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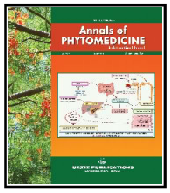

Review Article : Open Access

# A review on physicochemical characteristics, phytochemical and therapeutic potential of Yacon (*Smallanthus sonchifolius* (Poepp.) H. Robinson) flour

**Divyanshi Sharma, Abhimanyu Thakur, Rakesh Sharma, Manisha Thakur, Ankita Thakur, Kritika Kaushal and Pooja Soni**◆

*Department of Food Science and Technology, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan-173 230, Himachal Pradesh, India*

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**Abstract**

Yacon (*S. sonchifolius*) is a tuber crop native to South America, grown for its potential health benefits and unique physicochemical characteristics. The main cultivation of Yacon is done for its tuberous roots which are relatively sweet in taste and the tubers can be dried for the development of Yacon flour. It is mainly grown in Asia, Europe and North America and in India, the main cultivation of Yacon is done in North-Eastern states, Darjeeling hilly region and Himachal Pradesh due to its nutritional value and distinctive physicochemical characteristics. It is a rich source of beneficial bioactive compounds like polyphenols, phytoalexins, fructans, *etc*., which are responsible for its medicinal properties. The physicochemical characteristics of flour encompasses various aspects such as moisture content, water activity, TSS, sugars, titratable acidity, pH, ascorbic acid, phenol content, antioxidant activity, fibre content, protein content, total carbohydrates, FOS (fructo oligosaccharides) and ash content. The content of fructooligosaccharides has been reported in the range of 6.40 to 70.00%, TSS from 13.40 to 80.00°B and proteins 0.50 to 8.50% and having phytochemical properties like antimicrobial, antifungal, anticancer, antibacterial, hypolipedimic, antidepressant anti-inflammatory activities along with improving gut health as it is having bifidogenic effect.

## 1. Introduction

Yacon is a sweet tasting non starchy perennial herbaceous plant which belongs to the family Asteraceae. It is indigenous to South America with the highest germplasm found in Bolivia, Peru. Yacon has acquired its name Quechua meaning Yakku “tasteless” and Unu “water” (Paula *et al*., 2015) and considered as a multifunctional food because of the presence of many beneficial compounds such as polyphenols, phytoalexins, fructans, *etc*., which also contribute to its medicinal properties (Saeed *et al*., 2017; Cao *et al*., 2018). Yacon is known as Aricoma, Jicama, Arboloco, Llacum, Ground Apple and Peruvian Ground Apple around the world. It is also known as diet potato or Yacon potato in Brazil and as Yacon strawberry in United States (Vilhena *et al*., 2000). It is grown up to the elevation of 3500 m above main sea level commercially in Asia, Europe and North America (Gurung *et al*., 2018). In India, it is cultivated in some areas of North-Eastern states, Darjeeling hilly region and also gaining popularity recently in Himachal Pradesh due to its high nutritional value.

The main cultivation of Yacon is done for its tuberous roots which are relatively sweet in taste, have crispy and juicy texture and are mainly consumed in its fresh form (Reis *et al*., 2012). The texture and flavour of its tuberous roots has been described somewhat similar to a blend of apple and watermelon (Paula *et al*., 2015) with appearance to that of sweet potato (Scher *et al*., 2009). The shape of Yacon tubers can be pear shaped, reverse pear shaped, lemon shaped, cylindrical or spherical with its colour ranging from white, purple, cream, white with purple striations and pink to yellow (Huaycho *et al*., 2016). The weight of the Yacon tubers may vary from 50 to 500 g (Saeed *et al*., 2017) and a single plant can produce more than 10 kg of tubers (Ojansivu *et al*., 2011).

Freshly harvested Yacon has a very little calorific value and its tubers are rich source of vitamins ($B_1$, $B_2$, $B_3$, β carotene, *etc*.), minerals (potassium, phosphorous, calcium, magnesium, sodium and iron) as well as saccharides, fibre, proteins, amino acids, lipid, ash and polyphenols (chlorogenic acid, caffeic acid and ferulic acid). Saccharides, mainly, fructooligosaacharides which are prebiotic non-digestible carbohydrate make about 70-80% of the dry matter (Thakur *et al*., 2022). FOS has β (2-1) glycosidic linkage which consist of mainly kestose, nestose and fructofuranosyl nystose (Wagner *et al*., 2019) and act as prebiotic as they help in increasing the number of beneficial bacteria mainly *Lactobacilli* and *Bifidobacterium* (Pedreschi *et al*., 2003) and act as prebiotics. Yacon possess antioxidant, antimicrobial, antiviral, anti-inflammatory, anticarcinogenic, pre-biotic, laxative and hypoglycaemic effects due to the presence of several phytochemicals such as carotenoids, flavonoids, terpenoids, tannins, alkaloids, *etc*., as well as plays role in increased mineral absorption, weight reduction and total cholesterol reduction (Paula *et al*., 2015). Yacon also improves gut health as it has bifidogenic effect, help in prevention of constipation, colon cancer, diabetes, obesity, improves digestion, treat kidney problems and plays a role in skin rejuvenation (Lachman *et al*., 2003; Genta *et al*., 2009). Yacon can be dried into flour and the high levels of various phytochemical

**Corresponding author: Ms. Pooja Soni**
*Department of Food Science and Technology, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan-173 230, Himachal Pradesh, India*
**E-mail: poojasoni70188@gmail.com**
**Tel.: +91-9015391393**

compounds and FOS, allow its use in development of various value added products.

## 2. Development of Yacon flour

Scher *et al.* (2009) have reported suitable drying temperature for blanched Yacon tubers as 70ºC with the best physicochemical characteristics. Pereira *et al.* (2013) have reported drying process in Yacon tubers has been improved by osmotic dehydration, whereas, foam mat drying and freeze drying technologies have been used by Franco *et al.* (2016) and Khajehei *et al.* (2018), respectively. The best drying temperature for Yacon tubers have been recorded as 55ºC by Salinas *et al.* (2018), whereas Brito *et al.* (2019) have dried the Yacon in dehydrator (tray type) to obtain Yacon flour. Lancetti *et al.* (2020) have dried Yacon in three different forms as pulped Yacon, cut cubed pieces and sliced pieces for 16 hours at 65°C with the addition of bisulphite and concluded that the flour obtained from the sliced Yacon tubers showed the best physicochemical characteristics. Sotelo *et al.* (2021) have peeled and sliced Yacon tubers followed by drying at 55ºC in a forced convection tray dryer to obtain the Yacon flour. Gangta *et al.* (2023) carried out the study on drying of Yacon tubers and reported that pre-treatment with dipping in KMS 0.3% + citric acid 0.05% for 20 min followed by drying under mechanical cabinet drier at 60°C gives the yield of 11.12% with best physicochemical characteristics. The unit operations for the preparation of flour from Yacon tubers have been given in Figure 1.


**Figure 1: Unit operations for the preparation of flour from Yacon tubers.**

Moscatto *et al.* (2006) have observed the mean yield of Yacon flour as 7.50%, whereas a slightly higher yield of Yacon pulp powder has been reported as 7.94% by Pereira *et al.* (2013). The yield of Yacon flour prepared from sun dried tubers have been observed as high as 12.40%, whereas in solar dried and mechanical cabinet dried tubers, the yield of Yacon flour have been reported as 11.37 and 11.12%, respectively (Gangta, 2023)

### 2.1 Physicochemical characteristics of Yacon flour

The yield and quality of the dried product is influenced by various factors like initial moisture content, drying temperature and time, susceptibility of material to heat damage, pre drying treatments and moisture content of finished product. The various physicochemical characteristics of Yacon flour have been discussed further.

#### 2.1.1 Colour

Alles *et al.* (2013) have reported L* value as 76.25, a* value as -1.03 and b* value as 1.02 in Yacon flour, whereas Brites *et al.* (2016) have observed Lð , a* and b* values in Yacon flour as 97.47, 0.08 and 1.76, respectively. Sotelo *et al.* (2021) have observed Lð , a* and b* values as 61.70, 9.19 and 36.60, respectively in Yacon flour. Gangta *et al.* (2023) has reported Lð , a* and b* values as 56.61, 3.33 and 15.34, respectively, in case of flour prepared from sundried tubers, whereas in case of flour prepared from solar tunnel dried tubers, Lð value has been reported as 68.89, a* value as 2.16 and b* value as 10.87. In case of mechanical cabinet dehydrator (60 ± 2°C.), Lð , a* and b* values in the same have been reported as 68.93, 2.21 and 11.94, respectively.

### 2.1.2 Moisture

Moscatto *et al*. (2006) have reported moisture content in a wide range of 4.37 to 8.52% in different samples of Yacon flour, whereas the same parameter has been observed as 6.90% in dried Yacon flour (Rodrigues *et al*., 2012). Pereira *et al*. (2013) have reported a higher moisture content of 8.09% in Yacon pulp flour. A higher moisture content of 7.50% has been reported in Yacon flour by Brito *et al*. (2019). Mikhailov *et al*. (2020) have reported moisture content as 6.35% in Yacon flour, whereas lower moisture content of 5.77% has been recorded by Sotelo *et al*. (2021). The moisture content has been reported as 5.35, 4.34 and 4.31% in case of Yacon flour prepared from grinding of tubers dried in open sun, solar tunnel and mechanical cabinet dehydrator, respectively (Gangta *et al*., 2023).

### 2.1.3 Water activity

Alles *et al*. (2013) have observed water activity as 0.284 for Yacon flour obtained by membrane technology. A higher water activity in the range of 0.390 to 0.460 has been observed in dried Yacon flour by Salinas *et al*. (2018). Correa *et al*. (2021) have reported water activity in a wide range of water activity as 0.364 to 0.548 among different treatments of Yacon flour. The water activity has been reported as 0.213, 0.208 and 0.203 in case of Yacon flour prepared by grinding of tubers which were dried in open sun, solar tunnel and mechanical cabinet dehydrator, respectively (Gangta *et al*., 2023).

### 2.1.4 TSS

Scher *et al*. (2009) have reported TSS content in the range of 13.40 to 16.90 ºB in different treatments of dehydrated Yacon slices, whereas Pereira *et al.* (2013) have observed a higher TSS content as 42.00 °B in powder prepared from dried Yacon pulp. Gangta *et al*. (2023) has reported TSS as 71.40, 73.00 and 81.00 ºB in Yacon flour prepared from sun dried, solar dried and mechanical cabinet dried tubers, respectively.

### 2.1.5 Sugars

Brizzolari *et al*. (2019) have reported reducing sugar content as 40.90% in Yacon tuber powder. Mikhailov *et al*. (2020) have observed total sugars content as 50.63% in Yacon flour. The reducing sugars has been reported as 21.42, 29.26 and 39.09% in case of Yacon flour prepared from grinding of tubers dried in open sun, solar tunnel and mechanical cabinet dehydrator, respectively, whereas the total sugar content of the same has been reported as 54.39, 58.09 and 68.82%, respectively (Gangta *et al*., 2023).

### 2.1.6 Titratable acidity

Scher *et al*. (2009) have reported a wide range of titratable acidity as 4.08 to 6.64% in dehydrated Yacon slices, whereas Pereira *et al*. (2013) have observed the same attribute as 0.91% in powder prepared from dried Yacon pulp. The titratable acidity as 0.82, 0.86 and 0.90% in Yacon flour prepared from sun dried, solar dried and mechanical cabinet dried tubers, respectively, has been reported by Gangta *et al*. (2023).

### 2.1.7 pH

Scher *et al*. (2009) have reported pH in the range of 6.00 to 6.38 in dehydrated Yacon slices. The pH values has been reported as 5.41, 5.40 and 5.06 in case of Yacon flour prepared from grinding of tubers and dried in open sun, solar tunnel and mechanical cabinet dehydrator, respectively has been reported by Gangta *et al*. (2023).

### 2.1.8 Ascorbic acid

Kim *et al*. (2010) have reported ascorbic acid content in Yacon flour as 0.67 mg/100 g. The ascorbic acid content has been reported as 9.10, 10.02 and 22.95 mg/100 g in case of Yacon flour prepared from grinding of tubers dried in open sun, solar tunnel and mechanical cabinet dehydrator, respectively (Gangta *et al*., 2023).

### 2.1.9 Total phenols

Kang (2013) have reported total phenols in a wide range of 2400.00 to 3850.00 mg/100 g in Yacon flour, whereas the same has been observed as low as 275.00 mg GAE/100 g by Sousa *et al*. (2015). Caetano *et al*. (2016) have reported the total phenolic content in a wide range of 790.00 to 3080.00 mg/100 g in Yacon flour. The total phenolic content has been observed as 181.00, 83.00, 232.00 and 451.00 mg GAE/100 g in Yacon flour obtained from freeze-dried Yacon, dried Yacon pulp, dried Yacon cubes and dried sliced Yacon, respectively (Lancetti *et al*., 2020). Gangta *et al*. (2023) has observed total phenolic content as 145.10, 202.85 and 309.72 mg/100 g in Yacon flour prepared from sun dried, solar dried and mechanical cabinet dried tubers, respectively.

### 2.1.10 Antioxidant activity

The numerous bioactive phytoconstituents present act as scavengers of reactive oxygen species, and hence possess antioxidant activity (Thakur *et al.,* 2020). Sousa *et al*. (2015) have reported ABTS antioxidant activity as 222.00 mg AAE/ 100 g in Yacon flour. The ABTS antioxidant activity has been observed as 64.00, 21.00, 43.00 and 95.00 ìg TE/100 g in Yacon flour obtained from freeze-dried Yacon, dried Yacon pulp, dried Yacon cubes and dried sliced Yacon, respectively (Lancetti *et al*., 2020). The antioxidant activity [as per DPPH (2, 2-Diphenyl-1-picrylhydrazyl) radical scavenging activity] has been reported as 91.72, 93.42 and 94.89% in case of Yacon flour prepared from grinding of tubers dried in open sun, solar tunnel and mechanical cabinet dehydrator, respectively (Gangta *et al*., 2023).

### 2.1.11 Fibre

Rolim *et al*. (2011) have reported soluble and insoluble fibre as 2.67 and 9.45%, respectively in Yacon flour. Rodrigues *et al*. (2012) have observed higher fibre content as 13.25% in Yacon tuber flour, whereas the same attribute has been reported as 11.79% in flour prepared from dried Yacon pulp by Pereira *et al*. (2013). The same attribute has been observed as high as 11.10% as observed as observed by Danielita *et al*. (2019). Gangta *et al*. (2023) has reported crude fibre content as 3.44, 3.66 and 4.85% in Yacon flour prepared from sun dried, solar dried and mechanical cabinet dried tubers, respectively.

### 2.1.12 Protein

Rolim *et al*. (2011) have recorded protein content as 3.36% in Yacon flour, whereas lower protein content of 2.70% has been reported by Rodrigues *et al*. (2012). A higher protein content of 4.50% in powder prepared from dried Yacon pulp has been observed by Pereira *et al*. (2013). Danielita *et al*. (2019) have observed protein content as 2.55% in Yacon flour, whereas a lower content of 1.80% in the same has been recorded by Brizzolari *et al*. (2019). Mikhailov *et al*. (2020) have reported protein content as 6.88% in Yacon flour, while Sotelo *et al*. (2021) have recorded higher protein content of 8.50%. The protein content has been reported as 0.50, 0.60 and 0.78% in case of Yacon flour prepared from grinding of tubers and dried in open sun, solar tunnel and mechanical cabinet dehydrator, respectively (Gangta *et al*., 2023).

### 2.1.13 Total carbohydrates

Moscatto *et al*. (2006) have reported carbohydrate content in the range of 82.16 to 82.74% in Yacon flour, whereas carbohydrate content of 72.07% has been observed in powder prepared from dried Yacon pulp by Pereira *et al*. (2013). A higher carbohydrate content of 82.16% has been found in Yacon flour by Lim (2015). Brito *et al*. (2019) have reported the carbohydrate content as 73.50% in Yacon flour. Sotelo *et al*. (2021) have reported higher carbohydrate content as 80.04% in Yacon flour, whereas Gangta *et al*. (2023) has observed the same parameter as 58.38, 66.34 and 74.07% in Yacon flour prepared from sun dried, solar dried and mechanical cabinet dried tubers, respectively.

### 2.1.14 Fructooligosaccharides

The FOS present in tubers is a good source of energy and has a prebiotic effect, as they are used by beneficial bacteria that enhance colon health and aid in digestion. Genta *et al*. (2009) have reported FOS content as 44.20% in Yacon tuber powder, whereas a wide range of FOS as 6.40-65.00% in the same has been observed by Campos *et al*. (2012). A lower FOS content of 19.75% has been recorded in Yacon flour by Alles *et al*. (2013), while Rodrigues *et al*. (2012) have reported FOS content as high as 28.60%. Lim (2015) have reported higher FOS content as 55.33% in Yacon flour, whereas Caetano *et al*. (2016) have observed very wide range of FOS content as 6.40 to 70.00%.

### 2.1.15 Ash content

Pereira *et al*. (2013) have recorded lower ash content of 2.88% in flour prepared from dried Yacon pulp. The ash content has been observed in a wide range of 4.37 to 5.08 and 5.38 to 5.73 in foam mat dried Yacon juice flour and Yacon concentrate flour, respectively (Franco *et al*., 2016). Danielita *et al*. (2019) have reported ash content as 4.34% in Yacon flour, whereas the same parameter has been observed in a wide range of 1.10 to 6.70% by Brito *et al*. (2019). The ash content has been reported as 3.67, 3.62 and 3.55% in Yacon flour prepared from sun dried, solar dried and mechanical cabinet dried tubers, respectively (Gangta *et al*., 2023).

**Table 1: Physicochemical characteristics of Yacon flour**

| Parameter | | Range | Reference |
|---|---|---|---|
| **Colour** | **L*** | 56.61-97.47 | Alles *et al*. (2013); Brites *et al*. (2016); Sotelo *et al*. (2021); Gangta *et al*. (2023) |
| | **a*** | -1.03-9.19 | |
| | **b*** | 1.02-36.60 | |
| **Moisture (%)** | | 4.31-8.52 | Moscatto *et al*. (2006); Rodrigues *et al*. (2012); Pereira *et al*. (2013); Brito *et al*. (2019); Mikhailov *et al*. (2020); Sotelo *et al*. (2021); Gangta *et al*. (2023) |
| **Water activity** | | 0.203-0.548 | Alles *et al*. (2013); Salinas *et al*. (2018); Correa *et al*. (2021); Gangta *et al*. (2023) |
| **TSS (°B)** | | 13.40-81.00 | Scher *et al*. (2009); Pereira *et al*. (2013); Gangta *et al*. (2023) |
| **Total sugars (%)** | | 50.63-68.82 | Mikhailov *et al*. (2020); Gangta *et al*. (2023) |
| **Reducing sugars (%)** | | 21.42-40.90 | Brizzolari *et al*. (2019); Gangta *et al*. (2023) |
| **Titratable acidity (%)** | | 0.82-6.64 | Scher *et al*. (2009); Pereira *et al*. (2013); Gangta *et al*. (2023) |
| **pH** | | 5.06-6.38 | Scher *et al*. (2009); Gangta *et al*. (2023) |
| **Ascorbic acid (mg/100 g)** | | 0.67-22.95 | Kim *et al*. (2010); Gangta *et al*. (2023) |
| **Total phenols (mg GAE/100 g)** | | 83.00-3850.00 | Kang (2013); Sousa *et al*. (2015); Caetano *et al*. (2016); Lancetti *et al*. (2020); Gangta *et al*. (2023) |
| **Anti-oxidant activity (%)** | | 222.00 mg AAE/ 100 g | Sousa *et al*. (2015); Lancetti *et al*. (2020); Gangta *et al*. (2023) |
| | | 21.00-95.00 µg TE/100 g | |
| | | 91.72-94.89 | |
| **Fibre (%)** | | 2.67-13.25 | Rodrigues *et al*. (2012); Pereira *et al*.(2013); Danielita *et al*. (2019); Rolim *et al*. (2011); Gangta *et al*. (2023) |
| **Protein (%)** | | 0.50-8.50 | Rolim *et al*. (2011); Rodrigues *et al*. (2012); Pereira *et al*. (2013); Danielita *et al*. (2019); Brizzolari *et al*. (2019); Mikhailov *et al*. (2020); Gangta *et al*. (2023) |
| **Total carbohydrates (%)** | | 58.38-82.74 | Moscatto *et al*. (2006); Pereira *et al*. (2013); Lim (2015); Brito *et al*. (2019); Sotelo *et al*. (2021); Gangta *et al*. (2023) |
| **Fructooligosaccharides (FOS) (%)** | | 6.40-70.00 | Genta *et al*. (2005); Campos *et al*. (2012); Alles *et al*. (2013); Rodrigues *et al*. (2012); Lim (2015); Caetano *et al*. (2016) |
| **Ash content (%)** | | 1.10-6.70 | Pereira *et al*. (2013); Franco *et al*.(2016); Danielita *et al*. (2019); Brito *et al*. (2019); Gangta *et al*. (2023) |

### 2.2 Phytochemical and therapeutic potential of Yacon flour

Various phytochemical compounds have been reported in plants with their biological activity and include several varieties of medicinal and therapeutic plants (Thakur *et al.,* 2022). The interest in discovering new products with beneficial pharmacological effects is growing due to the huge potential of bioactive from fruits and their by-products to maintain or improve health (Hamid *et al.,* 2020). The consumption of various fruits and vegetables can reduce various types of cancer and are believed to have antimutagenic and anticarcinogenic effects (Thakur *et al*., 2019). Yacon is a rich source of beneficial bioactive compounds like polyphenols, phytoalexins, fructans, *etc*., which are responsible for its medicinal properties. Yacon flour have various phytochemical compounds specially fructooligosaccharides that are responsible for various health effects as a food. The various functional compounds can help in the reduction of various diseases like bronchitis, asthma, cold, flu, fever, cancer, CVD's and ultimately boost up the immunity (Bhatt *et al.,* 2021; Kaushal *et al.,* 2022). According to various studies, the phytochemicals helps to prevent from depression, plays a good role as a antimicrobial, antifungal, anti-inflammatory and also used for mood swings patients. The various components extracted using HPLC, *i.e.,* fructose (8.16 g), glucose (3.76 g), sucrose (7.25 g) and fructooligosaccharides (52.20 g) identified by Grancieri *et al.* (2023) and the fructooligosaccharides are well known to be used as functional food ingredient (Sharma *et al.,* 2020). The various studies carried out on phytochemical and therapeutic potential of Yacon flour have been mentioned in Table 2.

**Table 2: Phytochemical and therapeutic potential of Yacon flour**

| Property | Compounds/ minimal inhibitory weight | Method/ model used and results | Reference |
|---|---|---|---|
| **Antimicrobial** | Fructooligosaccharide- 340 mg/kg/d *Salmonella enteritidis serovar Typhimurium* in a mouse | Prevent infection against *S. Typhimurium* | Velez *et al.* (2012) |
| **Antifungal** | Yacon extract: 25 to 400 µg/ml | Effect against *Candida albicans* | Federizzi *et al.* (2023) |
| **Anticancer** | 7.5 pr cent FOS from Yacon flour for 8 weeks 25 mg/kg/ bw dimethylhydrazine in male Wistar rats | Effect against collectrol cancer | Grancieri *et al.* (2023) |
| **Antibacterial** | Yacon flour Diet + *B. longum*Yacon flour + *B. longum* in Wisatr rats | Increase in fracture strength Yacon flour (8.1%) Diet + *B. longum* (8.6%), Yacon flour + *B. longum* (14.6%) Prevention of disease like osteo-phorosis | Rodrigues *et al.* (2012) |
| **Hypolipedimic effect** | Yacon flour tablets 340-6800 mg/kg/ bw Diabetic ratsYacon flour 20 g twice a day | Effect against diabetic rats. Reduce the serum glucose level | Habib *et al.* (2011) Ashraf *et al.* (2022) |
| **Antidepressent** | Yacon tuber (100 mg/ kg) powder in mice | Mood improving potential | Wosko *et al.* (2021) |
| **Antiinflammatory** | Probiotic yogurt and Yacon flour Mice | Effect against obesity associated inflammation | Pereira *et al.* (2022) |

## 3. Conclusion

In certain countries, several products have been developed using Yacon tubers such as jam, syrup, concentrates, chips, flour, shake, RTS, marmalade, wine, herbal tea, chocolate, *etc*. The various physicochemical characteristics of fresh Yacon tubers and Yacon flour states that Yacon tuber and flour is a rich source of fructooligosaccharide, antioxidant activity and total phenols which makes it a valuable addition to the realm of functional foods. Yacon tubers and flour has high FOS, TSS and sugar content with a low glycemic index which makes it suitable for the patients suffering from diabetes, obesity and metabolic disorders. Yacon tuber and flour contains high ascorbic acid, protein, fibre and ash content. In conclusion, Yacon tubers and its flour are nutritionally and functionally rich which can be incorporated into various products to increase their functional value.

## Conflict of interest

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

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