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Health properties of oca (*Oxalis tuberosa*) and yacon (*Smallanthus sonchifolius*)

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Andean roots and tubers are underexploited crops; many contain compounds beneficial to health, so a greater knowledge of their properties is important for encouraging their consumption. The aim of this work was to study the content of bioactive compounds of yacon and oca and their effect on intestinal health using as a model rats of the Wistar strain. Two varieties of ocas (Overa and Rosada) and yacon, which contain significant amounts of fructooligosaccharides and phenolic compounds, were chosen. Rats of the Wistar strain were fed for two months with diets containing these foods in amounts sufficient to provide 8% of fiber. A significant decrease in pH values and an increment in lactobacilli and bifidobacteria counts in the cecum of rats fed with inulin, oca Rosada and Overa were observed; there was no significant decrease in enterobacteriaceae and enterococci counts. The cecum antioxidant activity was incremented in rats fed with the experimental foods with respect to the control diets. The components of dietary fiber and phenolic compound contents in yacon and oca produce effects that contribute to the intestinal health of the experimental animals.

Introduction

Andean roots and tubers are grown in small areas under traditional production systems under harsh conditions; they are essential to ensure food biodiversity, the livelihood of populations in the region and to preserve part of their culture.[1] In spite of being an excellent choice for agricultural and pharmaceutical industries, Andean roots and tubers have not been able to establish themselves in large markets.[2]

An increased consumption of these foods could substantially improve the nutrition of the Andean people of northwestern Argentina, and recover ancient food practices.[3]

Oca is a poorly studied Andean crop and according to Veitmeyer[4] it was a staple food for the Incas. Traditionally, oca was eaten boiled in soups or stews or dehydrated (caya), similar to potato chuño. Oca cultivation is very important in the Central Andes, especially in damp places between 2800 and 4100 m of altitude from Venezuela, Chile and Argentina, particularly in Ecuador, Peru and Bolivia. It is the second major tuber after the potato in Peru and Bolivia.[1,2]

Oca is considered a good source of calcium and iron[5] and comes second in antioxidant content after mashua (*Tropaeolum tuberosum*) followed by potato and ulluco (*Ullucus tuberosus*).[6] Also, significant amounts of fructooligosaccharides have been found in oca.[7]

Another important Andean crop is yacon (*Smallanthus sonchifolius*) which is a plant that was domesticated centuries ago by people from the region who were part of the pre-Inca culture.[8]

In Argentina it is grown only in the provinces of Jujuy and Salta.[8–10] Traditionally it was produced for local consumption only, but in recent years information about some of the promising properties of yacon has generated a growing interest in this product. Yacon is traditionally consumed to calm thirst during fieldwork[9] and it is consumed raw despite being a root. It has a pleasant sweet taste and leaves a refreshing feeling; this is the reason why the inhabitants of the Andes consider it to be a fruit. It has significant amounts of potassium, phenolic compounds derived from caffeic acid, antioxidants such as chlorogenic acid and tryptophan and several phytoalexins with antifungal activity.[11–13] Lobo *et al.*[14] found a stimulatory effect on intestinal calcium absorption in rats fed with diets supplemented with yacon flour. Yacon store their carbohydrates mainly as fructooligosaccharides (FOS),[8,15] unlike tubers and other roots that store it as starch.

Prebiotics have been defined as "a nondigestible food ingredient that beneficially affects the host by selectively stimulating the growth and/or activity of one or a limited number of bacteria in the colon that can improve host health".[16] In general, prebiotics are oligosaccharides, including fructooligosaccharides (FOS), galactooligosaccharides (GOS), isomaltooligosaccharides (IMO) and lactulose.[17]

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FOS are potential prebiotics since they are fermented by intestinal bacteria beneficial to the host such as lactobacilli and bifidobacteria.[16,18,19] Pedreschi *et al.*[20] showed that yacon was fermented *in vitro* selectively by bifidobacteria and lactobacilli; this would indicate their possible prebiotic effect. They are also used as a source of natural sweeteners and syrups appropriate for people with digestive problems.[21] Consumption of FOS and inulin modulates important physiological functions such as calcium absorption, lipid metabolism, and modification of the intestinal microbiota.[22] Bifidogenic bacteria, which inhibit the establishment of pathogenic bacteria and/or putrefaction and is directly related to the prevention of colon cancer in experimental models, grow after the consumption of FOS and inulin.[23] Similarly, it has been reported that these compounds promote higher resistance to infections and allergies.[24,25]

The resistant starch (RS) is the starch fraction which cannot be digested in the small intestine and is available, to some degree, for fermentation by bacteria in the large intestine.[26,27] It has in the gastrointestinal tract similar effects to soluble fiber; it increases transit time and is fermented to produce short chain fatty acids in the large intestine, resulting in a decrease in fecal pH values.[26]

Health and food industry professionals have great interest in obtaining more information on the effects of RS; this has led to extensive research on the contribution of RS to the non-digestible components of dietary carbohydrates and their physiological implications. Colonic fermentation, bacterial growth, postprandial glycemia, intestinal transit time and the energy values of foods are affected by the RS content of foods.[28] Kendall *et al.*[29] reported that RS significantly reduces postprandial blood glucose within 120 min after ingestion. The RS in the diet has a laxative effect. A supplement of 25 g per day in healthy subjects increased the daily production of feces above the normal level, with minimal gastrointestinal discomfort.[30]

Plants produce a wide range of antioxidants, such as ascorbic acid, carotenoids, polyphenols and enzymes with antioxidant activity that protect cells from oxidative damage.[31]

Both yacon and oca contain significant amounts of phenolic compounds. These provide important sensory properties of foods, they are responsible for the color, smell and taste of many plants, and they can also play an important role in the prevention of various diseases associated with oxidative stress.[32,33]

Recent investigations indicate that polyphenols do not function as antioxidants *in vivo* in the conventional way.[34] Instead, they provide significant protection against cellular oxidative stress by induction of endogenous mechanisms of enzymatic protection.[31]

Dietary fiber and antioxidants are components of functional foods and ingredients that are often studied separately. However, a portion of the bioactive compounds present in plant samples, antioxidants or not, are associated with dietary fiber components as a result of the ability of some of them to form complexes with proteins and polysaccharides.[35,36] More specifically, a considerable part of polyphenols may be associated with the insoluble fiber fraction, mainly the compounds with higher degree of polymerization, such as condensed tannins (proanthocyanidins) and hydrolysable tannins. A soluble fraction of fiber is usually associated with lower molecular weight polyphenols such as some flavonoids, phenolic acids, dimers and trimers of proanthocyanidins.[35,36] All this led to defining the term "antioxidant fiber" as a raw material with a high proportion of dietary fiber and substantial amounts of natural antioxidants associated with the non-digestible matrix compounds.[37]

It is important to consider the association between polyphenols and dietary fiber components because the associated compounds may be responsible for the beneficial health effects attributed to the fiber. The physiological effects depend on the type of compound, the concentration and bioavailability.[38]

The aim of this work was to study the content of bioactive compounds of yacon and oca and their effect on intestinal health using as a model rats of the Wistar strain.

Materials and methods

Materials

Two varieties of ocas (*Oxalis tuberosa*) were chosen for this work: Overa and Rosada provided by the Agricultural and Artisanal Cooperative Union Quebrada and Valleys (C.A.U.Que. Va.), Maimara, Jujuy, Argentina; and yacon (*Smallanthus sonchifolius*) purchased from Cooperative of Chorrillos, Barcena, Jujuy, Argentina.

Both products are grown in the Andean region of northwestern Argentina, in small plots with typical ancient techniques of family farming. They are grown in small valleys protected from strong winds; the land is arid, and the climate is cold, with large variations of temperature between day and night, and low rainfall (250 mm per year). Generally, only natural fertilizers are used.

The crops are sown in November and harvested in March/June. The products are transported from the field to the cooperative's processing plant. There they are classified by shape and size and stored in cold rooms.

Three samples of 5 kg of each product were collected during May and June from the processing plant. They were selected by size: 18–28 g for ocas and 260–380 g for yacon. They were transported to the laboratory and stored at 4 °C until the chemical analysis was completed, and then biological assays were performed.

Chemical analysis

The samples of oca and yacón were peeled using a kitchen vegetable peeler, and were cut into thin strips. All the analytical determinations were performed using AOAC methods.[39] Moisture was determined by drying in a convection oven, the AOAC 925.23 method. Lipid content was determined according to the Soxlet method, AOAC 963.15. The total protein content

was determined using the Kjeldahl (Buchi Digestion Unit K-435) procedure with a nitrogen-to-protein conversion factor of 6.25, the AOAC 991.20 method. Ash analysis used carbonization at 550 °C (Muffle furnace), the AOAC 945.46 method. Dietary fiber (soluble and insoluble) was determined using the AOAC 985.29 method.

Total (TS) and resistant (RS) starch

TS was determined by a technique described by Tovar *et al.*[40] and RS according to Goñi *et al.*[41] For the TS, the samples were dissolved in 4 N KOH, and for AR a prior digestion with pepsin solution was performed. Both techniques were followed by hydrolysis with alpha amylase (100 °C, 30 min for TS and 37 °C, 16 h for RS) and then digestion with amyloglucosidase, prior to dissolution of the starch with 4 N KOH for the RS. The glucose content was determined using an enzymatic kit in glucose oxidase/peroxidase (GOD/POD). The grams of glucose obtained were multiplied by 0.9 to convert glucose into starch.

Fructooligosaccharides (FOS)

FOS were removed from the food matrix with bidistilled water at 80 °C and with constant stirring and were quantified according to Zuleta *et al.*[42] using the high-resolution liquid chromatography technique (HPLC). The equipment consisted of a Gilson 322 pump system, a refractive index detector (Precision Instrument model Iota 2), Nucleogel® Sugar 810 Ca Column and Zeltec Column Heater Model ZC 90. The mobile phase was deionized water; the flow rate was 0.65 mL min^{-1}; the column temperature was 85 °C. The standards used were inulin, fructose and glucose (Sigma®).

All analytical determinations were performed in triplicate.

Health properties of oca and yacon

Rats of the Wistar strain (180–240 g body weight) obtained from the vivarium of the Biological Chemistry Institute "Bernabé Bloj", Faculty of Biochemistry, Chemistry and Pharmacy, National University of Tucumán were used. The animals were treated in accordance with the criteria established in the Guide for the Care and Use of Laboratory Animals.[43] The animals were separated randomly into seven groups of 6 rats each, identified as follows: lots fed with fiber free diet (FFD), cellulose diet (CD), resistant starch diet (RSD), inulin diet (ID), oca overa diet (OOD), oca rosada diet (ORD) and yacon diet (YD). Then, they were placed in individual cages, with free access to food and water. The diets were prepared to cover all nutritional requirements of the animals used; all components were constant in quantity and quality except for the fraction of non-digestible carbohydrates. This was incorporated to a level of 8% in all the experimental diets except the control group. To achieve this level some amounts of lyophilized oca overa, oca rosada, yacon and commercial cellulose, inulin and resistant starch were included, replacing an equivalent amount of the mixture of carbohydrates (sugar/starch 50/50), common in the formulated diets. Table 1 shows the diet composition. The weight and feed intake of the animals were recorded daily for 2 months. At the end of that period they were killed with an overdose of anesthesia and the cecum was removed aseptically. The cecum as well as its walls and their contents were individually weighed. The walls were washed with saline solution and dried. The pH of the cecal contents was measured (pH meter, Ultra Basic Denver Instrument).

The Food Efficiency (FE) was calculated as: body weight gain (g)/food consumed (g) at the end of the study.

Table 1 Composition of experimental diets

	Experimental diets (g)						
Ingredients (g per kg of diet)	Fiber free (FFD)	Cellulose (CD)	Resistant starch (RSD)	Inulin (ID)	Oca overa (OOD)	Oca rosada (ORD)	Yacón (YD)
Casein	100	100	100	100	100	100	100
Corn oil	50	50	50	50	50	50	50
Mineral mixture (AIN-93M)[a]	40	40	40	40	40	40	40
Vitamin mixture[b]	22	22	22	22	22	22	22
Cellulose (Sigma)	—	80	—	—	—	—	—
Resistant starch Hi-maize™ 260	—	—	266.7[d]	—	—	—	—
Inulin (Beneo GR)	—	—	—	80	—	—	—
Lyophilized oca Overa	—	—	—	—	177.3[d]	—	—
Lyophilized oca rosada	—	—	—	—	—	207.7[d]	—
Lyophilized yacón	—	—	—	—	—	—	116.3[d]
Carbohydrate mixture[c]	788	708	521.3	708	610.7	580.3	671.7
Total	1000	1000	1000	1000	1000	1000	1000

[a] Composition per kg: anhydrous calcium carbonate 357.00 g, monobasic potassium phosphate 196.00 g, potassium citrate (tripotassium, monohydrate) 70.78 g, sodium chloride 74.00 g, potassium sulphate 46.60 g, magnesium oxide 24.00 g, ferric citrate 6.06 g, zinc carbonate 1.65 g, sodium meta-silicate·$9H_2O$ 1.45 g, manganese carbonate 0.63 g, cupric carbonate 0.30 g, chromium and potasio sulphate·$12H_2O$ 0.28 g, boric acid 81.50 mg, sodium fluoride 63.50 mg, nickel carbonate 31.80 mg, lithium chloride 17.40 mg, anhydrous sodium selenate 10.25 mg, potassium iodate 10.00 mg, amónico paramolybdate·$4H_2O$ 7.95 mg, ammonium vanadate 6.60 mg, sucrose 221.02 g. [b] Niacin 3.00 g, calcium pantothenate 1.60 g, pyridoxine HCl 0.70 g, thiamine HCl 0.60 g, riboflavin 0.60 g, folic acid 0.20 g, biotin 0.02 g, vitamin B12 2.50 g, tocopherol 15.00 g, vitamin A palmitate 0.80 g, vitamin D3 0.25 g, menadione 0.075 g, sucrose 974.66 g. [c] Starch/sucrose: 50/50. [d] Amount necessary to cover the 8% fructooligosaccharides.

The cecal content was used for differential counting of bacteria and to study the antioxidant status. All experiments were performed under sterile conditions.

Bacteria differential counts

Serial dilutions (1/10) of cecal contents were done in 0.1% peptone (w/v) for each sample. Appropriate dilutions were placed on a Rogosa agar medium (Merck) for lactobacilli; a HHD agar medium for bifidobacteria;[44] a KF (Oxoid) medium for enterococci and a MacConkey (Britain) medium for enterobacteria.

Antioxidant activity of the cecum

The phenolic compounds extraction was performed according to Goñi *et al.*[45] Two consecutive extractions of the cecal contents were performed, first with a mixture of methanol–water (50 : 50 v/v, 25 mL g^{-1} sample) for 60 min; then with an acetone–water mixture (70 : 30 v/v, 25 mL g^{-1} sample) for 60 min too, both at room temperature. The extracts were combined and used to determine the content of total phenolic compounds by the Folin–Ciocalteu method[46] and the antiradical activity by the method described by Brand-Williams *et al.*[47] using the DPPH radical.

Scanning electron microscopy

Portions of the upper small intestine were fixed using a Karnovsky[48] solution for two hours and then washed with phosphate buffer at pH 7.4 and post-fixed in OsO_4 for 1 h in the same buffer. Then, they were dehydrated with a series of ethanol solutions of successively higher concentrations and then three times with acetone. Samples were mounted on a stub, coated with a thin film of gold by cathodic arc and examined using a scanning electron microscope (Jeol-35 FSEM).

Statistical analysis

The results are expressed as the mean ± standard deviation (n = 3 or 4 depending on the analysis). Comparison of the means was made by an analysis of variance (ANOVA) followed by Tukey's test. SPSS 15.0 software for Windows was used.

Results and discussion

The composition of oca and yacon is presented in Table 2. Carbohydrates are the principal components of dry matter. Among their components, soluble and insoluble fiber, resistant starch and fructooligosaccharides were found. Yacon does not contain resistant starch; it presents values of fructooligosaccharides higher than those of the two varieties of oca.

Health properties

The growth curves of experimental animals are shown in Fig. 1. It was observed that the animals fed with a diet including resistant starch (RSD) had higher body weight during the 2 months of the trial compared to the reference diets. This group had significantly higher weight of cecum (Table 3). Whereas Rodríguez-Cabezas *et al.*[49] found a positive correlation between higher feed intake and body weight gain, the results in this study showed no significant differences in feed intake between different animal groups (Table 4). This would indicate that the differences in body weight are due to different dietary components. It was observed that commercial FOS and inulin included in experimental diets did not inhibit the growth of animals, which is consistent with previous studies in pigs[49] and Wistar rats.[14]

The number of lactobacilli and bifidobacteria (Table 5) showed an increase in groups fed with RSD, ID, OOD and ORD. The last three had the most significant increase.

The increase in the number of bacteria is higher than that found by Rodríguez-Cabezas *et al.*[49] in rats fed with diets containing FOS and a mixture of commercial RS and FOS. The expected decrease in the count of enterobacteria and enterococci in diets containing soluble dietary fiber such as RS and FOS was not observed.

In the ID, YD and OOD groups only enterobacteriaceae counts decreased; enterococci counts decreased in groups fed with CD and ID but these differences were not significant.

The results are consistent with those found by Campos *et al.*[50] who obtained significant increases in lactobacilli and bifidobacteria counts in pigs fed with diets supplemented with inulin and yacon, with the absence of a significant decrease in the

Table 2 Proximal composition of oca and yacón

	Moisture[a]	Protein[a]	Lípid[a]	Ash[a]	Available carbohydrate[b]	Total dietary fiber[c]	Soluble dietary fiber[a]	Insoluble dietary fiber[a]	Resistant starch[a]	FOS[a]
Variety	(g per 100 g fresh food)									
Oca Overa	74.22 ± 0.62	1.59 ± 0.01	0.15 ± 0.03	0.75 ± 0.03	11.32	1.69	0.34 ± 0.08	1.35 ± 0.06	2.85 ± 0.18	7.43 ± 0.47
Oca Rosada	73.05 ± 0.38	1.37 ± 0.09	0.10 ± 0.01	1.16 ± 0.01	13.76	0.87	0.18 ± 0.07	0.69 ± 0.23	2.42 ± 0.05	7.27 ± 0.07
Yacon	86.09 ± 4.85	0.48 ± 0.02	0.04 ± 0.03	0.37 ± 0.01	3.10	1.03	0.35 ± 0.00	0.68 ± 0.06	ND	8.89 ± 0.58

[a] Mean ± standard deviation; n = 3. [b] Carbohydrate = 100 − (moisture + protein + lipid + ash + total fiber + fructooligosaccharides + resistant starch). [c] Total fiber = insoluble fiber + soluble fiber.

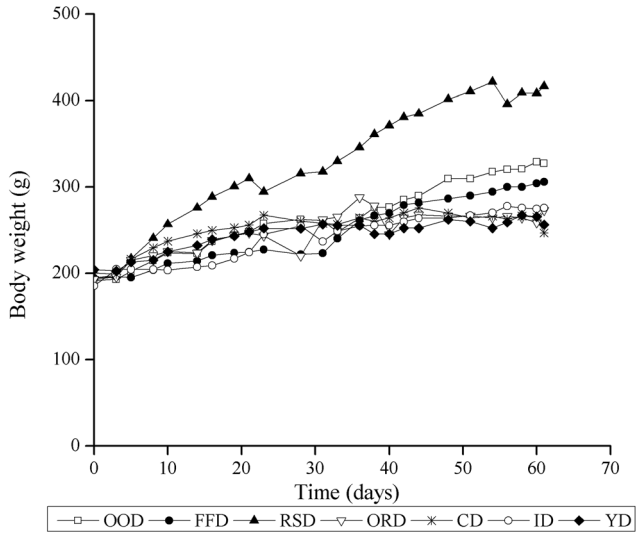

Fig. 1 Body weight of rats fed with experimental diets.

Table 3 Weight of cecal contents and wall

Diets	Cecum weight (g)[a]	Cecum wall weight (g)[a]	Cecal content weight (g)[a]	Cecum pH[a]
FFD	1.48 ± 0.16[a]	0.52 ± 0.11[a]	1.06 ± 0.26[a]	7.62 ± 0.23[c]
CD	1.64 ± 0.53[a]	0.48 ± 0.13[a]	1.16 ± 0.44[ab]	7.69 ± 0.05[c]
RSD	1.78 ± 0.22[ab]	0.72 ± 0.11[ab]	1.10 ± 0.25[ab]	7.67 ± 0.24[c]
ID	2.91 ± 0.48[c]	0.80 ± 0.08[b]	2.10 ± 0.48[bc]	6.61 ± 0.08[a]
OOD	2.16 ± 0.21[ab]	0.57 ± 0.05[ab]	1.58 ± 0.21[ab]	6.60 ± 0.11[b]
ORD	2.47 ± 0.70[c]	0.71 ± 0.25[ab]	1.77 ± 0.49[bc]	6.30 ± 0.20[ab]
YD	1.78 ± 0.55[a]	0.64 ± 0.09[ab]	1.14 ± 0.56[ab]	6.11 ± 0.11[ab]

[a] The results are presented as mean ± standard deviation; n = 3. Different letters in the same column show significant differences ($p < 0.05$).

Table 4 Body weight gain, feed intake and efficiency of diets

Diets	Body weight gain[a] (g)	Feed intake[a] (g per day)	Food efficiency[b]
FFD	106.20 ± 59.15[ab]	19.53 ± 6.26[a]	0.09 ± 0.04[ab]
CD	46.35 ± 33.82[a]	19.11 ± 6.17[a]	0.05 ± 0.04[a]
RSD	217.68 ± 11.64[c]	22.72 ± 8.33[a]	0.17 ± 0.01[c]
ID	68.68 ± 51.68[ab]	14.03 ± 6.15[a]	0.10 ± 0.08[bc]
OOD	146.25 ± 53.88[bc]	22.55 ± 7.40[a]	0.11 ± 0.03[abc]
ORD	76.20 ± 30.88[ab]	17.49 ± 5.14[a]	0.07 ± 0.03[ab]
YD	45.33 ± 15.81[a]	18.52 ± 8.24[a]	0.08 ± 0.02[ab]

[a] The results are presented as mean ± standard deviation; n = 3. Different letters in the same column show significant differences ($p < 0.05$). [b] Food efficiency = body weight (g)/food intake (g), measured at the end of the feeding period.

count of enterobacteria. In contrast, Varley *et al.*[51] did not observe any significant increase in lactobacilli and bifidobacteria counts in the cecum of pigs fed with diets supplemented with inulin. The increased lactobacilli count is related

Table 5 Effect of consumption of oca, yacon, inulin, resistant starch and cellulose in the cecum microorganism counts

Diets	Lactobacilli	Bifidobacteria	Enterobacteria	Enterococci
	log (CFU per g cecum content)[a]			
FFD	7.33 ± 0.49[ab]	8.54 ± 0.39[ab]	7.49 ± 0.70[ab]	7.60 ± 0.63[ab]
CD	6.32 ± 1.19[a]	7.71 ± 0.76[a]	7.35 ± 0.48[ab]	6.90 ± 0.57[a]
RSD	8.26 ± 0.71[bc]	9.36 ± 0.43[bc]	8.43 ± 0.40[c]	7.60 ± 0.63[ab]
ID	9.65 ± 0.87[cd]	10.25 ± 0.87[c]	6.74 ± 0.86[a]	7.01 ± 0.90[b]
OOD	9.72 ± 0.38[d]	9.42 ± 0.47[c]	7.12 ± 0.35[ab]	8.39 ± 0.25[a]
ORD	9.89 ± 0.63[d]	10.37 ± 0.48[c]	7.97 ± 0.67[b]	7.67 ± 0.62[ab]
YD	8.69 ± 0.30[bcd]	8.95 ± 0.53[b]	6.77 ± 0.13[a]	7.53 ± 0.31[ab]

[a] The results are presented as mean ± standard deviation; n = 3. Different letters in the same column show significant differences ($p < 0.05$).

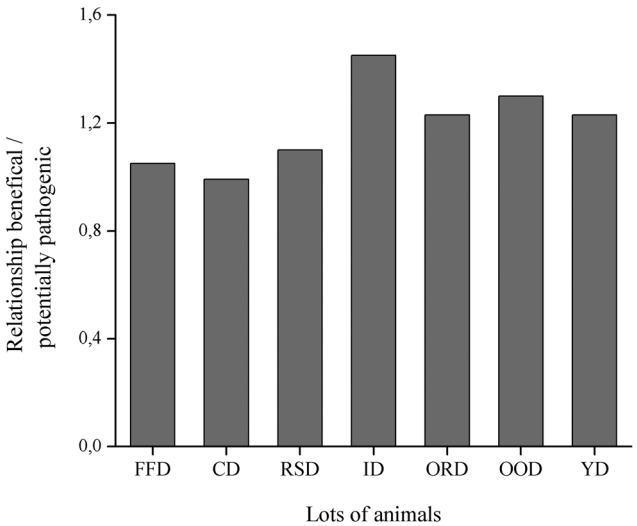

Fig. 2 Relationship between beneficial/potentially pathogenic microorganisms.

to the decrease in the pH value in the cecal contents of animals fed with diets containing 8% inulin, added in pure form or *via* lyophilized ocas and yacon. This is due to the lactic bacteria and bifidobacteria ferment FOS producing short chain fatty acids.[52]

Fig. 2 shows the relationship between beneficial bacteria (lactobacilli and bifidobacteria) and potentially pathogenic bacteria (entreobacteria and enterococci) for different lots of animals with experimental diets. It was observed that the ID, ORD, YD and OOD lots showed an increase in this relationship, which confirms the positive effect that these diets have in modulating the composition of the intestinal microflora.

Antiradical activity of the cecum

The antioxidant activity in the cecal content of animals fed with different experimental diets is shown in Table 6. It can be observed that diets also influence these values.

Table 6 Antiradical activity in the cecal contents of rats fed with the experimental diets

Diets	Phenolic compounds (mg galic acid per 100 g)[a]	Antiradical activity IC_{50} [a]
FFD	90.81 ± 1.45[bc]	44.13 ± 0.44[b]
CD	74.45 ± 3.04[ab]	43.63 ± 1.07[bc]
RSD	96.17 ± 1.04[c]	143.47 ± 3.50[d]
ID	68.56 ± 5.95[a]	78.39 ± 11.07[c]
OOD	102.91 ± 2.08[c]	24.62 ± 3.16[a]
ORD	161.90 ± 12.15[d]	23.95 ± 0.66[a]
YD	148.65 ± 11.45[d]	36.06 ± 10.31[ab]

[a] The results are presented as mean ± standard deviation; $n = 3$. Different letters in the same column show significant differences ($p < 0.05$).

The animals fed with OOD, ORD and YD showed an increment in the content of phenolic compounds and antiradical activity (ARA) in the cecal contents. The increment in the content of phenolic compounds produced by the ORD and YD diets is significant when compared with the others. The increment in ARA is also significant in the OOD and ORD lots. This may be because many phenolic compounds are associated with the fibers and so they get into the cecum undigested, which helps to support the antioxidant environment.

From these results it can be concluded that the consumption of non-digestible natural antioxidants increases the intestinal antioxidant capability which can prevent colonic diseases. As previously mentioned, it is important to consider the association of polyphenols and fiber which may be responsible for some of the beneficial effects that have traditionally been attributed to dietary fiber.

Scanning electron microscopy

Some authors have reported that long-term consumption of certain dietary fibers is associated with changes in the structure of the small intestine. Such changes include alterations in the length, weight and morphology of the mucosa.[53,54] To observe the effects of the non-digestible carbohydrates included in this work on the microvilli of the small intestine walls, analysis of the upper portion was performed using a scanning electron microscope.

Fig. 3 shows the results of microscopic observations in the villi of animal intestines of the FFD (a), CD (b), RSD (c), ID (d), ORD (e) and OOD (f) lots. Differences can be observed in intestinal morphology: intestinal villi in the FFD lot were smaller compared with the other lots. The CD lot (b) had slightly elongated villi whereas ORD (e) and OOD (f) lots showed wider oblate villi. This would indicate that the components of non-digestible carbohydrates included in the RSD (c), ID (d), ORD (e) and OOD (f) diets cause changes in the microvilli morphology.

These morphological changes are similar to those found by Hedemann *et al.*[55] in pigs fed with diets containing insoluble fibers. They associate these changes with improvements in intestinal morphology.

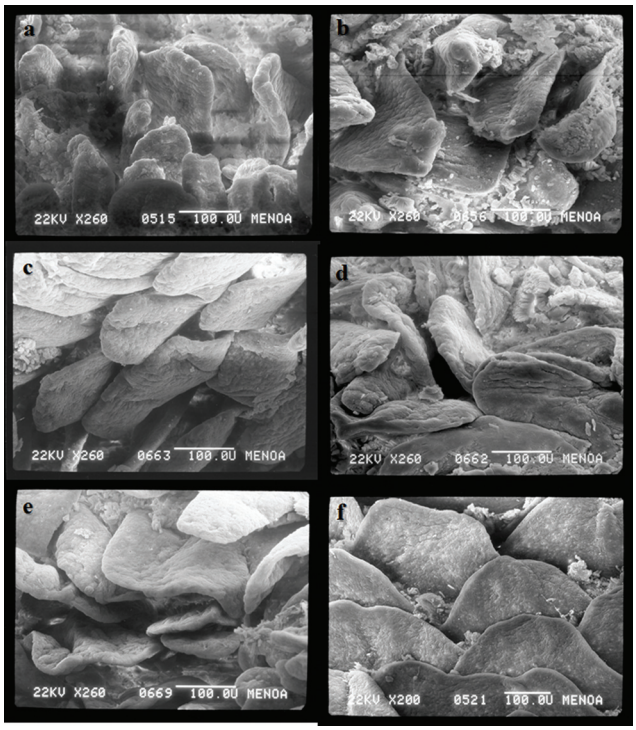

Fig. 3 Micrographs of the small intestine walls: (a) FFD, (b) CD, (c) RSD, (d) ID, (e) ORD, and (f) OOD. Scanning electron microscope micrographs (Jeol-35 FSEM). Electron Microscopy Laboratory of Northwest, UNT-CONICET (LAMENOA). Scale bar corresponds to 100 μm.

Kim *et al.*[56] in a study of rats fed with diets containing chicory (a good source of inulin) found similar changes in intestinal morphology to those shown in this study attributed to the presence of inulin.

According to these authors, the changes found in the intestinal morphology lead to improved lipid and cholesterol metabolism in experimental animals. It has also been shown that the consumption of soluble dietary fiber such as pectin and alfalfa produces swollen villi and partial loss of microvilli,[57] which results in the reduction of glucose absorption.[58]

Conclusion

A beneficial effect was found in experimental animals (white rats) fed with diets containing lyophilized oca (source of FOS), compared with those fed with fiber-free diets or diets with 8% of insoluble fiber. The beneficial effects observed were: decreased pH values in the cecum, increased counts of bifidobacteria and lactobacilli and a better relationship between beneficial and pathogenic microorganisms in the cecum. An increment was also observed in the values of phenolic compounds and ARA in the rat cecum.

In recent decades the population demands regarding the consumption of food have changed considerably since they have a greater knowledge of the relationship between food and its direct contribution to their health. Food today is not only

intended to satisfy hunger and provide the necessary nutrients for human beings but also to prevent diet-related diseases and to improve the physical and mental health of consumers. The knowledge of the nutritional and functional properties of native foods helps in preserving biodiversity. It is also useful to promote the incorporation of native foods into the diet as they, in addition to nutrients, provide bioactive compounds with beneficial health effects.

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