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An overview on phytochemical and therapeutic potential of yacon [*Smallanthus sonchifolius* (Poepp. and Endl.) H. Robinson]

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Abstract

Yacon also known as ground apple, is an underutilized, non-starchy perennial herbaceous crop which is cultivated for its tuberous roots which is similar to that of sweet potato in its appearance. It belongs to the family Asteraceae, native to South America and its cultivation have spread widely to several countries, such as the Czech Republic, China, Brazil, Japan, Italy and New Zealand. In India, it is grown in some areas of North-Eastern states and has got great potential due to high nutritional value and large size of its tubers. It can be eaten raw, boiled (in the form of soup), roasted, dehydrated or in form of beverages and roots of yacon contains considerable amounts of potassium and vitamin C. It is a rich source of beneficial bioactive compounds like polyphenols, phytoalexins, fructans, *etc*., which are responsible for its medicinal properties. Being is a rich source of fructooligosaccharides (FOS) and inulin, it has bifidogenic benefits for gut health which prevents constipation and reduce the concentrations of blood glucose and lipids. The other health benefits include prevention of colon cancer, diabetes and obesity by reducing the glycemic index and body weight. Yacon has recently become popular as a healthy functional food in Japan and other countries as its tubers are rich source of oligofructans and polyphenols whereas, the leaf extract has antidiabetic effects.

1. Introduction

Yacon [*Smallanthus sonchifolius* (Poepp. and Endl.) H. Robinson] commonly known as ground apple, is a perennial herbaceous plant that belongs to the family of Asteraceae. It has its origin in South America and the word yacon has been derived from the Quechua Indian language, where Yakku means "tasteless" and Unu means "water" (Paula *et al*., 2015). It is mostly cultivated for its edible tubers (Figure 1) and its leaves are used as fodder for livestock. The roots of yacon are juicy having a crunchy texture and sweet flavor and its leaves are used to make a medicinal tea (Delgado *et al*., 2013). It can be grown successfully in diverse climatic and soil conditions. It is grown on a commercial scale in Europe, North America and also in Asia (Gurang *et al*., 2018) whereas, in India, it is grown in some areas of North-Eastern states.

Yacon tubers are having low energy value due to the presence of the low-molecular-weight carbohydrate fructooligosaccharides (FOS) (Grau and Rea, 1997). Also, its roots lack starch and it serves as a natural substitute for sugar, thus it is a boon for diabetic patients. About 70-80 % of the total dry matter of yacon's tuber comprises of saccharides, dominantly the fructooligosaccharides (Lachman *et al*., 2003; Caetano *et al*., 2016). It stores carbohydrates in the form of FOS, which are the polysaccharides that cannot be digested by the human's gastrointestinal track and do not cause a spike in blood glucose level (Lachman *et al*., 2003). FOS is a dietary fiber that selectively stimulates the growth of health-promoting intestinal bacteria or beneficial probiotic strains including *Bifidobacteria*, *Lactobacilli*, *etc*. (Campos *et al*., 2012; Sousa *et al*., 2015).

Yacon is a multifunctional food because of the presence of several bioactive compounds including: fructans, phytoalexins and phenolic compounds. Due to the presence of these compounds in both roots and leaves, yacon exhibits prebiotic, antioxidant and antimicrobial properties (Lin *et al*., 2003; Geyer *et al*., 2008). In Peru, it is popularly consumed as an antirachitic food while, in Bolivia it is used for curing diabetes and digestion problems. Andean people used it as a skin rejuvenator and also for curing kidney and liver disorders (Paula *et al*., 2015). The various physicochemical and antioxidant characteristics along with phytochemical and therapeutic potential of different plant parts of yacon has been discussed further in detail.

Figure 1: Edible yacon tubers.

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2. Physicochemical and antioxidant characteristics

Yacon tubers are sweet in taste, which are crunchy and juicy, traditionally its consumption is as fresh fruit (Paula *et al.*, 2015). The data mentioned in Table 1, show that the moisture content on fresh weight basis, is in range of 86.77-91.71 and 84.31 % for roots and tubers, respectively, whereas, on dry weight basis it has been reported as 20.63 and 5.77% for tubers and roots. The mean TSS content of roots has been reported as 6.50-10.20 % and the protein content of the same on fresh weight basis was recorded as 1.27-4.49 in roots, 0.3- 3.02 % in tubers, 17 % in leaves and 11 % in stem. The yacon has been found to be low in fat or lipid content and higher in carbohydrate content in the range of 7.48-27.15 % (roots). Out of total dry matter, saccharides constitute of 70-80% and fructooligosaccharides (FOS) serve as their dominant saccharide along with fructose (4.13-7.34 %), glucose (1.76-2.37 %) and sucrose (1.75-3.25 %) as sugars in the tubers (Khajehei *et al.*, 2018). The FOS content on fresh weight basis has been reported in the range of 4.81-5.19 % in roots and 5.05-31.23 % in tubers whereas, on dry weight basis, it has been reported as 88.58 % in its roots. Lachman *et al.* (2003) have reported the mean tuberous root composition per 100 g of fresh matter as 81.3, 13.8, 0.9, 1.0, 0.1 and 1.1 g of water, saccharides, fibre, proteins, lipids and ash, respectively. The mean mineral contents per 100 g of fresh matter are reported as 334, 34, 12, 8.4, 0.4 and 0.2 mg of potassium, phosphorus, calcium, magnesium, sodium and iron, respectively. The various vitamins like B_1, B_2, C, β-carotene and polyphenols in the same weight has been reported as 0.07, 0.31, 5.0, 0.13 and 203 mg, respectively.

The phytochemical content of the peels of yacon tubers showed that it is a good source of phytochemicals along with considerable antioxidant activity while having low sugar content. Polyphenols are classified as reducing agents and when combined with other dietary reducing agents such as vitamin C, E and carotenoids, they are known as effective antioxidants, protecting the body against oxidative stress and illnesses such as cancer, coronary heart diseases and hyperinflammation (Kashyap *et al.*, 2017; Thakur *et al.*, 2020; Hamid *et al.*, 2022). The total phenol content, total flavonoid content and antioxidant activity of the peel of yacon tubers has been reported higher than than its flesh and even higher than those of whole tubers (Khajehei *et al.*, 2018). Campos *et al.* (2012) studied the total phenolic content and antioxidant capacity of flesh of thirty-five accessions of yacon tubers and reported it as 7.90-30.80 (mg chlorogenic acid equivalent/g DW) and 23.3-136.0 (μmol trolox equivalent/ g DW) as per ABTS radical scavenging activity. The range of the content for various antioxidant compounds and antioxidant activity of yacon has been presented in Table 1.

Table 1: Physicochemical and antioxidant characteristics of various yacon plant parts

Composition	Fresh weight basis	Dry weight basis	References
Moisture (%)	86.77-91.71% (roots) 84.31% (tubers)	20.63% (tubers) 5. 77% (roots)	Correa *et al.* (2021); Simanea-Sotelo *et al.* (2021)
TSS (°B)	6.50-10.20% (roots)	-	Correa *et al.* (2021)
Protein (%)	1.27-4.49% (roots) 0.3-3.02% (tubers) 17% (leaves) 11% (stem)	2.43% (tubers) 8.50% (roots)	Moscatto *et al.* (2006); Kim *et al.* (2010); Reyes *et al.* (2014); Puentes and Amador (2020); Correa *et al.* (2021); Simanea-Sotelo *et al.* (2021)
Fat (%)	0.06% (tubers and leaves)	0.37% (tubers and leaves) 0.49%	Kim *et al.* (2010); Reyes *et al.* (2014); Puentes and Amador (2020); Correa *et al.* (2021)
Lipids (%)	0.02-0.07% (roots)	0.07-1.0% (roots)	Moscatto *et al.* (2006); Puentes and Amador (2020); Correa *et al.* (2021)
Carbohydrates (%)	7.48-27.15% (roots)	73.80% (tubers) 80.04% (roots) 92.52%	Moscatto *et al.* (2006); Kim *et al.* (2010); Reyes *et al.* (2014); Puentes and Amador (2020); Correa *et al.* (2021); Simanea-Sotelo *et al.* (2021)
Fructose (%)	-	4.13-7.34% (tubers)	
Glucose (%)	-	1.76-2.37% (tubers)	
Sucrose (%)	-	1.75-3.25% (tubers)	
FOS %	4.81-5.19% (roots) 5.05-31.23% (tubers)	88.58% (roots)	Kamp *et al.* (2019); Puentes and Amador (2020); Correa *et al.* (2021)
Fructans %	-	20.34% (roots)	Lancetti *et al.* (2020)
Fiber %	0.22-0.5% (tubers) 0.83% (roots)	1.63-7.0% (tubers) 0.76% (roots)	Kim *et al.* (2010); Reyes *et al.* (2014); Puentes and Amador (2020); Correa *et al.* (2021); Simanea-Sotelo *et al.* (2021)

Ash%	0.27-0.59% (roots) 0.41% (tubers)	2.07% (tubers) 4.26% (roots) 0.79-3.95%	Moscatto *et al.* (2006); Kim *et al.* (2010); Reyes *et al.* (2014); Puentes and Amador (2020); Correa *et al.* (2021); Simanea-Sotelo *et al.* (2021)
Total phenols (mg GAE/g)	13.4-24.9 mg/g (leaves)	39.9-76.1 mg/g (leaves)	De Andrade *et al.* (2014); Ueda *et al.* (2019)
Total flavonoids (mg/g)	7.06-11.4 mg/g (leaves)	15.03-51.4 mg/g (leaves)	de Andrade *et al.* (2014); Ueda *et al.* (2019)
Gallic acid (mg/g)	-	0.04-1.97 mg/g (leaves)	
Caffeic acid (mg/g)	0.445-0.625% (leaves)	0.12- 0.47 mg/g (leaves)	
Ferulic acid (mg/g)	-	0.16-0.85 mg/g (leaves)	
Coumaric acid (mg/g)	-	0.07-0.19 mg/g (leaves)	
Tannins (mg/g)	6.86-14.2 mg/g (leaves)	13.8-27.9 mg/g (leaves)	Ueda *et al.* (2019)
Proanthocyanidin (mg/g)	0.579-0.587 mg/g (leaves)	1.51-5.61 mg/g (leaves)	Ueda *et al.* (2019)
Antioxidant activity DPPH assay (µg/ml)	73.1-159 µg/ ml (leaves)	-	Ueda *et al.* (2019)
Antioxidant activity ABTS assay (µg/ml, mg/100g)	100-199 µg/ ml (leaves)	356-377 mg/100 g (whole tubers)	Khajehei *et al.* (2018); Ueda *et al.* (2019)
Antioxidant activity FRSA assay (mg/ml)	403 mg/ml (leaves)	-	Reyes *et al.* (2014)
Antioxidant activity DPPH assay (µg/ml)	73.1-159 µg/ml (leaves)	-	Ueda *et al.* (2019)
Antioxidant activity ABTS assay (µg/ml, mg/100 g)	100-199 µg/ml (leaves)	356-377 mg/100 g (whole tubers)	Khajehei *et al.* (2018); Ueda *et al.* (2019)
Antioxidant activity FRSA assay (mg/ml)	403 mg/ml (leaves)	-	Reyes *et al.* (2014)

Table 2: Phytochemical compounds present in yacon leaves and tubers

Extract	Compounds	Results	References
Leaves	Chlorogenic, caffeic, gallic and ferulic acid	Regulation of liver enzymes, decrease in blood glucose level and weight.	Baroni *et al.* (2016)
	Enhydrin, uvedalin, fluctuanin, polymatin B, sonchifolin and minor lactones	Reduction in post-prandial glucose (0.8 mg/kg body weight).	Genta *et al.* (2010)
Tuberous roots	Polyphenols and fructooligosaccharides	Increase in catalase activity, decrease in glucose level.	Dionisio *et al.* (2015)
	Increase in insulin-positive pancreatic cells and reduction in postprandial peak glucose and plasma triacylglycerol and LDL levels	FOS and saccharides.	Habib *et al.* (2011)
	Chlorogenic acid (CGA)	Decrease in triglyceride concentrations, total cholesterol and plasma glucose.	Park *et al.* (2009)
	Fructo- oligosaccharides	Hypoglycemic and antidiabetic properties.	Caetano *et al.* (2016).

3. Phytochemical and therapeutic potential

Plants are powerful sources of several phytocompounds with biological activity and this list includes a variety of medicinal or therapeutic plants (Thakur *et al.*, 2022). The great possibilities of bioactive from fruits and their by-products to maintain or improve health, is increasing the interest in finding new products with positive pharmacological effects (Hamid *et al.*, 2020). Yacon consists of many beneficial bioactive compounds like polyphenols, phytoalexins, fructans, *etc.* (Table 2) which are present in both roots and leaves of yacon that are responsible for antioxidant, prebiotic and antimicrobial properties due to which yacon is regarded as multifunctional food (Cao *et al.*, 2018). The phytochemicals like flavonoids, terpenoids, carotenoids, tannins, alkaloids are found to have antioxidant, antiviral, anticarcinogenic and anti-inflammatory activity as well as they are known to reduce respiratory infections (Hamid *et al.*, 2021). The bioactive compounds/nutraceuticals also improve individual's immune response and act primarily as immunomodulators and assist our defence system (Kaushal *et al.*, 2022). The novel caffeic acid esters compounds present in yacon roots are 2,4- or 3,5-dicaffeoylaltraric acid, 2,5-dicaffeoylaltraric acid and 2,3,5- or 2,4,5-tricaffeoylaltraric acid as reported by Takenaka *et al*. (2003). Lin *et al*. (2003) extracted the yacon leaves followed by chromatographic separation which yielded two new antibacterial melampolide-type sesquiterpene lactones; namely, 8β-tigloyloxymelampolid-14-oic acid methyl ester and 8β-methacryloyloxymelampolid-14-oic acid methyl ester (antimicrobial activity against *Bacillus subtilis* and *Pyricularia oryzae*) along with four known melampolides, sonchifolin, uvedalin, enhydrin and fluctuanin (antibacterial activity against *B. subtilis*).

Yacon roots and leaves are rich sources of polyphenols with good antioxidant activity which is associated with the prevention of cancer and arteriosclerosis (Gurang *et al.*, 2018). The abundance of fructooligosaccharides (FOSs) of the inulin type which accumulates in the tuberous roots exhibits the therapeutic effects of yacon. These types of non-starch soluble fibers inhibit digestive enzymes and slow the release of sugars from starches, which lowers the glycemic index of yacon (Padilla-Gonzále *et al.*, 2020). The phytochemical potential of different plant parts of yacon has been mentioned in Table 3.

Table 3: Phytochemical potential of different plant parts of yacon

Property	Plant part	Compounds/minimal inhibitory weight	Method/model used and results	References
Antibacterial	Leaves	Fluctuanin: 2 mg Uvedalin: 36 mg Enhydrin: 50 mg 8b-methacryloyloxymelam polid-14-oic acid methyl ester: 60 mg 8b-tigloyloxymelampolid-14-oic acid methyl ester: 100 mg Sonchifolin: 150 mg	Antibacterialpaper-disc assay Inhibitory action against *Bacillus subtilis*	Lin *et al.* (2003)
Antifungal	Leaves	Sonchifolin, polymatin B and uvedalin enhydrin. Melampolide, sonchifolin, polymatin B, uvedalin and enhydrin	Inhibitory effect against *Pyricularia oryzae* -	Inoue *et al.* (1995) Lachman *et al.* (2012)
Antimicrobial	Leaves	Ent-kaurenoic acid *S. aureus:* 125 µg ml^{-1} *S. epidermidis:* 250 µg·ml^{-1} *B. subtilis:* 1000 µg·ml^{-1}	Disk diffusion method gram-positive organisms (*S. aureus, Staphylococcus epidermidis and Bacillus subtilis*)	Padla *et al.* (2012)
Antiinsecticidal	Leaves	Ent-kaurenoic acid and 15-α-angeloy loxy-*ent*-kauren-19-oic acid 16-epoxide.	-	Lachman *et al.* (2012)
Hypoglycemic and antidiabetic	Dried roots Freeze-dried Leaves	- - Chlorogenic acid (CGA)	Streptozotocin-induced diabetic rats Humans Streptozotocin-induced diabetic rats	Satoh *et al.* (2013); Oliveira *et al.* (2016) Scheid *et al.* (2014) Park *et al.* (2009)
Hypolipidemic effect	Root Dried root flour	- Normal and streptozotocin-induced diabetic rats	Hypercholesterolemic male Wistar rats Lower dose of FOS (340 mg/kg) exhibit more hypolipidemic effect than higher doses (6800 mg/kg) lower levels of malondialdehyde reported in liver and kidney	Oliveira *et al.* (2016); Oliveira *et al.* (2013) Genta *et al.* (2005) and Habib *et al.* (2011)

4. Conclusion

Phytochemical refers to plant chemical which includes a wide variety of compounds that occur naturally in plants. Yacon tubers are rich in various compounds and contain saccharides, fibre, proteins, amino acids (tryptophan) lipids, ash, vitamins like B_1, B_2, C, β-carotene and polyphenols like chlorogenic acid along with minerals like potassium, phosphorus, calcium, magnesium, sodium and iron. 70-80% of dry matter is composed of saccharides, mainly fructooligosaccharides which is a prebiotic non-digestible carbohydrate because of which yacon tubers have got huge potential in preventing digestive disorders such as diabetes and obesity. In yacon leaves, polyphenolic antioxidants like hydroxycinnamic acids and chlorogenic acid are present whereas di- and sesquiterpenes like ent-kaurenic acid (ent-kaur-16-en-19-oic acid) have also been reported. Depending upon the phytochemical and therapeutic potential of yacon its tubers and other plant parts could be uses in other food and/or feed products, nutraceuticals, pharmaceuticals.

Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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