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Review Article
Nutritional and Healthical Aspects of Yacon (*Smallanthus sonchifolius*) for Human, Animals and Poultry

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Abstract

Non-digestible oligosaccharides as well as phenolic compounds inulins and fructooligosaccharides of *Smallanthus sonchifolius* make it an attractive functional food. Consumption of these non-digestible oligosaccharides improves gastrointestinal metabolism, increases the growth of bifido bacteria in the colon and also acts as antioxidant, antimicrobial, prebiotic, growth promoter, hypoglycemic, hepatoprotective compounds via lowering alanine aminotransferase (ALT) and increasing mineral absorption to maintain bone homeostasis and also help to reduce cholesterol and triglyceride levels. Past to present literature have been reviewed and the results indicated that *Smallanthus sonchifolius* root consumption modulates the immune system by regulating the intestinal secretion of IgA and interferon IFN-γ subsequently enhancing resistance to infections and allergic reactions. This role not only facilitates the exclusion of potential pathogenic bacteria but also ultimately increases defense of the host. Previously published literature has focused on rat, human, pig and livestock but biological and clinical evidence is scarce on the same aspect in poultry. Therefore, this review article aimed to highlight the origin, chemical composition, different beneficial uses and biohazards of yacon plant (which contains 70-80% fructooligosaccharides (FOS)) that could be used as a novel natural prebiotic in poultry feed. The FOS could improve different health aspects and productive performance criteria of different poultry species. To recommend yacon plant as a natural and safe medicinal agent, more indices need to be determined in further studies on different livestock and poultry species on molecular level to assure its benefits and to give accurate recommendation for the optimal levels to be added as feed additive.

Key words: Yacon, prebiotic, fructooligosaccharides, inulin, nutritional aspects, poultry

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Poultry feed industry routinely uses the antibiotic growth promoters to enhance the production performance of birds. The antibiotic resistance is becoming an alarming issue across the world. Many measures have been taken to reduce the risk of infection, such as applying preventive drugs, combining use of antibiotic and hygienic or nutritional management[1-6]. Thus, due to the fact that bacteria developed resistance against many common antibacterial agents and infectious diseases; it continued to be one of the greatest health challenges worldwide. Conversely, conventional antimicrobial agents are not only generating multiple drug resistance but also induce intolerable toxicity and several adverse effects. Therefore, alternative strategies are the need of time to resolve rising pathogenic diseases to overcome this alarming problem[7]. Medicinal plants and their extracts are currently gaining more attention due to their extensive beneficial effects such as promoting growth and immune enhancement for animal and poultry production[8]. So, as a replacement of these antibiotic growth promoters, researchers found that the medicinal plants are the best option. Various plants like garlic (*Allium sativum*), neem (*Azadirachta indica*), kalonji (*Nigella sativa*), ginger (*Zingiber officinale*), turmeric savory (*Curcuma longa*), sea-buckthorn (*Hippophae rhamnoides*), mint (*Mentha arvensis*) and quercetin and its derived product, etc. have been well elucidated[9,10]. In these studies, different parts (seed, leaves, roots, bark and other vegetative parts) of given medicinal plants and their extracts were used in the diets of different animals. Poultry is susceptible to potentially large number of pathogens (*E. coli*, Clostridia and *Salmonella* spp.). In the last few decades, the functional foods were gaining an attractive interest across the world. Yacon (*Smallanthus sonchifolius*) is a well-known functional food that destined several bioactive compounds, having various biological effects such as antimicrobial[11], antioxidant[12], prebiotic[13], enhancing mineral absorption[14], reducing cholesterol and triglyceride level[15] and hypoglycemic effects[16].

Yacon (*Smallanthus sonchifolius*) is a good source of inulin and fructooligosaccharides (FOS) that helps to reduce the pH and ultimately stimulates the mineral absorption (calcium and magnesium)[17]. These minerals are crucial constituents of hydroxyapatite crystals [$Ca_{10}(PO_4)_6(OH)_2$] present in the bone structure[17], play role in reduction of cholesterol levels[18,19] and also inhibit the production of some carcinogens and toxins in human colon[20]. The FOS and inulin compounds are abundant in yacon plant that modulate the growth of intestinal commensal microbiota, subsequently increase mineral absorption which leads to maintain the bone structure, compete with potential pathogenic microbes and thus ultimately boost up the immunity of host[21,22].

Dietary yacon tuberous roots as well as leaves and stems showed positive effects on growth performance in cattle[23]. In another study the effect of yacon and black maca's extract was investigated in diabetic mice which showed a positive effect on glycemic levels and male reproductive function. Kim[24] studied the diet supplemented with yacon and pin needle powder at the rate of 1.0 and 0.5%, respectively which showed positive effects in lowering pH, cholesterol and also improving broiler meat quality[25]. Diet supplemented with yacon at 6.5% reduced blood glucose levels in mice[26].

Previously published studies have already proved several functions of yacon in human, livestock and poultry. The aforementioned systematic literature had been reviewed from different sources like Google Scholar, PubMed/Medline, Ovid, ISI Web of Science and SCOPUS. Because of the limited literature about the use of yacon in poultry, it is the first reappraisal to recommend yacon plant and the plant extract as a prebiotic source for poultry industry. Therefore, the objective of this review was to broaden knowledge and attract the attention of scientists, veterinarians and poultry nutritionist towards the importance of yacon (*Smallanthus sonchifolius*) in poultry nutrition as a novel and safe prebiotic agent.

PLANT PROFILE

Yacon is a perennial herbaceous root plant that belongs to family Asteraceae, native to the Andean regions of South America[27,28]. This herbaceous plant has branches with height of stems about 2-2.5 m high. Yacon (*Smallanthus sonchifolius)* yields starchy, fruit-like roots of various shapes and sizes that are routinely consumed as raw having sweet taste. Their crunchy texture resembles that of an apple. One plant is expected to yield more than 10 kg of roots[17].

Data presented in Table 1 illustrated the chemical composition of yacon (*Smallanthus sonchifolius*). These data which were collected from different published literature, showed that the root retain low concentrations of micronutrients; phosphorus, calcium and iron, as well as substantial amounts of vitamin C and potassium. Among the macronutrients such as carbohydrates stand out given their high concentration and total fiber is about 30% of these carbohydrates. Among the total carbohydrates, the oligosaccharide content may reach 46%. Thus, its composition is mainly composed of carbohydrates and water that are stored in the form of fructooligosaccharides and other free sugars.

Table 1: Chemical composition of yacon tuberous roots

Substances (g/100)	Manrinque *et al.*[32]	Lachman *et al.*[30]	Santana and Helena[34]	Vasconcelos *et al.*[35]
Carbohydrates	Nd	13.8	Nd	Nd
Oligosaccharides	Nd	Nd	Nd	1.89
Proteins	0.1-0.5	1.0	Nd	0.13
Fat	Nd	0.1	Nd	0.01
Moisture	85-90	81.3	Nd	91.10
Energy (kcal)	14-22	Nd	Nd	Nd
Total fiber	Nd	0.9	Nd	2.95
Ash	Nd	1.1	Nd	Nd
Potassium	0.185-0.295	0.334	Nd	Nd
Calcium	0.006-0.013	0.012	Nd	Nd
Phosphorous	Nd	0.034	Nd	Nd
Iron	Nd	0.0002	Nd	Nd
Retinol	Nd		Nd	Nd
Carotene	Nd	0.00013	Nd	Nd
Thiamin	Nd	0.00007	Nd	Nd
Riboflavin	Nd	0.00031	Nd	Nd
Niacin	Nd	Nd	Nd	Nd
Ascorbic acid	Nd	0.005	Nd	Nd
Tryptophan	Nd	Nd	0.00146	Nd

Nd: Not determined

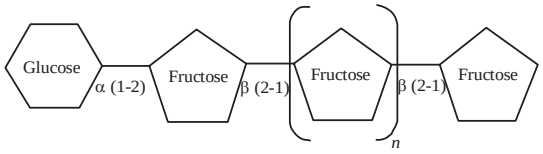

Fig 1: Chemical structure of insulin-type fructans (n may vary from 2-10 or 2-60)

Previously published studies proved that the inulin is considered as a chief carbohydrate in the yacon's root. It is worth noting that FOS is predominant in yacon. The difference between fructooligosaccharides (FOS) and inulin exist in the number of fructose molecules that make up the polysaccharide chains. In inulin fructose, molecules vary from 20 to 60, while fructooligosaccharides have short chain that is between 2 and 10 fructose molecules (Fig. 1). It was proved that the FOS could be considered as a subclass of inulin[15,23]. Inulin and FOS are also known as inulin-type fructans. The chemical structure of these soluble fibers is shown in Fig. 1, in which the glycosidic bond fructose-fructose β (2-1)[29] is present.

DISTRIBUTION

In fact, the *Smallanthus sonchifolius* plant could adapt with different climatic regions and soils which explains its expansion outside the Andean region. Yacon (*Smallanthus sonchifolius*) is presently cultivated in given areas like Brazil, Argentina, the Czech Republic, Bolivia, Ecuador, Italy, Korea, New Zealand, Japan, Peru and the United States of America[17].

TRADITIONAL USES

Yacon (*Smallanthus sonchifolius*) syrup is an excellent source of FOS and its long-term ingestion produced beneficial health effects on obese women with insulin resistance[29]. Yacon can be eaten as raw, roasted, boiled (in the form of soup), beverages[30], syrup[31] or processed[16] in jam form[32], vinegar[33], used in form of flour[34], juice and chips[35] (Table 2). As well, as other functions of yacon like potential weight loss aid, control of type II diabetes, natural sweetener, cancer preventer, preventer of fatty liver, triglycerides reducer, prebiotic, cure for constipation, antioxidant, anti-fungal and tribal herbal medicine (Fig. 2).

TRADITIONAL BIOACTIVE COMPOUNDS IN YACON

All food constituents present in original food or added to as a carrier food are deliberated bioactive compounds[36]. Thus, functional foods can be classified on the base of present bioactive compounds[37]. Yacon tuberous root is a multifunctional food, because it contains numerous bioactive compounds, such as phytoalexins which have antimicrobial activity[14], phenolic compounds that have antioxidant activity such as chlorogenic acids[15,16] and high contents of fructans, insulin and fructooligosaccharides that have prebiotic properties[18,38,39].

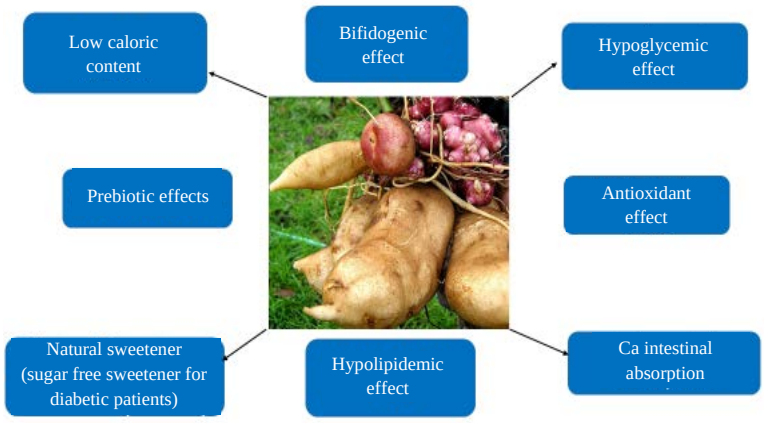

Fig. 2: Functional properties of the yacon (*Smallanthus sonchifolius*) plant

Table 2: Different products of yacon available in different areas

Regions	Uses of yacon	Different Products
Origin areas of yacon The Andean region: Peru, Bolivia, Ecuador, Colombia and Argentina	Consumer used as a fruit and to be sold at the local market in boiled, baked form or used for making a refreshing drink. Also for skin rejuvenation, to relieve intestinal, hepatic and renal disorders and also used in different religious festivities	Like syrup, juice, puree, candy, marmalade and tea leaves available in supermarkets
Cultivated areas of yacon New Zealand, Brazil, Japan, Czech Republic, S-Korea, Taiwan, Hainan and Philippines	Available in different commercial products, cultivation, extensive and amateur gardenings	In market available in different forms like vegetable, syrup, juice, in sweet pastries, in fermented vegetables, air-dried tuber slices, vinegar and also as a source of ethanol
Other areas also cited in literature USA, Italy, Russia, Mexico and Estonia		

Lachman *et al.*[30]

PREBIOTICS EFFECT OF YACON (*Smallanthus sonchifolius*) IN DIFFERENT ANIMAL SPECIES

It has been noted that *Bifidobacterium* and lactobacilli increase the fermentation from yacon tuberous roots as well as commercial FOS[40]. This fermentation is due to FOS which is necessary for the hydrolysis of β(2-1) bonds in fructans, produced by the *Bifidobacterium* and lactobacilli[34]. Another study was conducted to evaluate the prebiotic property of yacon tuberous root flour in mouse. The results showed stimulating effects on the growth of lactobacilli and bifidobacteria and the intestinal immune system with increases in IgA and different cytokines[41] and also significant effect on intestinal flora as well as improving the Th1/Th2 cytokine balance through its prebiotic effect on the number of beneficial bacteria in mice[42]. Dietary supplementation of yacon also increased the growth of lactobacilli and bifidobacteria, increased the cell density, crypt formation and also increased levels of short chain fatty acids in intestine of Guinea pig[43]. Yacon (*Smallanthus sonchifolius)* tea administered at the rate of (2%) to diabetic rats *ad libitum* in the place of water during 30 days trial increased the concentration of circulating insulin[19]. The feed offered with FOS (yacon source) at the rate of 7 g day^{-1} increased the faecal bifidobacteria and had no effects on faecal pH or dry matter in sheep gut[44,45]. The oral administration of yacon (*Smallanthus sonchifolius*) leaves extract showed positive anti-cancer action in H22 tumor mice model that study based foundation for further elicit idea to work on yacon leaves[46]. Moreover other studies showed that the presence of inulin in the milk replacer of pre-ruminant calves could lead to significant increase in live body weight gain, better feces consistency in veal calves and broilers[13] (Table 3). It was suggested that the increase in body weight might be attributed due to increased fermentation at the small intestine followed by increased flow of microbial nitrogen at large intestine, stable microflora composition at rumen, small and large intestines of calves[47] (Fig. 3).

POULTRY

Major caecal microflora of the chicken includes Enterobacteriaceae, *Lactobacillus* and *Enterococcus* in day old chicken and at 14th day *Bacteroides* and *Eubacterium*

Table 3: Functional properties of the yacon plant in different animal species

Sources of yacon	Doses	Species	Effects	References
Plant's flour	340 mg FOS kg^{-1} day^{-1}	Rats	Increase insulin-positive pancreatic cell	Scheid *et al.*[29]
Extract of yacon root	6.5%	Rats	Significantly Improve insulin sensitivity in the insulin-resistant state	Satoh *et al.*[28]
Yacon powder	7.4 g of FOS	Human	Decrease in serum glucose levels	Scheid *et al.*[29]
Yacon syrup	0.29 g and 0.14 g FOS kg^{-1} day^{-1}	Human	Improve insulin-resistance state	Lomax and Calder[25]
Yacon syrup	6.4 g FOS day^{-1}	Human	Accelerates the colonic transit	Scheid *et al.*[29]
Extract of yacon root	1 mL kg^{-1} b.wt., day^{-1}	Rats	Positive effect on TAG and HDL	Habib *et al.*[54]
Yacon root extract	3.0 and 5% FOS in diet	Mouse	Positively improves the immune parameters	Habib *et al.*[54]
Aqueous extract of yacon root	2.2 mL (1% FOS)	Rats	Effect on DNA damage and cell proliferation	Roselino *et al.*[55]
Dried extract of yacon root	340 mg kg^{-1} day^{-1} in diet	Mouse	Growth of bifidobacteria and lactobacilli	Da Silva Almeida *et al.*[57]
Yacon+pin needle powder	1.0 and 0.5%,	Broiler	Effect on meat quality	Nidaullah *et al.*[13]
Yacon+mugwort powder	1.0 and O.5%,	Broiler	Decreased pH and cholesterol	Van der Wielen *et al.*[50]
Yacon powder	Offered *ad libitum*, 5 and 7.5% FOS in diets	Rats	Enhanced mineral absorption in Intestine	Habib *et al.*[54]
Maca+yacon	2.4 g day^{-1}	Mouse	Showed positive effects on glucose and triacylglycerol levels	Satoh *et al.*[28]

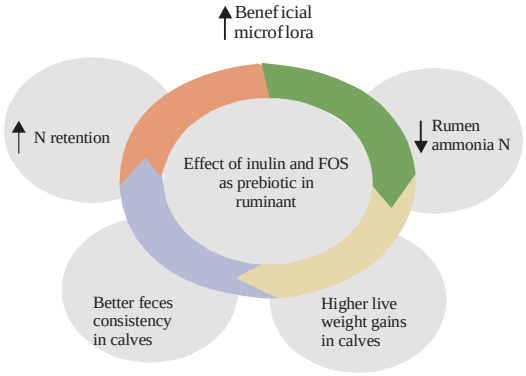

Fig. 3: Schematic diagram on effect of inulin and FOS as prebiotic in ruminant

spp. got established[48]. The microflora present in poultry gut are supposed to play multidimensional role including digestion, pathogen exclusion, immune stimulation, help in metabolism, vitamin synthesis, etc. *In vitro* study indicated that *Salmonella* cannot grow in the presence of oligo-fructose, while *Lactococcus lactis*, *Enterococcus faecium* and *Pediococcus* can grow because these secrete enzyme to use oligofructose as energy source[14]. Therefore, nowadays, it is important to incorporate inulin as prebiotic for overcoming *Salmonella* infection in chickens because inulin supplementation decreases the colonization of *Salmonella* in the intestine[27,49] and also improves the growth performance of layers and broilers. Inulin, being a prebiotic, cannot digest in gut of broiler chicken by own enzymes but Bifidobacteria and Lactobacilli digest it in the large intestine and produce numerous Short Chain Fatty Acids (SCFA) and lactic acids[49]. The production of fatty acids at large intestine subsequently leads to lower luminal pH (Acidic) and increase mineral absorption[50] (Fig. 4). Present literature showed that inulin can be considered as a good prebiotic and yet not explored the biological importance of FOS and inulin compounds that are present in yacon (*Smallanthus sonchifolius*). On the basis of literature, there is evidence that there is lack of information about the use of yacon in poultry. So, it is speculated that yacon root plant (inulin and FOS) could be more useful as prebiotic additive in poultry diets and livestock as well.

BENEFICIAL EFFECTS OF YACON'S (*Smallanthus sonchifolius*) COMPOUND IN HUMAN HEALTH

Some herbal plants such as artichoke (*Helianthus tuberosus*), chicory (*Cichorium endivia*) and yacon having 10-15, 5-10 and 3-19% of fresh FOS weight, respectively are considered as a good source of FOS and inulin[51] but yacon is well-known as an excellent source of FOS[29,52].

The ingestion of yacon plant and its extract including FOS compound has effectively diminished the chance of infectious diseases caused by pathogenic microorganisms such as diarrhea and respiratory disorders in children[45]. Fructooligosaccharides are able to escape enzymatic digestion in the upper part of the gastrointestinal tract, subsequently reaching the colon in intact form before undergoing microbial fermentation. Dietary intake of FOS triggers bifidogenic effect by selectively exciting the proliferation of beneficial bacteria (bifidobacteria) in the human's colon[29,53]. The end products of FOS are Short Chain Fatty Acids (SCFA), fermentation by the intestinal microbiota can also favor the growth of health-promoting bacteria like *Bifidobacterium* spp. and *Lactobacillus* spp., while reducing or maintaining pathogenic populations such as *Clostridium* spp. and *Escherichia coli*[54,55].

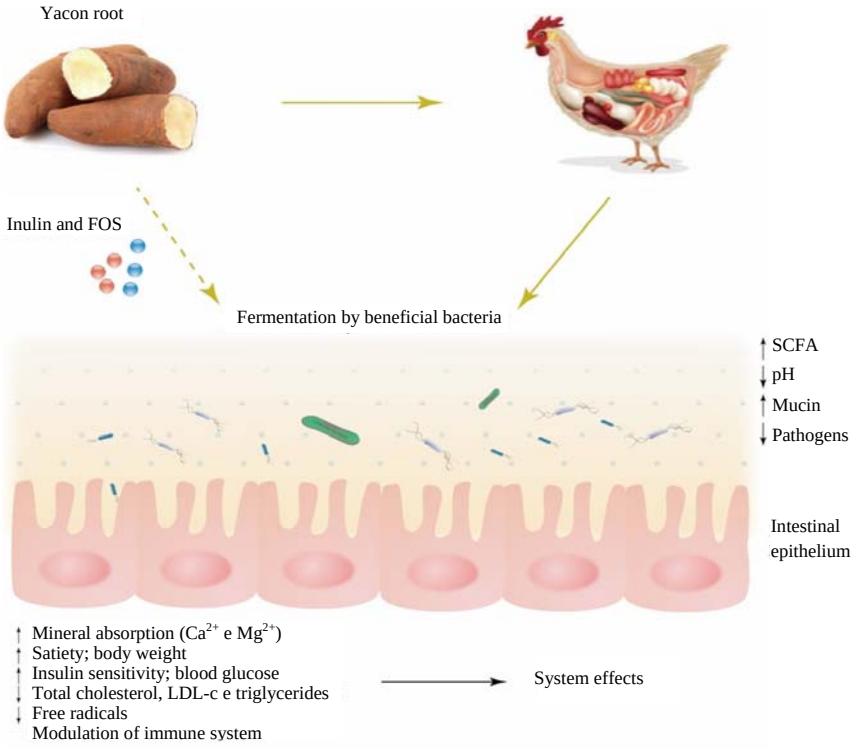

Fig. 4: Yacon root ingestion and health promoting benefits of inulin and Fructooligosaccharides (FOS) in poultry health and production

Thus, FOS are small soluble dietary fibers that exhibit prebiotic activity. In another study the effect of yacon was assessed on the concentration of glucose and lipids in human blood. The groups that received yacon, showed a positive effect on glucose and triglyceride levels (mean reduction of 0.32 and 0.43 mmol L^{-1}, respectively) without exerting any adverse effects[56]. Yacon syrup significantly reduces the body mass index in women[25,55].

ADVANTAGES OF YACON (*Smallanthus sonchifolius*)

The *Smallanthus sonchifolius* tuberous roots as well as leaves and stems could be used in the diet of cattle and other domestic animals to enhance their production performance[49]. The tuberous roots of yacon similar to sweet potatoes have a much sweeter taste and crunchy flesh. The sweetness of yacon is due to high content of fructose (70%). It is more sweeter than table sugar and does not stimulate insulin production and glycaemic reaction[57]. Therefore, yacon is the good choice of natural food for diabetes patients.

Yacon fruit could be used in different commercial food products e.g., in sweet pastries, ethanol as well as in chips preparation. Yacon plant juice treated with carbon powder for clarification, deodorization and decolorization has been processed in food industry[40,58].

DISADVANTAGES OF YACON (*Smallanthus sonchifolius*) CONSUMPTION

Overeating of yacon may be uncomfortable but don't has life-threatening effects. Symptoms of overfeeding include abdominal pain, bloating and diarrhea[59,45]. In addition, yacon tuberous roots ingestion markedly accelerates colonic transit, subsequent increasing tool frequency[46,60]. Up to now, only one report found in literature which showed that the 55-year-old woman suffered from anaphylaxis after yacon ingestion[61].

CONCLUSION

Yacon is a food that has gaining more attention among the consumers and scientific community due to therapeutic importance, such as hypoglycemic effects, laxative effects, enhancing mineral absorption and strengthen bone health; in addition to weight loss, reduction in blood cholesterol, as well as antimicrobial, antioxidant and prebiotic effects. Especially,

FOS and inulin compounds are abundant in yacon plant that modulate the growth of intestinal commensal microbiota, subsequently increase mineral and leads to maintain the bone structure and strengthen immunity of the poultry birds. Based on literature evidences, yacon plant has many functional properties, so it could be used as a prebiotics source in different species including human, livestock and poultry. The main objective of this review was to highlight the importance of use of yacon as an alternative source of growth promoter and prebiotic to replace synthetic antibiotic to cope with medicinal cost.

SIGNIFICANT STATEMENTS

- Yacon plant containing 70-80% fructooligosaccharides (FOS) and inulin could be used as an inexpensive, efficient and safe growth promoter to improve overall animal performance
- Prebiotic derived from yacon has significant potential to replace the synthetic antibiotic and minimize the antibiotic resistance
- Consumption of non-digestible oligosaccharides destined in yacon plant would improve gastrointestinal metabolism and growth of commensal microflora of host
- Yacon plant possess various biological properties such as antioxidant, antimicrobial, prebiotic, growth promoter, hypoglycemic, hepatoprotective as well as increase mineral absorption to maintain bone homeostasis and also help to reduce cholesterol and triglyceride levels

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