Yacon [*Smallanthus sonchifolia* (Poepp. et Endl.) H. Robinson] chemical composition and use – a review

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ABSTRACT

Yacon [*Smallanthus sonchifolia* (Poepp. et Endl.) H. Robinson], a native plant of the Andes, belongs to the family *Compositae* (*Asteraceae*) and it represents a traditional crop of the original population of Peru used in traditional medicine. A major portion of tuberous root biomass is composed of water (> 70% of fresh weight). Saccharides, especially oligofructans, form 70–80% of dry weight, protein content ranges between 0.3% and 3.7%. Fructooligosaccharides of inulin type β (2→1), mainly oligomers (GF_2–GF_{16}), are known for their ability to keep the colon healthy. Yacon sweetness is predominantly caused by fructose, which is by some 70% sweeter than sucrose. Other oligosaccharides are 1-kestose and nystose. Diabetics and persons suffering from digestive problems are recommended to consume yacon because its sugars are not available from the small intestine. The mean tuberous root composition per 100 g of fresh matter is 81.3, 13.8, 0.9, 1.0, 0.1 and 1.1 g of water, saccharides, fibre, proteins, lipids and ash, respectively. Mean mineral contents per 100 g of fresh matter are 334, 34, 12, 8.4, 0.4 and 0.2 mg of potassium, phosphorus, calcium, magnesium, sodium and iron, respectively. Vitamins B_1, B_2, C, β-carotene and polyphenols in the same weight are present at mean concentrations 0.07, 0.31, 5.0, 0.13 and 203 mg, respectively. Yacon can be considered an industrial crop, particularly as a source of inulin. The used forms are flour, syrup, extract from tuberous roots and moreover leaf extract for the preparation of yacon infusion with hypoglycaemic effect. In yacon leaves di- and sesquiterpenes with protective effects against insects are present, among them mainly *ent*-kaurenic acid (*ent*-kaur-16-en-19-oic acid) and its derivative – 15-α-angeloyloxy-*ent*-kauren-19-oic acid 16-epoxide. Other components are polyphenolic antioxidants, esp. hydroxycinnamic acids and chlorogenic acid. A new antifungal melampolide – sesquiterpene lactone named sonchifolin, as well as three known melampolides, polymatin B, uvedalin and enhydrin, were isolated from leaf extracts of yacon. Three major phytoalexins were isolated: 4'-hydroxy-3'-(3-methylbutanoyl)acetophenone, 4'-hydroxy-3'-(3-methyl-2-butenyl)acetophenone and 5-acetyl-2-(1-hydroxy-1-methylethyl)benzofuran.

Keywords: yacon; chemical composition; biological activity; use

Botanical characterisation

Yacon [*Smallanthus sonchifolia* (Poepp. et Endl.) H. Robinson], syn. *Polymnia sonchifolia*, a native of the Andes closely related to the sunflower (Figure 1), is a vigorous, herbaceous perennial plant (family *Compositae* or *Asteraceae* – sunflower family). The plant produces large tuberous roots similar to sweet potatoes in appearance, but they have a much sweeter taste and crunchy flesh. The plants are extremely hardy and are able to grow under hot or cold conditions. Yacon grows up to a height of two meters, has large opposite sagittate leaves with serrate margins, and multiple yellow-orange flowers 3 cm in size. The plant is distinguished by having two kinds of tuberous roots, a central rhizome with "eyes" for producing new stems, and multiple edible tuberous roots radiating from the rhizome. The brittle, tan to purple, smoothly tapered edible tuberous roots are actually fattened roots that can be up 40 cm in length and weigh two kilos. The edible tuberous roots are crunchy like a crisp, sweet, juicier than any pear. Like the sunflower, the yacon presents distributed big leaves of to even along very little ramified shafts. The plant grows in warm, temperate Andean valleys, but can be found at altitudes up to 3 200 m (Zardini 1991). It represents the typical inflorescence – grouping of flowers in a called structure chapter. Tuberous root crops, in which tuberous roots are formed after cessation of stem growth, seem to have a similar mechanism of tuberous root formation to potato. On the other hand, the similarities with potato seem to be low in tuberous root crops, in which tuberous roots thicken from the base of the stem (Nakatani and Koda 1992). Smallholders in the Andes cultivate yacon fairly commonly for subsistence (Hermann et al. 1998).

Chemical composition

A major portion of root biomass is composed of water that usually exceeds 70% of fresh weight. Due to a high

Research Project MSM 412100002 of the Faculty of Agronomy of the Czech University of Agriculture in Prague supported this review.

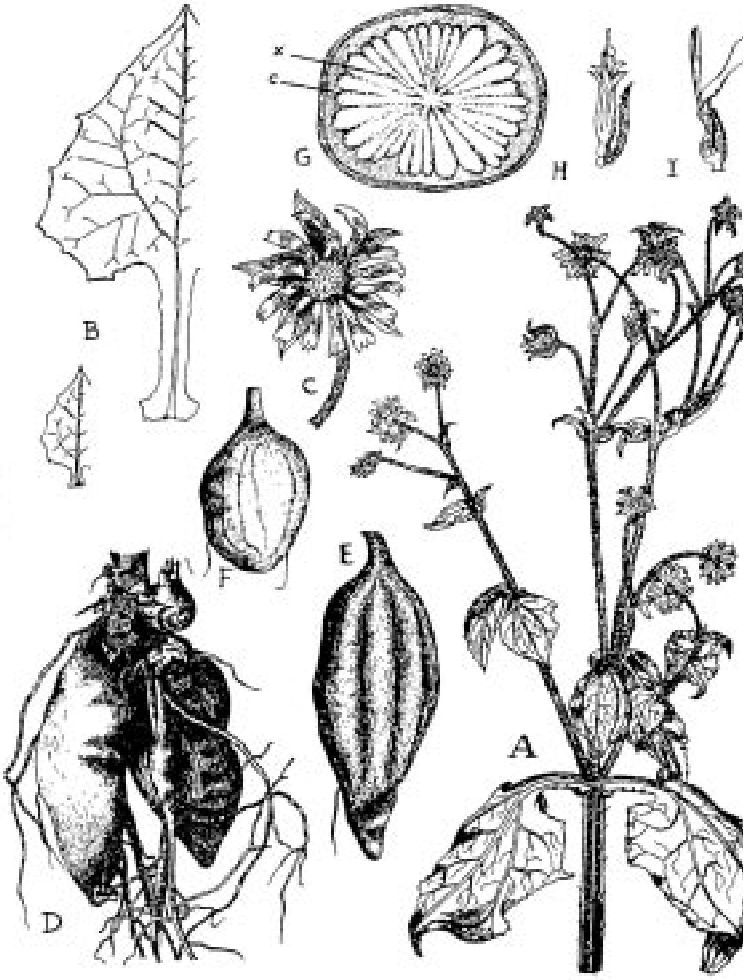


Figure 1. Botanical and morphological aspects of yacon (León 1964)

A = flowering branches, B = leaves, C = flower head, D–F = tuberous roots, G = tuberous root in cross-section (x = xylem, c = cortical tissues), H = staminal disk flower, I = pistillate ray flower

water content, the root energy value is low. The tuberous roots contain only 0.3–3.7% protein (Table 1), but 70–80% of dry matter is composed of saccharides, mainly fructooligosaccharides (Goto et al. 1995). The underground storage organs of yacon accumulate over 60% (on dry basis) of inulin type β (2→1) fructans, mainly oligomers (GF_2–GF_{16}) (Itaya et al. 2002). The structures of kestose and nystose, the main fructooligosaccharides, are given in Figure 2. Fukai et al. (1993, 1997) determined fructan content and the activities of sucrose:sucrose fructan fructosyltransferase (EC 2.4.1.99), fructan:fructan fructosyltransferase (EC 2.4.1.100), and fructan hydrolase in each part of yacon during the vegetation period. They found that during summer the amount of fructans accumulated in each part was minimum despite of the existence of relatively high specific activities of sucrose: sucrose fructosyltransferase and fructan:fructan fructosyltransferase in the stems, tuberous roots, and rhizomatous stem. As Goto et al. (1995) confirmed by using enzymatic, C-13-NMR, and methylation analyses, the fructooligosaccharides represent mainly oligosaccharides from trisaccharide to decasaccharide with terminal sucrose (inulin type fructooligosaccharides). Hermann et al. (1998) reported that yacon fructans are of low molecular mass and yacon has a significant fructose (3–22% of root dry matter) and glucose (2–5% of root dry matter) content (Ohyama et al. 1990). The calculated yacon food energy 619–937 kJ/kg of fresh matter is very low and has similar properties like dietary fibre (Quemener et al. 1994). The highest dry matter and fructan yields were observed in dodecaploid lines as compared with octoploid ones. Cisneros-Zevallos et al. (2002) evaluated three accessions of yacon from Huanco (Peru) for their saccharide distribution and stability after 0, 15, 30, 45 and 90 days of storage at 4°C and room temperature (25°C). The results indicated high variability in fructooligosaccharide content (2.1–70.8 g/100 g dry matter) and a reverse relationship between fructooligosaccharide content and reducing sugars. In three accessions Cisneros-Zevallos et al. (2002) estimated a decrease in the initial amount of

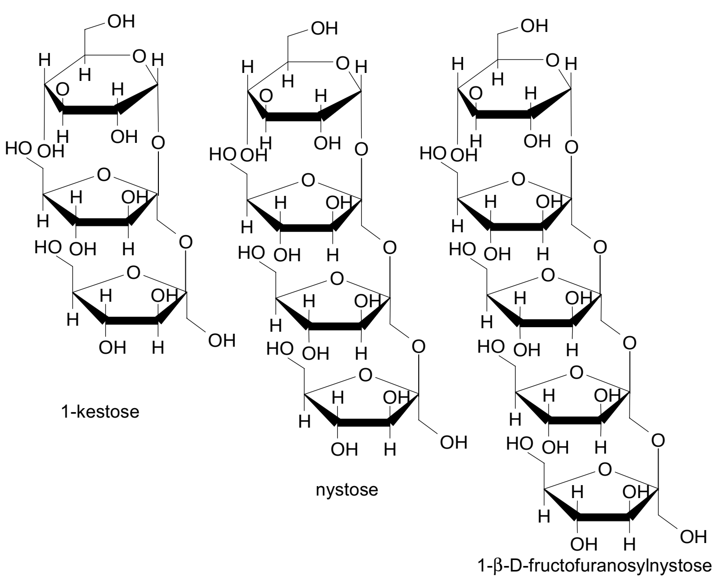
Table 1. Chemical composition of tuberous roots, leaves and stems

Compound	Tuberous roots							
	fresh				dry			
	A	B	C	D	A	B	C	D
Water (%)	69.50	92.70	86.6	84.80	–	–	–	–
Ash (%)	2.40	0.26	–	3.50	6.71	3.59	–	23.03
Proteins (%)	2.22	0.44	0.30	3.70	7.31	6.02	2.24	24.34
Lipids (%)	0.13	0.10	0.30	1.50	0.43	1.32	2.24	9.87
Fibre (%)	1.75	0.28	0.50	3.40	5.73	3.88	3.73	22.37
Saccharides (%)	19.67	–	–	–	67.53	–	–	–
Compound	**Leaves**			**Stem**			**Leaves and stem**	
	A		F	A		F	B	
	fresh	dry	dry	fresh	dry	dry	fresh	dry
Water (%)	83.20	–	–	86.70	–	–	92.00	–
Ash (%)	2.68	15.98	12.52	1.35	10.23	9.60	1.03	14.49
Proteins (%)	2.87	17.12	21.18	1.51	11.37	9.73	1.13	15.97
Lipids (%)	1.24	7.40	4.20	6.30	2.26	1.98	0.22	3.04
Fibre (%)	1.68	10.04	11.63	3.57	26.85	23.82	1.11	15.69
Saccharides (%)	1.44	8.58	–	1.55	11.70	–	–	–

A – Calvino (1940), B – Bredemann (1948), C – León (1964), D – Nieto (1991), F – Frček et al. (1995)

fructooligosaccharide 46.5, 32.8 and 21.6% at 25°C after 15 days and 73.3, 56.5 and 76.8% after 90 days of storage at 25°C and coincidentally an increase in reducing sugar content (mean value 42%). Fructooligosaccharide content also decreased at 4°C but at a lower proportion in comparison with the temperature 25°C (1.65, 2.94 and 3.6% after 15 days of storage and 27, 17 and 21% after 90 days of storage).

The content of saccharides in yacon tuberous roots is given in Table 2 (Valentová et al. 2001). Itaya et al. (2002) investigated the activities of the enzymes sucrose 1-fructosyl transferase, fructan:fructan 1-fructosyl transferase and fructan 1-exohydrolase in rhizophores and tuberous roots of yacon plants during their complete growth cycle under field conditions. The higher values were found at the beginning of tuberisation (3-months old plants) and at the flowering phase (7-months old plants). The results showed that synthesising activities in yacon plants were higher in rhizophores than in tuberous roots while the hydrolysing activity predominated in tuber-



GF_2 – trisaccharide consisting of one molecule of glucose and two molecules of fructose
GF_3 – tetrasaccharide consisting of one molecule of glucose and three molecules of fructose
GF_4 – pentasaccharide consisting of one molecule of glucose and four molecules of fructose

Figure 2. Chemical structure of three main fructooligosaccharides (GF_2–GF_4)

Table 2. Contents of saccharides in yacon tuberous roots (Valentová et al. 2001)

Saccharide	Content (mg/g dry matter)
Fructose	350.1 ± 42.0
Glucose	158.3 ± 28.6
Sucrose	74.5 ± 19.0
GF_2	60.1 ± 12.6
GF_3	47.4 ± 8.2
GF_4	33.6 ± 9.3
GF_5	20.6 ± 5.2
GF_6	15.8 ± 4.0
GF_7	12.7 ± 4.0
GF_8	9.6 ± 7.2
GF_9	6.6 ± 2.3
Inulin	13.5 ± 0.4

Table 3. Contents of some elements and minor compounds in yacon tuberous roots (mg/100 g fresh matter)

Element or compound	Tuberous roots (fresh matter)		Leaves (Frček et al. 1995)	Stem (Frček et al. 1995)
Calcium	23	(Grau and Rea 1997)	1805	967
Potassium	228.2	(Hermann et al. 1998)		
Iron	0.3	(Grau and Rea 1997)	10.82	7.29
Copper	0.96	(Valentová et al. 2001)	< 0.5	< 0.5
Manganese	0.54	(Valentová et al. 2001)	3.067	< 0.5
Zinc	0.67	(Valentová et al. 2001)	6.20	2.93
Phosphorus	21	(Grau and Rea 1997)	543	415
Retinol	10	(Grau and Rea 1997)		
Carotene	0.08	(Grau and Rea 1997)		
Ascorbic acid	13	(Grau and Rea 1997)		
Thiamin	0.01	(Grau and Rea 1997)		
Riboflavin	0.11	(Grau and Rea 1997)		
Niacin	0.33	(Grau and Rea 1997)		

ous roots. Yacon tuberous roots contain polyphenols (2030 mg/kg) with predominating chlorogenic acid (48.5 ± 12.9 mg/kg). Among the amino acids, tryptophan (14.6 ± 7.1 mg/kg) content was high (Valentová et al. 2001). Contents of important elements and other minor compounds are given in Table 3. Yan at al. (1999) studied the antioxidative activity of yacon root by 1,1-diphenyl-2-picrylhydrazyl (DPPH) assay. Antioxidants were extracted by methanol and isolated and purified by gel permeation chromatography and preparative reverse-phase HPLC and identified by NMR and mass spectrometry. A major antioxidant compound found in tuberous roots was chlorogenic acid (Figure 3). Yoshida et al. (2002) determined that among the crude enzyme solutions of potato, mushroom, eggplant, edible burdock and yacon, the latter showed a remarkable oxidative activity to bisphenol A that was converted to a monoquinone derivative and a small amount of the bisquinone derivative. Inoculation of sliced yacon tuberous roots with *Pseudomonas cichorii* resulted in the formation of three antifungal phytoalexins derived from 4-hydroxyacetophenone: 4'-hydroxy-3'-(3-methylbutanoyl)acetophenone (I), 4'-hydroxy-3'-(3-methyl-2-butenyl)acetophenone (II) and 5-acetyl-2-(1-hydroxy-1methylethyl)benzofuran (III) (Takasugi and Masuda 1996) (for the chemical structure see Figure 4).

More constituents are present in yacon leaves, where catechol, terpenes and flavonoids were reported (Valentová et al. 2001). Methanol extract from yacon leaves contained *ent*-kaurenic acid (*ent*-kaur-16-en-19-oic acid) (IV) in the fraction soluble in ethyl acetate and similar diterpene, a kaurene derivative, 15-α-angeloyloxy-*ent*-kauren-19-oic acid 16-epoxide (VII) (Kakuta et al. 1992). These and two other known angeloyloxykaurenic acids [18-angeloyloxy-*ent*-kaurenic acid (VI) and 15-α-angeloyloxy-*ent*-kauren-19-oic acid (V) – Figure 5] were reported to be present in yacon leaves (Inoue et al. 1995). The high content of *ent*-kaurenic acid and its derivatives in the yacon leaves indicates that these diterpenes play an important physiological role in the defensive mechanism of the glandular trichome exudates. Moreover, an antifungal melampolide, 8-angeloyl-1(10),4,11(13)-germacratriene-12,6-olid-14-oic acid methyl ester, called sonchifolin (VIII in Figure 6, Inoue et al. 1995), as well as three

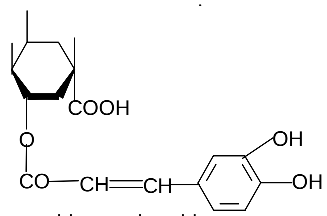


Figure 3. Chlorogenic acid – yacon major antioxidant

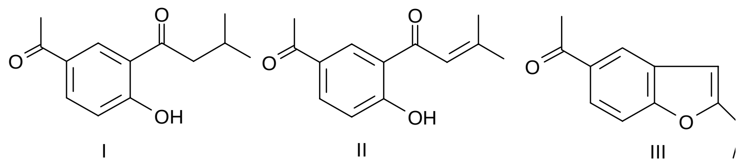


Figure 4. Antifungal phytoalexins of yacon tuberous roots

known melampolides – polymatin B (IX), uvedalin (X) and enhydrin (XI) (Figure 6) were isolated from yacon leaf extracts in 70% methanol in the fraction soluble in ethyl acetate using column chromatography on silicagel by HPLC (Goto et al. 1995). These compounds are sesquiterpene lactones, called melampolides, with fungicidal properties. *Ent*-kaurenic acid is one of the intermediates in the biosynthesis of phytohormones gibberellins and it occurs in the propolis of Brazilian wild bees (Valentová et al. 2001).

Uses of yacon potentials and advantages

The tuberous roots of yacon have a sweet taste and because the human body is not able to metabolise the fructooligosaccharides, yacon does not put on body weight (da Silva et al. 2002). Large tuberous roots similar in appearance to sweet potatoes have a much sweeter taste and crunchy flesh. Yacon sweetness is caused by fructose, which is by some 70% sweeter than table sugar and does not stimulate insulin production and does not bring a glycaemic reaction (Cisneros-Zevallos et al. 2002). From this point of view, yacon saccharides have been an ideal sweetener for diabetics – instead of entering immediately into the blood stream as the glucose from sucrose does, fructose has a slower and more complete metabolising process and does not affect the immune system negatively. Yacon has been consumed commonly by diabetics and persons suffering from digestive disorders. Yacon also possesses the properties to treat kidney complaints and skin-rejuvenating activity. Fructooligosaccharides are the products recognised and used as food ingredients and prebiotics (Pedreschi et al. 2002). Pedreschi et al. (2002) found that *Lactobacillus plantarum* NRRL B-4496 and *L. acidophilus* NRRL B-1910 completely utilised the GF_2 molecule while *Bifidobacterium bifidum* was apparently able to utilise molecules with higher DP. Fructooligosaccharides (2 to 9 molecules of fructose) have received much attention as prebiotics due to their small utilisation by the body and their ability to enhance the growth of probiotics. The strong demand is not just due to the sweet flavour and taste of yacon that make it pleasant to eat, but to its active components that have a positive effect on the digestive system and due to its effect against cancer and diabetes (Zardini 1991). In the calculation of food energy (148–224 kJ/kg fresh matter) fructans are similar to dietary fibre in the intestinal tract (Quemener et al. 1994) and are broken down by stomach acidity to a significant extent, but some degradation and fermentation occur in the colon by its bacteria (Silva 1996).

Wei et al. (1991) and Ohyama et al. (1990) reported a decrease in fructans and an increase in fructose during yacon storage for three months under cold conditions. Farmers in Brazil and Japan produce a number of processed yacon products, such as air-dried tuber slices (Grau and Rea 1997, Kakihara et al. 1997), unrefined yacon syrup that has a consistency of honey and can be marketed as a dietetic sweetener (Hermann et al. 1998), or a juice without addition of sweeteners, synthetic colorants and preservatives, with only small additions of vitamin C. The yacon tuberous roots serve as a source of raw material for the production of sweet pastries, fermented vegetables and ethanol; they can be used as "chips" in dehydrated form. Another product is yacon juice treated with active carbon powder to obtain its clarification, decolorisation and deodorisation (Hondo et al. 2000a). Hondo et al. (2000b) suggested acetic acid fermentation of yacon juice with *Acetobacter pasteurianus* for production of improved yacon vinegar containing natural fructooligosaccharides.

Yacon slices and stripes retain crunchiness during cooking and could be used in Asian stir-fried dishes. In recent time a combined membrane-processing system is promising for value-added yacon products using a purified concentrate of non-digestible saccharides (Kamada et al. 2002). Combination of ultrafiltration and nanofiltration was proved to be highly efficient when the purity of non-digestible saccharides increased from 81 to 98%.

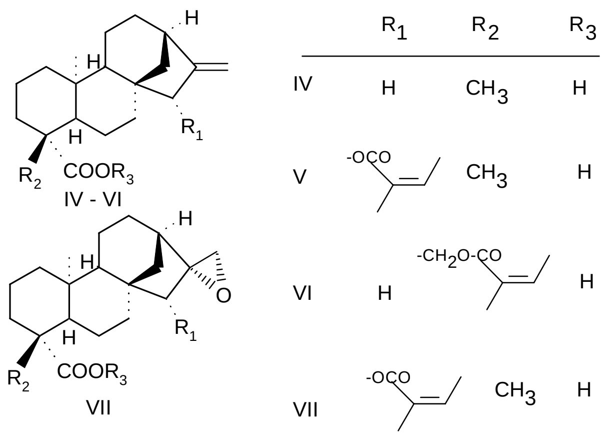


Figure 5. *Ent*-kaurenic acid and its derivatives present in yacon leaves

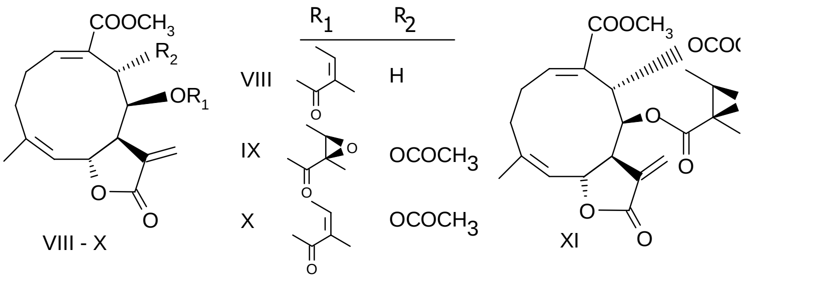


Figure 6. Antifungal melampolides present in yacon leaves

One of the main yacon properties is medicinal. Antidiabetic medicinal properties were attributed mainly to yacon leaves (Kakihara et al. 1997). Dried yacon leaves were used to prepare a medicinal infusion or mixed with common tea leaves in Japan. Volpato et al. (1997) demonstrated the hypoglycaemic activity of water extract of dried yacon leaves in feeding experiments with rats with induced diabetes. Aybar et al. (2001) tested the hypoglycaemic effect of water extract of yacon leaves in normal, transiently hyperglycaemic and streptozocin-induced diabetic rats. 10% yacon decoction administered intraperitoneally produced a significant decrease in plasma glucose levels in normal rats. After 30 days of the infusion administration, diabetic rats showed improved body (plasma glucose, plasma insulin levels, body weight) and renal (kidney weight, kidney to body weight ratio, creatinine clearance, urinary albumin excretion) parameters in comparison with diabetic controls. Yacon water extracts induced an increase in the plasma insulin concentration. Diuretic and healing effects on the skin were also mentioned (Valentová et al. 2001).

The yacon tuberous roots as well as stems and leaves containing a high level of proteins could be used as a food for cattle and other domestic animals (Grau and Rea 1997, Grau et al. 2001).

CONCLUSIONS

Yacon [*Smallanthus sonchifolia* (Poepp. et Endl.) H. Robinson, *Asteraceae*], an important Andean species grown for its juicy tuberous root, is potentially beneficial in the diet to diabetics. Moreover, fructooligosaccharides forming a major proportion of yacon tuber dry matter are known for their ability to keep the human colon healthy. The juice pressed from yacon tuberous roots is expected to be used as a sweetener containing natural fructooligosaccharides. Another use is the preparation of medicinal infusions from yacon dried leaves with antidiabetic and hypoglycaemic activity, improving digestive disorders. Yacon is effortless to grow and has no problems with pests or diseases due to protective effects of its di- and sesquiterpenes. Regarding the fact that yacon could be cultivated under climatic conditions of the Czech Republic, it seems that it could be a good source of raw material for the assortment of nutraceuticals of domestic origin.

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Received on January 21, 2003

ABSTRAKT

Chemické složení a využití jakonu [*Smallanthus sonchifolia* (Poepp. et Endl.) H. Robinson] – studie

Jakon [*Smallanthus sonchifolia* (Poepp. et Endl.) H. Robinson] – rostlina pocházející z And – patří do čeledi *Compositae* (*Asteraceae*) a představuje plodinu původního obyvatelstva v Peru používanou v tradičním lékařství. Většinu biomasy kořenů tvoří voda (> 70 % čerstvé hmoty). 70–80 % sušiny jsou sacharidy, zvláště fruktany, 0,3–3,7 % bílkoviny. Frukto-oligosacharidy obsažené v hlízách jakonu jsou β (2→1) inulinového typu a zvláště oligomery (GF_2–GF_{16}) jsou známy svou schopností udržovat tlusté střevo v dobrém zdravotním stavu. Sladkost jakonu je způsobena především fruktosou, která je o 70 % sladší než sacharosa. Z dalších oligosacharidů jsou zastoupeny především 1-kestosa a nystosa. Jakon konzumují především diabetici a lidé trpící zažívacími problémy, neboť obsahuje nevstřebatelné sacharidy, které nejsou štěpeny a vstřebávány v tenkém střevu. 100 g jakonových hlízových kořenů obsahuje průměrně 81,3 g vody, 1 g bílkovin, 0,1 g tuku, 13,8 g sacharidů, 0,9 g vlákniny a 1,1 g popelovin. Ve 100 g jakonových hlízových kořenů je dále obsaženo průměrně 203 mg polyfenolů, 12 mg vápníku, 8,4 mg hořčíku, 334 mg draslíku, 34 mg fosforu, 0,2 mg železa, 0,4 mg sodíku, 130 mg β-karotenu, 0,07 mg vitaminu B_1, 0,31 mg vitaminu B_2 a 5 mg vitaminu C. Jakon lze považovat za průmyslovou plodinu, zejména jako zdroj inulinu. Z jakonových hlíz se vyrábí mouka, sirup, extrakt a z listů extrakt s hypoglykemickým účinkem. V listech jakonu jsou obsaženy seskvi- a diterpeny s obrannými účinky proti hmyzu, z nichž jsou zastoupeny zvláště *ent*-kaurenová kyselina (*ent*-kaur-16-en-19-ová kyselina) a její derivát – 16-epoxid 15-α-angeloxy-*ent*-kauren-19-ové kyseliny. Z dalších sloučenin jsou zastoupeny polyfenolické antioxidanty, zejména hydroxyskořicové kyseliny a chlorogenová kyselina. Z extraktů jakonových listů byly izolovány melampolidy s protiplísňovými účinky – nový seskviterpenický lakton nazvaný sonchifolin a rovněž tři známé melampolidy – polymatin B, uvedalin a enhydrin. Byly izolovány tři dominantní fytoalexiny – 4'-hydroxy-3'-(3-methylbutanoyl)acetofenon, 4'-hydroxy-3'-(3-methyl-2-butenyl)acetofenon a 5-acetyl-2-(1-hydroxy-1-methylethyl)benzofuran.

Klíčová slova: jakon; chemické složení; biologická aktivita; využití

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