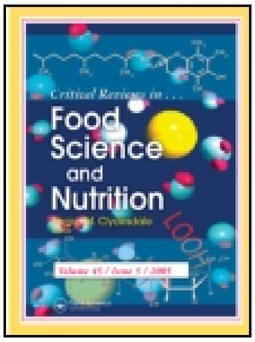

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Yacon (*Smallanthus Sonchifolius*): A Food with Multiple Functions

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Functional foods are the focus of many studies worldwide. This is justified by the effects they have on public health and thus interest in elucidation of the mechanisms involved in their actions. The present review aims to broaden the discussions of the functional properties attributed to yacon (Smallanthus sonchifolius)*, considered a food with multiple functions since it possesses bioactive compounds (antimicrobial, antioxidant, and probiotic substances) that exert beneficial effects on the body. Although some studies have already demonstrated several of these functions, clinical evidence is scarce, making it necessary that more studies are conducted in this area. Still, since the availability of this food in the market is relatively new, its popularity depends on publications aimed at consumer education and development of new products by the food industry.*

Keywords Functional food, prebiotic, insulin-type fructans, antioxidant, antimicrobial

INTRODUCTION

The beneficial effects of many foods are primarily known as a result of observing the eating habits of the oriental population, who present reduced incidences of several noncommunicable chronic diseases (breast cancer, osteoporosis, and cardiovascular diseases). However, recent scientific interest is in elucidating the food components responsible for such actions and mechanisms by which they act (Oliveira et al., 2002; Antunes et al., 2007). The term “functional food” was introduced in Japan in the mid-80s with use of FOSHU, an acronym for *Food for Specific Health Use* (Sgarbieri and Pacheco, 1999). This terminology refers to all foods similar in appearance to conventional foods, which contain biologically active components and when consumed as part of a regular diet, can produce physiological benefits with the potential to reduce the risk of chronic diseases in addition to their basic nutritional functions (FAO, 2007).

The search for this type of food has attracted attention not only from the scientific community but also from the public, who desire to maintain healthy nutritional status and reduce the risk or delay the onset of diseases. Given the growing interest for this type of product, a scenario of increased demand and consequent development of new products by the food industry has been created.

Yacon (*Smallanthus sonchifolius*), considered a functional food, has been grown for centuries by pre-Hispanic people for their subsistence. Its use has been overlooked until the mid-80s, when peculiarities were found in its chemical composition that could be beneficial to human health. Since then, findings and disclosure of its properties have stimulated its marketing (Maldonado et al., 2008). Considering this emerging interest, past and present data obtained on this root should be published and made available to the public. Therefore, the objective of the present review is to broaden discussions on functional properties attributed to yacon, and for this purpose the major scientific studies published so far will be used to validate the benefits that yacon has on health.

GENERAL INFORMATION ON YACON

Origin and Production

The yacon word is derived from the Quechua Indian language, meaning Yakku “tasteless” and Unu “water”, but each country may present its own derivations. In Brazil, it is known as the yacon potato or *diet* potato, in Peru and Ecuador is named aricoma or jicama, and in the United States is called yacon strawberry (Vilhena et al., 2000).

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Yacon belongs to the family Asteraceae and is native to South America, specifically the Andean valleys of Colombia, Ecuador, Peru, Bolivia, and northwestern Argentina. Traditionally, it is grown at altitudes from 2000 to 3100 m. Maturity is reached between 6 and 12 months after planting when flowering begins and plant height can reach 1.0 to 2.5 m (Manrinque et al., 2005).

Cultivation of yacon occurs in different countries for food and medicinal uses (Fernández et al., 1997; Vilhena et al., 2000; Seminário et al., 2003; Duarte et al., 2008). This migratory route began in the 1960s, when it was transported from Ecuador to New Zealand. In 1985, it was taken from New Zealand to Japan where the first studies were performed to determine its chemical composition and beneficial effects on health. From Japan, yacon arrived in Brazil (1989) (Seminário et al., 2003; Moscatto et al., 2004), brought by Japanese immigrants. Currently, it is also cultivated in Central Europe, particularly in the Czech Republic (Valentova et al. 2004).

Physicochemical and Sensory Characteristics and Implications of Conservation Techniques

Table 1 shows the chemical composition of yacon *in natura* according to data compiled from different studies. It is observed that the root presents low concentrations of micronutrients such as calcium, phosphorus, and iron, and considerable amounts of potassium and vitamin C. Among macronutrients, carbohydrates stand out given their high concentration, but it is noteworthy that the total fiber may represent about 30% of these carbohydrates. When considering total fiber, it is observed that the oligosaccharide content (which corresponds to a portion of soluble fiber) may reach 46%. Thus, its composition is primarily composed of water and carbohydrates which are principally stored in the form of fructooligosaccharides (FOS) and other free sugars.

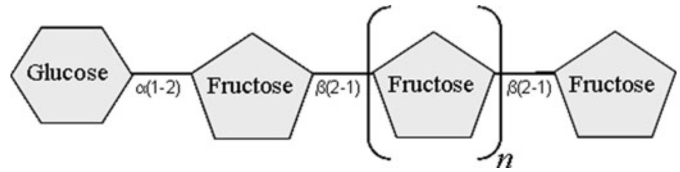

Figure 1 Representation of the structure of insulin-type fructans (*n* may vary from 2–10 or 2–60).

Despite scientific references citing that insulin is the main carbohydrate in the root, it is important to note that in yacon FOS is predominant. The difference between FOS and insulin resides in the number of fructose molecules that make up the polysaccharide chains. In insulin, this number varies from 20 to 60, whereas in FOS, whose chains are shorter, these are between 2 and 10 fructose molecules (Fig. 1). This means that the FOS can be considered a subgroup of insulin, which is why some authors prefer the term insulin -type FOS to refer more precisely to the nature of these sugars (Goto et al., 1995; Seminário et al., 2003; Manrique et al., 2005). Insulin and FOS are also denominated insulin-type fructans, a generic term used to describe oligo or polysaccharide prebiotics in which the glycosidic bond fructose–fructose $\beta(2.1)$ predominates (Roberfroid, 2005; Yıldız, 2011) (Fig. 1). Considering the chemical structure of these soluble fibers, during the human digestive process the hydrolytic enzymes are not able to cleave the β(2-1) bonds.

The FOS present in the root are nonreducing sugars and present the advantage of not being susceptible to the Maillard reaction. Regarding stability, these compounds are stable at pH greater than 3 and at temperatures up to 140°C. Thus, FOS are not degraded in most thermal processes used in the food

Table 1 Chemical composition of yacon *in natura* (g/100 g)

	Grau and Rea (1997)	Manrinque et al. (2004)	Hermann et al. (1999)	Lachman et al. (2003)	Santana and Cardoso (2008)	Vasconcelos et al. (2010)
Carbohydrates	nd	nd	9–13	13.8	nd	5.51
Oligosaccharides	nd	nd	nd	nd	nd	1.89
Proteins	0.4–2.0	0.1–05	2.7–4.9	1.0	nd	0.13
Lipids	0.1–0.3	nd	0.112–0.464	0.1	nd	0.01
Moisture	70–93	85–90	nd	81.3	nd	91.10
Total fiber	0.3–1.7	nd	3.1–4.1	0.9	nd	2.95
Ash	0.3–2.0	nd	4.3–6.0	1.1	nd	nd
Potassium	nd	0.185–0.295	0.180–0.290	0.334	nd	nd
Calcium	0.023	0.006–0.013	0.056–0.131	0.012	nd	nd
Phosphorus	0.021	nd	0.182–0.309	0.034	nd	nd
Iron	0.0003	nd	nd	0.0002	nd	nd
Retinol	0.010	nd	nd	nd	nd	nd
Carotene	0.00008	nd	nd	0.00013	nd	nd
Thiamin	0.00001	nd	nd	0.00007	nd	nd
Riboflavin	0.0001	nd	nd	0.00031	nd	nd
Niacin	0.00033	nd	nd	nd	nd	nd
Ascorbic acid	0.013	nd	nd	0.005	nd	nd
Tryptophan	nd	nd	nd	nd	0.00146	nd

nd = not determined.

industry (Santana and Cardoso, 2008), an important factor in the development of new products.

The shelf life of yacon is limited due to its high water content (Genta et al., 2005). In addition, yacon has been reported as a good source of the phenol oxidase enzyme, which catalyzes the oxidation of phenolic compounds. Upon peeling, the root suffers rapid browning when its tissue is exposed to air. This is because during removal of the outermost plant tissues the cell membranes are disrupted and the polyphenols and tannins found inside the outer skin are available to mix with other components, mainly cytoplasmic enzymes, which can cause the process known as enzymatic oxidation. This oxidation occurs in the presence of free oxygen, which causes the freshly cut surface of the yacon root to brown quickly, making it and its products visually unattractive. Control of this browning is usually limited to enzyme inhibition, which occurs via condensation of polyphenols with amino compounds and polymerization of polyphenols. Methods proposed for the prevention of oxidation are: dehydration, low temperature storage, use of antioxidants and removal of oxygen from the medium (Yabuta et al., 2001; Mayer, 2006; Santana and Cardoso, 2008). These processes are simple alternatives that ensure chemical stability without significant changes to the carbohydrates profile (Genta et al., 2005).

The composition of the yacon roots are influenced by the cultivar, seasons of planting and harvesting, planting altitude, postharvest storage conditions (time and temperature), and especially the methodology used for quantification of these substances (Seminário et al., 2003; Manrinque et al., 2005; Yun et al., 2010).

Despite the Andean origin, the yacon is a species highly adaptable to different climates (develops in regions with temperatures ranging from 0–24ºC), altitudes (800–2800 m above sea level), and soil types (Manrique et al., 2005; Santana and Cardoso, 2008). However, at lower altitudes, maturity is early. This stage is then followed by a period in which oligofructan content in the rhizophores and tuberous roots increases (Santana and Cardoso, 2008).

In the Andean region, yacon can be harvested throughout the year in well-watered and frost-free soils. On the other hand, there are areas with only one growing season where planting is performed at the beginning of the rainy season (Manrique et al., 2005).

Regarding the time and temperature of storage, upon harvest of the root they become independent units and therefore chemical and biochemical transformations play an important role in energy production for the respiration and transpiration processes (Santana and Cardoso, 2008). The energy required to meet metabolic demands of the root are provided by depolymerization of the stored insulin-type fructans chains. Thus, after harvest, there is rapid alteration in the chemical composition of carbohydrates in which polymerized sugars tend to depolymerize as the postharvest time increases, i.e., fructans are hydrolyzed to di-and monosaccharides by action of the enzyme fructan hydrolase (FH), which converts fructans into sucrose, fructose, and glucose. The enzyme invertase can then act on this substrate (sucrose molecules), to produce free fructose and glucose (Carvalho, 2004).

After a week of storage at room temperature (25°C), about 30 to 40% of FOS are converted into simple sugars (Graefe et al., 2004). However, according to Manrique et al. (2005), the speed of this conversion is slower if yacon is stored under refrigeration (approximately 4–10°C), and this condition also aids to reduce the rates of roots decay and deterioration during storage. Due to depolymerization of accumulated fructans after harvest, it is very important to establish a postharvest management routine that seeks to minimize changes in the content and distribution of carbohydrates in order to prolong shelf life. It appears that greatest content of oligofrutanos is guaranteed when the roots are immediately processed after harvest or refrigerated (Manrique et al., 2005). These measures allow for greater conservation and stabilization of oligofrutanos.

Popular Use

The yacon root has a sweet flavor and crunchy texture, similar to a combination of apple and watermelon (Herbal Guides, 2010), and can be eaten raw, boiled (in the form of soup), roasted, dehydrated, in beverages (Anonymus, 1989; Vilhena et al., 2000), or processed (Genta et al., 2005) in the form of jam (Prati et al., 2009), syrup (Manrique et al., 2005), vinegar (Hondo et al. 2000a), flour (Moscatto et al., 2004, Rosa et al., 2009), chips (dried yacon cut into slices), and juice (Santana and Cardoso, 2008). In Japan, the tuberous roots are transformed into bakery products, fermented beverages, freeze-dried powder, or pulp, pickles, and other products (Santana and Cardoso, 2008).

In the region of Cajamarca, Peru, yacon is used as an antirachitic food. Andean folk medicine claims that the roots act as a remedy for liver and kidney diseases. In Bolivia, the root is consumed by people with diabetes and digestion problems. Andean farmers also consider it a skin rejuvenator, and according to one popular version, the residents of Cajamarca eat yacon before bedtime to slow aging. The aerial portion of the plant is used for preparation of medicinal teas, where studies have shown that tea made from the leaves presents hypoglycemic and hypocholesterolemic activities (Vilhena et al., 2000; Valentova et al., 2004).

The subterranean organs of yacon which contain 60 to 70% fructans in the form of insulin-type FOS can be used in the manufacture of dietary products and baby food, the production of fructose syrup, a sugar of great interest to the food industry (Vilhena et al., 2000), and also used in veterinary medicine to effectively counter digestive disorders in cattle (Seminário et al., 2003).

It is interesting that literature does not report potential toxic effects of yacon (Genta et al., 2005; Geyer et al., 2008; Genta et al., 2009), where it is assigned to historically safe use in South America and other regions (Ojansivu et al., 2011) with the exception of the work of Yun et al. (2010), who reported the first case of anaphylaxis after ingestion of yacon roots by a 55-year-old Korean woman. This woman was treated in the hospital for developing generalized urticaria, pruritus, and coma within 5 minutes of ingesting yacon roots. Skin tests were carried out with juice extracted from the yacon root and results presented 3.5 × 4.0/positive reaction to histamine, negative reaction to saline, and 4.5 × 7.0/positive reaction to yacon juice. There were also reports of tingling, pain, and numbness in the oral cavity and around the lips about 5 minutes after ingestion of 2 g of the yacon root. Oral susceptibility testing was interrupted because the patient complained of chest tightness and dizziness.

FUNCTIONAL PROPERTIES OF YACON

Bioactive Compounds

All food substances (nutrients or not) present in unmodified food or added to a carrier food are considered bioactive compounds (FAO, 2007). Thus, functional foods can be classified according to the bioactive compounds present (Magalhães et al., 2010). Yacon is a multifunctional food because it contains several bioactive compounds, including: phytoalexins which have antimicrobial activity (Inoue et al., 1995), phenolic compounds that exert antioxidant activity, such as chlorogenic acids (Seminário et al., 2003; Genta et al., 2005), and high contents of fructans (insulin and FOS) that have prebiotic properties (Lobo et al., 2007; Geyer et al., 2008; Gibson, 2008; Genta et al., 2009).

Antimicrobial Substances

Evidence of the antimicrobial properties of yacon is revealed by the peculiarities of its cultivation: planting of yacon requires practically no pesticides, which suggests that this plant naturally contains antimicrobial substances and insecticides (Lin et al., 2003). Different antimicrobial compounds have been identified in the leaves of yacon. Inoue et al. (1995) isolated four antifungal agents from extracts of yacon leaves: sonchifolin, polymatin B, and uvedalin enhydrin. These authors found that sonchifolin presented high fungicidal activity against *Pyricularia oryzae*, a fungus which causes disease in rice paddies. Lin et al., (2003) isolated six antibacterial compounds from yacon leaves, and among the six sesquiterpene lactones, one presented potent antimicrobial activity against *Bacillus subtilis* and *Pyricularia oryzae*.

Antioxidant Substances

When compared with other tuberous roots, yacon contains a high concentration of polyphenols, about 200 mg/100 g of moist weight (Manrinque et al., 2005). This value is significant because few drinks considered rich in phenolic compounds have similar amounts: coffee (200–500 mg/cup), tea (150–200 mg/cup), and red wine (200–800 mg/cup) (Santana and Cardoso, 2008).

Polyphenols, such as chlorogenic acid ($C_{16}H_{18}O_9$), are chemical compounds with antioxidant properties since they prevent the oxidation of biomolecules by reacting with unstable atoms or molecular structures, such as free radicals (Manrinque et al., 2005; Cerqueira et al., 2007). Free radicals come into contact with the body in different ways, for example, inhalation of tobacco smoke and air pollution, ingestion of toxic substances (pesticides) or may be produced in the body by means of ionizing radiation and even by the cellular metabolism. The cell metabolism is a constant source of free radicals, since about 5% of oxygen, which acts as a final electron acceptor in the mitochondria, is not neutralized with the formation of water. Thus, the highly unstable species derived from oxygen ($O_2^{\bullet -}$, H_2O_2, $HO^{\bullet}$) act as free radicals. These compounds damage cell membranes by oxidizing lipids and proteins, and as a consequence destroy them and may cause changes in DNA, leading to many health problems, including increased risk of cancer (Abranches, 2009). Free radicals are also associated with cardiovascular diseases because they cause the oxidation of low-density lipoprotein cholesterol particles (LDL-c). When these enter the subendothelial layer by not being degraded, they generate an inflammatory process that amplifies the production of free radicals and as a final result lead to thickening and hardening of the arteries, reducing the arteriolar lumen (Manrinque et al., 2005).

Despite the high concentration of polyphenols in the root, much higher quantities are found in the leaves and stem of yacon (Manrinque et al., 2005). Hondo et al. (2000b) reported that yacon juice contains 850 ppm of phenolic compounds. The most abundant polyphenols in yacon are chlorogenic acid and phenols derived from caffeic acid (Manrinque et al., 2005). Of the five principal phenolic compounds in yacon, three are esters of caffeic acid and two are metabolites of chlorogenic acid (3-caffeoylquinic acid and 3,5-dicaffeoylquinic acid); phenolic compounds are common in plants of the family Asteraceae (Takenaka et al. 2003).

Terada et al. (2006) showed that yacon roots present strong antioxidant activity and suggested potential benefits of dietary supplementation to reduce the risk of type 2 diabetes mellitus. In this study, tricaffeoylaltraric acid was identified as the compound responsible for the most potent antioxidant activity observed.

Probiotic Substances

Different types of fructans are encountered in nature, but from a nutritional standpoint and for use in the food industry FOS and insulin as the most important (Seminário et al., 2003; Manrinque et al., 2005). While other roots store energy in the form of starch, yacon mainly stores energy in the form of insulin-type fructans (Yun et al., 2010).

As previously mentioned, the human being does not have enzymes capable of cleaving β(2-1) bonds during digestion, thus after consumption insulin and FOS are selectively fermented in the colon by a group of desirable bacteria, most notably those of the genus *Bifidobacterium*. Bifid bacteria improve gastrointestinal operation (Pedreschi et al., 2003), generating organic acids such as lactate and the short chain fatty acids (SCFA) acetate, propionate, and butyrate. Resulting from the synthesis of organic acids, the metabolism of the insulin-type fructans indirectly generates 1.5 to 2.0 kcal.g^{-1} for the host (Gibson and Roberfroid, 1995; Flamm et al., 2001; Geyer et al., 2008).

Favorable effects associated with the fermentation of insulin and FOS in the colon include increased absorption of certain minerals such as calcium and magnesium due to decreased pH and consequent solubilization of complex salts (Manrinque et al., 2005; Lobo et al., 2006, Lobo et al., 2007; Saulnier et al., 2009). These minerals are essential components of hydroxyapatite crystals [$Ca_{10}(PO4)_6(OH)_2$] present in the bone structure (Cashman, 2007), contribute to reduction of cholesterol levels (Seminário et al., 2003; Manrinque et al., 2005), and inhibit the production of toxins and carcinogens in the colon (Manrinque et al., 2005).

FOS and insulin may even modulate the physiology of the intestine similarly to dietary fiber by increasing bowel movements, reducing intestinal transit time, and promoting water retention in stools (similar to the osmotic action of laxatives). Together, these effects can control and reduce the risk of constipation (Chen et al., 2000; Manrinque et al., 2005).

Serving as a fermentative substrate for bifidobacteria, one of the major groups of probiotic bacteria (Pedreschi et al., 2003), FOS and insulin beneficially modulate the intestinal microbiota (FAO, 2007). Thus, yacon may be considered prebiotic. Through fermentation and consequent growth promotion of microorganisms beneficial to intestinal health, prebiotics are able to change the composition and functionality of the microbial population. They assume this role not only to facilitate the exclusion of potential pathogens by competition, but also to modulate the immune system, increasing defenses of the host (Berg, 1996; Lomax and Calder, 2009a; Saulnier et al., 2009).

Probiotics are considered live microorganisms which when present in adequate amounts provide health benefits to the host (FAO, 2002). Consumption of yacon is a way to stimulate the growth of these microorganisms in the colon. An *in vitro* study evaluating the fermentative capacity of three probiotic strains (two lactobacilli and one *bifidobacterium*) on FOS from yacon roots and commercial FOS revealed that all were able to ferment FOS from the yacon root (Pedrisch et al. 2003). These bacteria produce the intracellular enzyme fructosilfuranosidase necessary for hydrolysis of β(2-1) bonds in fructans (Roberfroid, 2005). An example of the influence of FOS on intestinal microbiota is found in the clinical study conducted by Guigoz et al. (2002). The authors found an increase in bifidobacteria counts in the feces of elderly individuals who received 8 g of FOS in the diet/day, consumed for 3 weeks. The bifidobacteria count increased on average 2.8 $\pm$ 0.57 log CFU/g of feces after 3 weeks of supplementation and decreased on average 1.1 log CFU/g of feces after a period without FOS, confirming the bifidogenic effect of FOS in this population group.

Increase in the number of bifidobacteria leads to greater competition with pathogenic bacteria for binding sites in the intestinal epithelium and competition for nutrients, inhibiting survival of harmful strains. Probiotic species are also capable of producing metabolites such as acids and bacteriocins which act as pathogen antagonists (Gibson and Fuller, 2000). An example of this is *Lactobacillus* and *Bifidobacterium* spp., originating from the human intestinal microbiota and producing antimicrobial substances that are active *in vitro* and *in vivo* against enterovirulent microorganisms involved in disorders such as diarrhea (Servin, 2004). Studies such as this reinforce the principle that probiotic bacteria can be used in therapeutic strategies for the control of human diseases (Ng et al., 2009).

In addition, De Simone et al. (1987) suggested that microbial substances, such as cell wall components and cytoplasmic antigens may cross the intestinal epithelium through M cells, resulting in the presentation of antigens to lymphocytes in the Peyer's patches and therefore activation of the immune response. Specific T lymphocytes expand, mature, and together with other components of the immune system amplify the synthesis of cytokines which contribute to defend the host and protect the intestinal surface (Denariaz et al., 1999; Hooper and Gordon, 2001; Liévin-Le Moal and Servin, 2006).

Besides the action of T lymphocytes, there is also the production of antibodies, specifically secretory immunoglobulin A (IgA) by differentiated B lymphocytes. Antibodies are transported across the epithelial layer toward the intestinal lumen. In the intestinal lumen, these antibodies react with specific antigens to prevent physical interaction of harmful agents (such as bacteria) with the intestine surface. This process is called immune exclusion and prevents the activation of inflammatory reactions that may damage the integrity of the mucosal surface. Therefore, probiotics are involved in local defenses, since they prevent colonization of the intestine by pathogens (Liévin-Le Moal and Servin, 2006; Romeo et al., 2010) and can serve to constantly stimulate the production of IgA. Lomax and Calder (2009b) compiled information from 21 studies with laboratory animals to suggest that aspects related to innate and adaptive immunity of the intestine, as well as systemic immunity, are affected by insulin-type fructans. This category of prebiotics is able to improve the ability of the host to successfully respond to intestinal infections and modify certain inflammatory conditions.

In summary, the different functional effects attributed to the consumption of yacon are (Fig. 2): laxative (Chen et al., 2000; Geyer et al., 2008; Genta et al., 2009), hypoglycemic (Aybar et al., 2001; Genta et al., 2009), increased mineral absorption and maintained bone health (Lobo et al., 2007; Lobo et al., 2009), reduced weight (Genta et al., 2009), reduced cholesterol (Manrinque et al., 2005) and triglyceride levels (Genta et al., 2005), antioxidant (Simonovska et al., 2003; Valentova et al., 2004), antimicrobial (Inoue et al., 1995; Lin et al., 2003; Takenaka

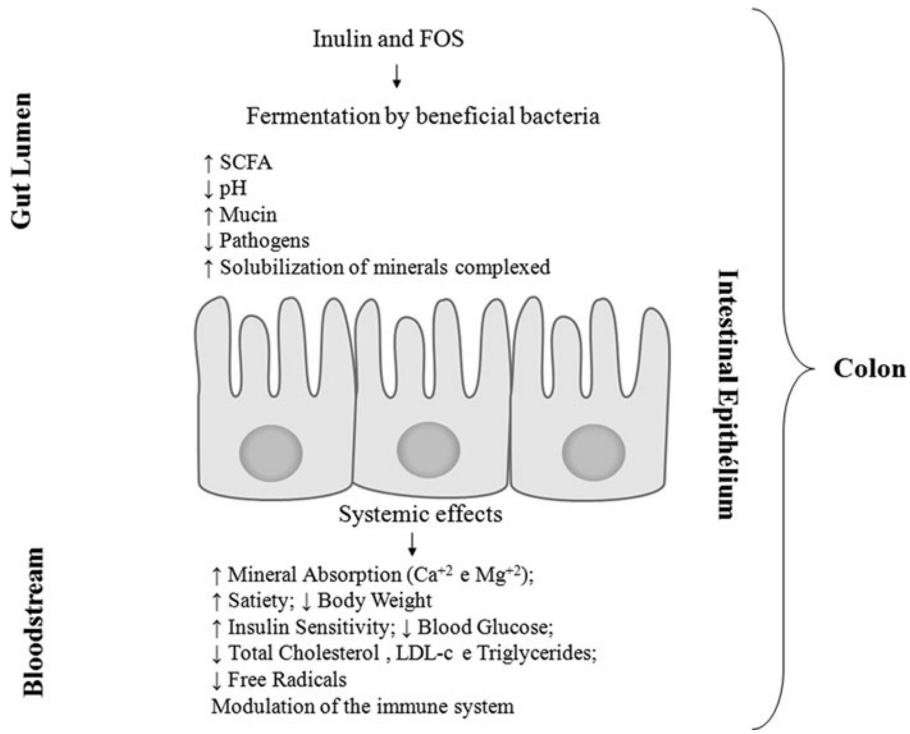

Figure 2 Representation of the functional role of yacon (*Smallanthus sonchifolius*). Abbreviation: SCFA, Short chain fatty acids.

et al., 2003; Terada et al., 2006), and prebiotic (Pedreschi et al., 2003).

FUNCTIONAL EFFECTS OF YACON

There are few studies in literature that assess the functional effects of yacon; however, those that are available provide information on the use of this promising food. The principal studies that address the functional properties of yacon are presented as follows.

Studies in Animal Models

A study with healthy and diabetic *Sprague–Dawley* rats showed that consumption of tea made from yacon leaves can help lower blood sugar, and also have positive effects on renal parameters. Yacon tea (2%) administered *ad libitum* in the place of water for 30 days to diabetic rats increased the concentration of circulating insulin (Aybar et al., 2001). However, the authors warn that the nature of the chemical component (s) responsible for these effects is not yet known nor are the compound (s) found in yacon roots. It should be noted that this effect is probably not due to the FOS, since its concentration in the yacon leaves is very low (Manrique et al., 2005).

Valentova et al. (2004) verified in *Wistar* rats the effects of tea made from yacon leaves on the viability of hepatocytes, oxidative damage, glucose metabolism, as well as its effect on the expression of cytochrome P450. The authors also confirmed the antioxidant, cytoprotective (given the increased activity of cellular detoxification via P450), and anti-hyperglycemic properties.

Another study that reinforces the hypoglycemic action of yacon is that of Baroni et al. (2008) in which the effect of consuming yacon leaf extract was investigated on blood glucose levels in diabetic and healthy rats. After 14 days of treatment, a decrease in plasma glucose was observed in diabetic and nondiabetic animals that consumed the extract. Genta et al. (2005) analyzed the influence of yacon root flour consumption as a dietary supplement (340 and 6800 mg FOS/kg body weight/day) on biochemical parameters. The study was conducted with *Wistar* rats, to which the two doses evaluated were offered during four months. There was a reduction in serum triglycerides, whereas no gastrointestinal symptoms such as diarrhea or constipation were observed; and analysis of the gastrointestinal tract showed that yacon supplementation resulted in significant enlargement of the cecum, where there is high fermentative activity of bifidobacteria.

Lobo et al. (2007) has evaluated the balance of calcium and magnesium, density and bone strength, and cecum mucosal morphometry of *Wistar* rats growing fed diets supplemented with yacon flour (5 or 7.5% FOS). The consumption of yacon resulted in a positive alteration of cecal histology (diet supplementation with 7.5% FOS significantly increased the number and depth of cecal crypts compared to the control group), balance of the minerals analyzed and positive influence on bone parameters.

Clinical Studies in Human Beings

Few studies have evaluated the influence of yacon ingestion in human health; however, the encountered results, although modest, are promising regarding the incorporation of this food to consumption habits. An example of this is the work conducted by Geyer et al. (2008) who revealed a reduction of intestinal transit time (59.7 ± 4.3 h to 38.4 ± 4.2 h), increased frequency of bowel movement (1.1 ± 0.1 times/day for 1.3 ± 0.2 times/day), and regarding stool consistency, there was a trend toward softer stools. These results were obtained after administration of 20 g yacon syrup/day (equivalent to 6.4 g FOS) for two weeks. Although none of these parameters reached statistical significance, they do indicate the clinical importance of these results.

Valentova et al. (2008) evaluated the effect of yacon on lipid and glucose concentrations in the blood of 101 individuals. In the group that received yacon, a positive effect was observed on triglyceride (mean reduction of 0.32 mmol/L) and glucose levels in the blood (mean reduction of 0.43 mmol/L), showing no adverse effects.

Genta et al. (2009) investigated the tolerance and health benefits resulting from the use of yacon syrup in overweight or obese and mildly dyslipidemic women. Women were divided randomly into three groups: (1) received yacon syrup containing 0.29 g FOS/kg body weight/day, (2) received 0.14 g FOS/kg body weight/day, and (3) received placebo syrup. The body mass index (BMI) was significantly reduced in the treated group, where this effect was not observed in the control group. Supplementation increased the frequency of defecation during the trial period by about 3.5 times compared to the placebo group. The most prominent effect observed was that after 120 days of treatment, where levels of fasting insulin and the HOMA-IR index (Homeostasis Model Assessment), an indicator for estimation of insulin resistance, significantly decreased compared to values prior to treatment, and no change was observed in the placebo group. It was also noted that after the intervention period, the groups receiving the yacon syrup presented a tendency for increase calcium concentration in the blood in relation to the initial concentration: 2.59 ± 0.01 *vs*. 2.21 ± 0.02 mmol/L ($p < 0.05$).

NUTRITIONAL RECOMMENDATIONS

A specific recommendation for the safe consumption of FOS/insulin is not yet available in the literature. The Dietary Reference Intakes for Total Fiber (National Academy of Sciences, 2005) recommends that adequate intake is 38 g for adult men and 25 g for adult women. This recommendation includes dietary fiber naturally present in vegetables and functional fiber synthesized or isolated from plants or animals and shown to be of benefit to health. The Brazilian food legislation (Resolution n°. 18/99) provides for the functional and or health claims of a nutrient from food. The legislation states that the FOS and insulin can be claimed as long as the portion of the product ready for consumption provides at least 3 g of insulin or FOS (if the food is solid) or 1.5 g of insulin or FOS (if the food is liquid). It also highlighted that the use of the ingredient (FOS or insulin) should not exceed 30 g in the daily recommendation of the product ready for consumption, as indicated by the manufacturer (Brasil, 2008). Also, according to the Herbal Guide (2011), the daily intake of approximately 200 g of yacon root has enough FOS/insulin to exert functional properties. Thus, further studies are needed to develop specific recommendations for the FOS/insulin.

Table 2 Production and composition of FOS in different plant species

Plant	T (FOS)/ha	FOS (% of fresh weight)
Artichoke	4.5	10–15
Chicory	0.9	5–10
Yacon	5.7	3–19

T = ton; ha = hectare.
Source: Van Loo et al. (1995) cited by Hauly and Moscatto (2002); Manrique et al. (2005); and Oliveira and Nishimoto (2004).

In addition to the beneficial properties mentioned, yacon appears to be a promising alternative to traditional FOS sources, such as chicory (*Cichorium endivia*) and artichoke (*Helianthus tuberosus*) (Pedreschi et al., 2003). Yacon is considered the highest plant source of FOS (Genta et al., 2005; Genta et al., 2009); it represents the greatest production of FOS in tons per hectare, compared to Jerusalem artichoke and chicory, and also possesses the greatest fructan content on a fresh basis when compared with traditional sources (Table 2).

Another favorable aspect of this plant is its high productivity. Yield is strongly affected by the planting location and the cultivar. Good management, fertilizer application, and use of high-quality seeds may lead to increased production (Manrique et al., 2005). It should also be mentioned that the plant permits for erosion control and has potential use as forage (both the subterranean and aerial portions) (Grau and Rea, 1997; Santana and Cardoso, 2008).

CONCLUSIONS

Yacon is a food that has become increasingly more well-known among the population due to disclosure of its therapeutic properties, which appears to involve: laxative effects, hypoglycemic effects, increased mineral absorption and bone health maintenance, weight reduction, reduction of total cholesterol, as well as antioxidant, antimicrobial and prebiotic effects. However, further studies are needed on this food to better elucidate its effects, since much of the data reported so far originates from studies in animal models and few studies involve humans. New knowledge obtained in the clinical field will allow for better scaling of the impact of yacon consumption on human health, since understanding of the effects and action mechanisms involved will allow for its appropriate use as a food with multiple functions.

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