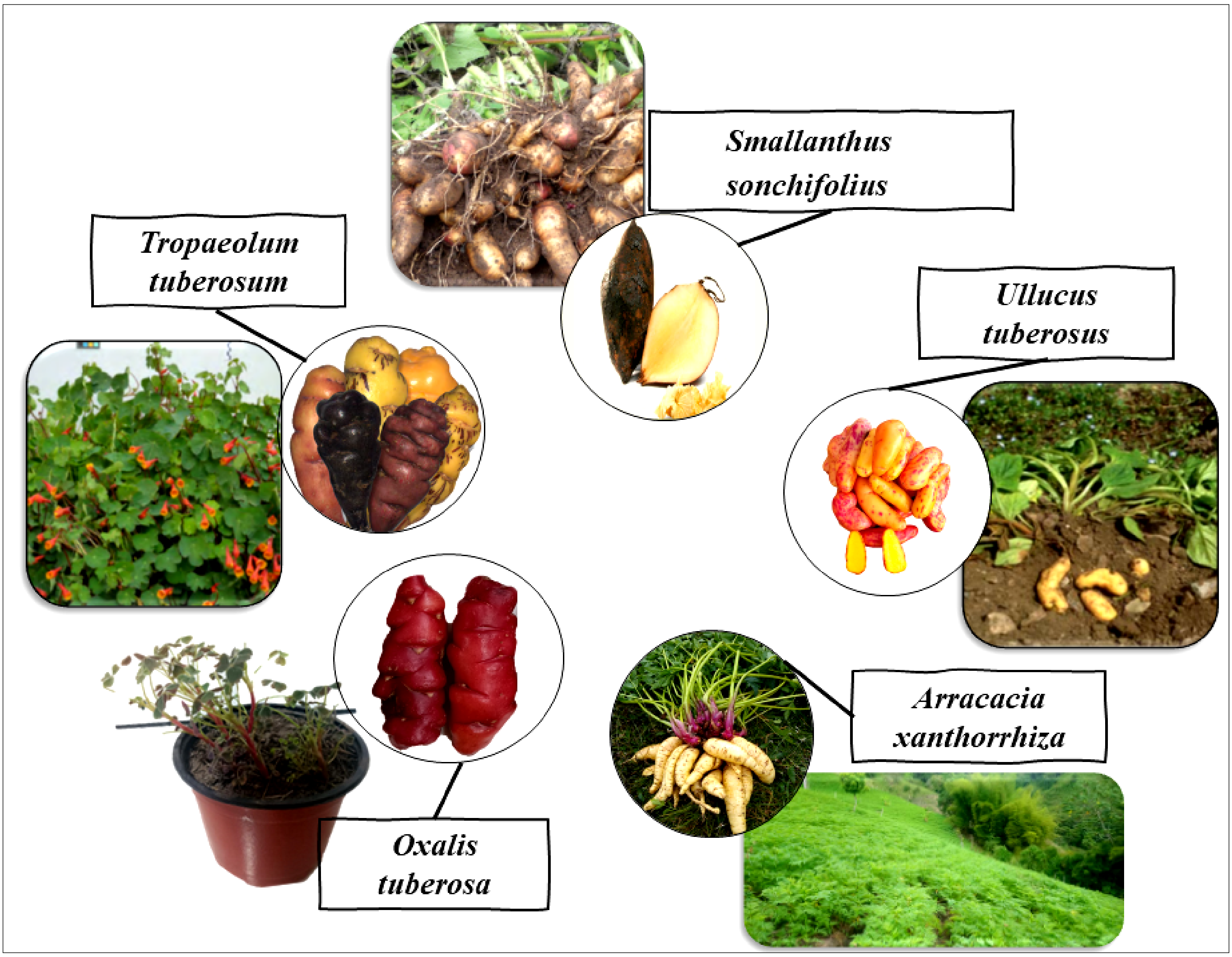

Fig. 3. Some examples of Andean tubers (source: 87-90).

Tropaeolum tuberosum

Tropaeolum tuberosum, commonly known as Mashua, is a tuber from Andean highlands. Its skin colors range from white or yellow to red or purple (Fig. 3). It can measure between 5-15 cm long and 3-6 cm wide at its distal or apical end (10). It contains approximately 35 % fresh starch, fiber and some secondary compounds such as polyphenols, anthocyanins, carotenoids and glucosinolates (GLS), with glucoaubrietin being found in the highestproportion (96–99 %) (54). These compounds are present in higher content compared to other vegetables such as cauliflower, broccoli and maca, with concentrations reported from 0.27 to 54.2 µmol/g, depending on the cultivar, post-harvest time and cultivation conditions (55). Products of GLS hydrolysis, including isothiocyanates, thiocyanates, thiones, epithionitriles and nitriles possess anticancer and anti-inflammatory activity. Phenethyl isothiocyanate in particular, has been reported to have an anti-tumor effect, suppressing the migration and invasion of lung cancer cells. Therefore, the presence of GLS in this species may be responsible for its medicinal uses (56, 47).

Ullucus tuberosus

Ullucus tuberosus, commonly known as Ulluco, is a tuber with periderm that varies in color from yellow, orange, red, magenta to purple, while its pulp is white or yellow. It typically measures about 1 cm in diameter and up to 6 cm in length on average (21, 57) (Fig. 3). Nutritionally, it is considered a good source of carbohydrates, with approximately 65 % of its dry weight corresponding to starch. It also contains proteins, fiber, vitamin C and betalains. Betalains are associated with antioxidant, anti-inflammatory, antimalarial and antitumor activities and their consumption have also been recommended for possible protection against stress-related conditions and the few sources of betalains in the daily diet (58). Ulluco is consumed fresh, although applications have also been developed for starch extraction for industrial purposes (59).

Arracacia xanthorrhiza

Commonly known as Arracacha, this plant is native to South America and is cultivated mainly in Brazil, Colombia, Venezuela, Ecuador, Peru and Bolivia. Its tubers vary in color from white to yellow and purple, measuring up to 4 cm in thickness and 20 cm in length (Fig. 3). Nutritionally, it is considered a rich source of carbohydrates, providing 25 g/100 g, with approximately 80 % of this content being starch. The yellow tubers, due to their color, contain carotenoids which are precursors of vitamin A. Additionally, Arracacha contains niacin and minerals such as calcium, iron and phosphorus making it a potential nutraceutical food suitable for children, the elderly or convalescent individuals. It has a slightly sweet nutty flavor and is highly digestible (25-27).

Smallanthus sonchifolius

The Andean crop commonly known as Yacon has a skin that varies from tan to dark brown and its pulp can range from white and yellow to purple and orange. The tuber can grow up to 40 cm in length and weigh up to 2 kg (28) (Fig. 3). Yacon has a sweet taste because it is a rich source of β-(2→1) fructo-oligosaccharides (FOS), ranging from 6.4-65 g/100 g dry matter. These include ketose, nystose and fructofuranosylnystose. It also contains phenolic compounds, mainly chlorogenic acid, ranging from 7. 9 - 30.8 mg/g dry matter and other derivatives of caffeic acid. These compounds provide several health benefits, such as prebiotic, anti-diabetic, antioxidant and antimicrobial effects (30, 60). Since the fructan in Yacon are not hydrolyzed by human digestive enzymes, they are considered as dietary fibers that pass through the gastrointestinal tract unchanged, attributing immunomodulatory properties to Yacon by increasing the production of short-chain fatty acids (61).

Technological developments and applications

Oxalis tuberosa

A snack based on maize semolina with sweet Potato, mashua and three varieties of goose flour was developed to promote its consumption throughout the year, not just during the production season (62). Textural analysis showed a relationship between porosity and hardness and a change in optical properties, possibly due to the loss of reducing sugars during Maillard reactions with proteins. The extrusion process reduced the water content of the mixture by approximately 5.6 %. The snacks exhibited high hygroscopicity, which posed a challenge for packaging and marketing the products. Additionally, the antioxidant capacity of *O. tuberosa* juice and *Gaultheria glomerata* (Cav.) fruit in a functional beverage has been determined (63). It was observed that a mixture of 300 mL of goose juice, 800 mL of Gaultheria juice, 1000 mL of treated water and 220 g of refined sugar provides 40.13 kcal/100 g of total energy. The protein content was 1.38 %, fat 1.08 %, moisture 99.5 %, ash 1.82 % and carbohydrate content 6.22 %. The antioxidant profile showed a total polyphenol content of 1.825 g gallic acid (GA)/100 g and antioxidant activity of 89.56 µmol of Trolox/100 g. Therefore, the drink made from these 2 species is a viable nutritional option for people who engage in rigorous and frequent physical activity.

By adding 6.6 % and 13.2 % red Potato flour (*O. tuberosa*) (PR) to gluten-free English bread, the texture of the product improved without affecting its physical characteristics (64). Additionally, the dough became more extensible and less hard and the volume increased. The crumb was more uniform and the protein content increased to 5 %. The inclusion of red Potato flour (*O. tuberosa*) in extruded products made from corn semolina resulted in a decrease in fat content from 8.86 % to 5.60 %, a decrease in the glycaemic index compared to the control and an increase in ash content from 1.81 % to 2.30 %.

Similarly, in extruded products made from corn semolina and red Potato flour (HPR), the inclusion of HPR altered the water absorption index values (3 %). The extrudates' water solubility index increased from 6.18 % to 20.19 % and their fracturability increased from 201.58 N to 495.68 N (65) when the HPR was used at 100 %. The luminosity of the extrudates decreased from 44.37 % to 25.06 %. Additionally, the extrudates showed a higher total phenol content of 2.88 mg AG/g dry sample compared to the control's 0.44 mg AG/g dry sample. Therefore, the use of HPR allows for the development of extrudates with favorable physicochemical characteristics and antioxidant properties. In an extrudate obtained from a mixture of Oca (*O. tuberosa*) flour (HO) and oats, it was observed that increasing the fiber content decreased the glycaemic index to 65.04 % and the starch hydrolysis percentage to 67.29 %, thus enabling a controlled release of sugar into the bloodstream (66). Moreover, the inclusion of HO in the extrudates increased their antioxidant activity. Therefore, this food can be considered functional due to its health benefits.

It has been investigated that prebiotic activity exhibited by three Andean tubers, Oca, Papalisa and Potato, as fermentation substrates for *Lactobacillus brevis* strain CJ25, which is used in the production of Potato Cheese (67). This study noted a pH reduction by 0.7 units, enhancing food safety by inhibiting the growth of pathogenic microorganisms. Moreover, *L. brevis* CJ25 demonstrated survival under simulated conditions of 3 h at pH 2.5 and resistance to bile acids. Hence, fostering such fermentations could positively impact the Andean regional economy and the community health. Furthermore, research indicates that Wistar rats fed with Yacon and Oca experienced an increase in *Lacto bacilli* and Bifidobacteria, correlating with a decrease in pH from 7.62 to 6. The antioxidant activity in the cecum of rats fed with Andean tubers increased at about 33 days compared to the control diet. The total content of phenolic compounds was about 137.82 mg AG/100 g tuber. These finding suggest a beneficial effect of Yacon and Oca diets on the intestinal health (11).

Tropaeolum tuberosum

In evaluating the biotransformation of GLS present in mashua using lactic acid bacteria and its *in vivo* absorption in rats, it was found that the bacteria utilize all the GLS. In rats, the GLS were absorbed and metabolized, with low contents detected in stool (0.02 %) and urine (0.59 %) and they were present in plasma up to 3 h after consumption (56). This suggests that *T. tuberosum* is a beneficial product for human health.

Ethanol extracts of *Moringa oleifera*, *T. tuberosum* and *Annona cherimola* have demonstrated antioxidant and antiproliferative activity against colorectal cancer (CRC) cell cultures grown as monolayers. These extracts inhibited colon cancer cells and showed synergistic activity with the chemotherapeutic agent 5-FU, providing new therapeutic options for the prevention and treatment of colorectal cancer (68). When two alkaloids identified in *T. tuberosum* were evaluated in human cancer cell lines, slight cytotoxic activity was observed with IC_{50} values between 27.45 ± 0.80 μM and 31.07 ± 0.87 μM. Significant anticancer potential was observed with IC_{50} values between 1.26 ± 0.57 μM and 1.37 ± 0.09 μM, which led to an increase in the rate of apoptosis of these cells (69). Additionally, isolated macamides from *T. tuberosum* exhibited anti-glycation and anti-inflammatory effects. In skin cells, these compounds inhibited the production of TNF-α with IC_{50} values of 9.38-10.06 μM and the formation of BSA-MGO at concentrations of 9.38-5.30 μM. Significant cross-link cleavage was also observed, with modification rates ranging from 6.58 to 18.8 % (70). Furthermore, isolated alkamides from this tubers showed anti-TNF-α activity with IC_{50} values of 1.56-3.12 μM and suppressed NF-κB with IC_{50} values of 0.02-3.54 μM. These compounds can be used for the development of new synthetic analogs as anti-inflammatory agents (11).

Ullucus tuberosus

The color stability of Ulluco extracts has been studied to utilize the betalains present in this tuber as a natural colorant. The findings indicate that Ulluco extract is effective as a colorant across a wide pH range (21). Specifically, when added to highly acidic foods, the color intensity of Ulluco extract was lower but remained more stable over time. At pH 4, the extract exhibited a significantly lower color intensity (C * ab ~ 40), but the stability of the red tone (hab) over time was higher, making betalains from Ulluco appealing to the food industry for applications requiring long-term color stability. By understanding the color variations, it is possible to obtain a specific color for a product. Moreover, when Ulluco betalains were added to foods with a pH between 5 and 6, the antioxidant capacity increased by 1.3 times compared to those with a pH of 4. This antioxidant capacity was further enhanced when the food is subjected to a cooking process at 80 °C. Additionally, storing the food at 4 °C preserved the maximum possible amount of initial betalains and maintained their antioxidant capacity (71). This research suggests that Ulluco betalains are not only valuable for their coloring properties but also for their potential health benefits, making them an attractive natural additive in food products.

Interesting results have been reported regarding the use of aqueous extracts of *U. tuberosus* in wound healing, as shown in *in vitro* models. Furthermore, levels of cell proliferation were increased. These extracts were found to be non-toxic to fibroblasts even at high concentrations. Additionally, collagenase activity increased by 12 %, suggesting that it could be an effective agent for treating scars. Enhanced migration and procollagen production facilitated tissue regeneration without scarring, while an increase in MMP-1 promoted wound healing during the phases of cellular remodeling and differentiation (22).

The consumption of this tuber can be incorporated into low-fat yogurt as Ulluco flour (FU), which fortifies the yogurt due to its starch content and enhances stability and viscosity. With the addition of FU to the yogurt, acid production during fermentation increased, achieving the final pH of 4.5 in 5.5 h compared to 7 h for the control. After 20 days of storage, the yogurt exhibited pseudoplastic rheological behaviour and sensory attributes showed greater acceptability with 0.9 % FU. This suggests that FU can be considered a valuable gelling and nutritional agent (72).

Arracacia xanthorrhiza

Instant powdered drinks have emerged as an alternative for those who require quick and easy food consumption. Therefore, extruded flours from roots and tubers were used in the development of this type of product, as the starch present in these cultures has a higher content of amylopectin than amylose. Thus, obtaining suspensions with improved thickening and stabilizing characteristics as well as viscoelastic fluid consistency and stability over a wide pH range, is ideal for the development of instant beverages (73). An instant dairy drink has been formulated using extruded Arracacha flour and the addition of folic acid. The resulting product has good sensory acceptance and is characterized by a high content of protein (13.33 %), soybean (10.94 %), almonds (22.02 %) and dietary fiber (3.12 %). The starch digestibility rate was 43.61 ± 0.12 %, progressively increasing to an average value of 56.80 ± 0.11 % at 60 min, indicating intermediate digestion of the mixture (74). When evaluating the effect of yellow Arracacha on an experimental model of ovarian polycystic disease, it was found that it regulated sexual hormone function, including follicle-stimulating hormone (FSH), estradiol, luteinizing hormone (LH) and testosterone due to the presence of polyphenols in its composition (75).

Smallanthus sonchifolius

The prebiotic effect of Yacon has been reported in a guinea pig model (30). The study observed FOS contents ranging from 6.4 to 65 g/100 g dry matter, total phenolic compounds from 7.9 to 30.8 mg of chlorogenic acid and antioxidant capacity between 23 to 136 μmol Trolox equivalent/g dry matter. In addition, the growth of bifidobacteria and *Lacto bacilli* was promoted and high levels of short-chain fatty acids were generated in the cecal material. This resulted in improved cell density and crypt formation in the tissue of the cecum, which are beneficial effects for colon health. The identified FOS were AJC 5189, AKW 5075 and

AMM 5163, which may be of interest to the nutraceutical industry.

During the production of Yacon syrup, positive effects on postprandial glucose and insulin response have been observed through various mechanisms. These include increased viscosity and gel formation in the intestine, reduced glucose diffusion, altered intestinal transit time and prolonged carbohydrate absorption (76). The hypoglycaemic activity of *S. sonchifolius* was evaluated in rodents with streptozotocin-induced diabetes, revealing a reduction in glucose levels and an increase in plasma insulin levels following administration. Additionally, its relatively low-calorie content has been investigated for its antidiabetic activity. Tests of α-amylase and α-glucosidase activity inhibition yielded positive results, suggesting that the bioactive compounds present in this tuber may be useful in treating this disease (29).

Yacon has been associated with positive effects on intestinal and bone health. Studies on rats have reported that Yacon, either alone or in combination with kefir, reduced intraluminal pH, improved intestinal permeability (by decreasing the excretion of lactulose and mannitol) and increased the balance of calcium and osteocalcin, a biomarker of bone formation (77). Similarly, positive effects of Yacon flour (YF) on oxidative stress, inflammation and endotoxemia have been reported in rats with induced colorectal cancer (CRC), where YF increased levels of fecal secretory immunoglobulin A and decreased lipopolysaccharides, tumor necrosis factor alpha and interleukin-12. Additionally, the production of short-chain fatty acids acetate, propionate and butyrate showed interactions with nuclear factor kappa B (NF-κB), Toll-like receptor 4 (TLR4) and NADPH oxidase through *in silico* analysis. Therefore, treatment with YF could be a promising food to reduce inflammation caused by CCR (78).

Significant improvements in growth performance were observed when black rockfish were fed with Yacon juice, including increased weight gain, specific growth rate, feed intake, feed efficiency and protein efficiency ratio. Activities of plasma digestive enzymes (amylase, trypsin and lipase), lysozyme and antioxidant enzymes (superoxide dismutase, catalase and glutathione) were mostly higher in the groups of fish fed with Yacon juice (79). Similarly, the potential of Yacon to prevent diabetic nephropathy has been evaluated through anti-inflammatory, antioxidant and anti-fibrotic mechanisms. It has also been shown to reduce the proliferation of mesangial cells and levels of transforming growth factor beta-1 (TGF-β1). In one study, the effects of different concentrations of Yacon (5, 10 and 50 µg/mL) on cellular models of diabetic nephropathy were examined. Results indicated that Yacon could decrease the gene expressions of SMAD2, SMAD3 and SMAD4 proteins while increasing the expression of SMAD7. This suggests that Yacon has therapeutic potential against cancer (80).

Table 4 shows some of the commercial products developed from these Andean tubers since the Andean associations began an entrepreneurial journey to initiate the trade of their products and look for economic alternatives.

Table 4. Prepared products from Andean tubers.

Tuber	Products	Reference
Oxalis tuberosa	-	
Tropaeolum tuberosum	Milk drink	(81)
Ullucus tuberosus	Whole Ollucus in brine	(82)
Arracacia xanthorrhiza	Flour	(83)
Smallanthus sonchifolius	Tea bags, dietary supplements, honey, chips, flour	(84-86)

Conclusion

The Andean tubers *Oxalis tuberosa*, *Tropaeolum tuberosum*, *Ullucus tuberosus*, *Arracacia xanthorrhiza* and *Smallanthus sonchifolius* contain various phytochemicals of interest with the potential to be employed in the development of products and processes that will generate added value, thereby contributing to the economic sustainability of the indigenous communities where these crops are grown. Despite limited commercial applications, the existing scientific research indicates positive health effects from these tubers, largely due to their antioxidant capacity and nutritional composition. This underscores the need for further research. Currently, trade in these tubers is restricted and their economic return is low because their potential benefits are not widely known. Developing products and processes based on these Andean tubers could not only provide economic benefits but also can promote the conservation of biodiversity and preserve the cultural heritage of the associated indigenous communities.

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Authors' contributions

ARCL is the main author who conducted the research work, with the assistance and guidance of JFSD, JAAV, MRSS, ACFG, SDNF, SYSB and RRH, to carry out the design, data acquisition and proper writing 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.

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