Stability of fructooligosaccharides, sugars and color of yacon (*Smallanthus sonchifolius*) roots during blanching and drying

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Summary

Yacon (*Smallanthus sonchifolius*) root is an important source of fructooligosaccharides (FOS). This study evaluated the influence of the blanching and drying processes on the sugars, FOS and color of the obtained flour. Blanching in boiling water of 5 mm slices for 6 min allowed to inactivate 95% of polyphenol oxidase and peroxidase activity. Blanching solutions containing ascorbic, citric and lactic acid were detrimental in terms of FOS retention (68.2 – 87.4%) due to hydrolysis mainly of GF3, GF4 and GF5 FOS and also important losses of reducing sugars (RS) were observed (69.5 - 87.4% retention). Blanching treatments that included ascorbic acid/$CaCl_2$ prevented RS and FOS losses and improved color of the obtained flour. The drying tested temperatures of 50 - 80 ºC did not affect the RS retention and FOS losses associated to hydrolysis and the use of 80 ºC rapidly reduced the water content and minimized browning reactions yielding flours with excellent color characteristics with high FOS content that can be derived to the elaboration of prebiotic containing functional foods or for the extraction and purification of FOS.

INTRODUCTION

Yacon (*Smallanthus sonchifolius* Poepp. & Endl), an Andean crop that grows at altitudes of 1000 – 3200 m above sea level is particularly known as an abundant source of β-(2→1) fructooligosaccharides (FOS) (Goto *et al*., 1995). FOS are considered as prebiotics and yacon FOS prebiotic effects have been demonstrated *in vitro* and *in vivo* being selectively fermented by bifidobacteria and lactobacilli (Pedreschi *et al*., 2003; Campos *et al*., 2012). The high concentrations of fructans have potential for colon cancer prevention (de Moura *et al*., 2012). FOS-rich yacon root flour could be considered as a potential hypolipidemic agent with a great therapeutic benefit in diabetes and other hyperlipidemic conditions through changes in lipid metabolism (Habib *et al*., 2011). Stimulatory effects of yacon FOS on calcium intestinal absorption, bone mineral retention and structural properties in the femoral midshaft of Wistar rats fed *ad libitum* with diets supplemented with yacon flour, have also been reported (Lobo *et al*., 2007).

Previous reported studies revealed a degradation of FOS content in yacon roots during postharvest storage (Asami *et al*., 1991; Lachman *et al*., 2004). The decrease of FOS in yacon roots leads to large amounts of free sugars as degradation products due to depolymerisation (Graefe *et al*., 2004). The breakdown of FOS is catalysed by the enzyme fructan-exohydrolase (FEH), which liberates terminal fructose molecules (Fukai *et al*., 1997). In order to avoid significant loss of prebiotic effect, yacon roots must be processed quickly after harvest.

An alternative of yacon root use is the elaboration of flour rich in FOS content as ingredient in the elaboration of different foods (e.g., bread, pastries, yogurt, dehydrated soups, among others) or as raw material to obtain FOS through extraction and purification processes. However, the high water content (80.9 a 92.5%) (Campos *et al*., 2012), high content of phenolic compounds and polyphenol oxidase (PPO) activity present in the roots (Neves & da Silva, 2007) are responsible of the fast browning after tissue rupture during processing.

Blanching as a pre-treatment is usually carried out to prevent off flavours and color changes resulting from enzymatic reactions and to decrease the initial microbial load but it could be associated to the reduction of sensory and nutrient quality in foods, mainly due to Maillard reaction and non-enzymatic browning. Previous studies have studied different blanching and drying conditions to obtain yacon flour (Padilha *et al*., 2009; Reis *et al*., 2012; Rodrigues *et al*., 2014; Scher *et al*., 2009). However, those studies have associated yacon quality loss to thermal processing and have not studied in detail, the FOS, sugars and color stability. Diverse studies have studied the stability of commercial inulin and FOS (partially purified) in model systems, mainly buffered, simulating processing conditions (pH and temperature) of food (Blecker et al., 2002; L'homme *et al*., 2003a., Huebner *et al*., 2008; Courtin *et al*., 2009; Matusek *et al*., 2009) but few studies have evaluated the stability of the added components or FOS content in the food matrix submitted to real processing conditions (L'homme *et al*., 2003b; Matusek *et al*., 2011; Vega & Zuniga-Hansen, 2015). Up to our knowledge, up to date no previous study have reported the combined effect of different blanching-drying treatments on the FOS profile and content stability of yacon. Thus, the objective of this study was to evaluate the influence of the different blanching – drying conditions on the FOS content and profile, reducing sugar content and color of the obtained flour.

MATERIALS AND METHODS

Materials and chemicals

Catechol, 3,5 dinitrosalysilic acid, glucose, fructose, 2-mercaptoethanol, ascorbic acid, citric acid and lactic acid were obtained from Sigma-Aldrich (USA). Hydrogen peroxide, sodium chloride, calcium chloride and sucrose were obtained from Merck (Germany). Guaicol was obtained from Himedia (India), polyvinylpyrrolidone from Calbiochem (Germany), HPLC

grade acetonitrile and ethanol from J.T. Baker (USA), and inulinase I-2017 from Sigma-Aldrich (USA).

Yacon roots (*Smallanthus sonchifolius* Poepp. & Endl) from the Region of Junin (Peru) were purchased from a local market. The material was transported to the laboratory, washed with 200 ppm sodium hypochlorite and then dried with towel paper. The roots were stored at 5˚C for 3 days at most until processing.

Study of the blanching methods: hot water and steam

Three independent replicates of 250 ± 25 g of yacon roots with skin were cut in slices of 5, 10 and 20 mm thickness and 4.5 ± 0.5 cm diameter. Blanching in distilled boiling water (95 ± 3°C) with a sample:water ratio of 1:5 (w/v) was used or steam blanching at 100˚C in an autoclave at atmospheric pressure. For both blanching methods, processing times of 2, 4 and 6 min were tested. Immediately after blanching, samples were cooled in a 1% $CaCl_2$ solution at room temperature for 5 min, with a sample: solution ratio of 1:4 w/v. Water content, PPO and POD activities, FOS and RS were analyzed.

Study of blanching using hot water plus additives

Three independent samples of 250 ± 25 g of yacon slices with skin of 4.5 ± 0.5 cm diameter and 5 mm thickness were submitted to boiling blanching water in a sample: water ratio of 1:5 w/v for 4 min. Different food additives, concentrations and combinations in the blanching solution were tested: 500 ppm ascorbic acid (AA), 500 ppm citric acid (CA), 500 ppm lactic acid (LA), 250 ppm AA+ 250 ppm CA, 250 ppm AA + 250 ppm LA, 4% NaCl, 0.5% $CaCl_2$, 500 ppm AA + 4% NaCl, 500 ppm AA + 0.5% $CaCl_2$. Additionally, blanching assays with different concentrations of AA (500, 250, 100 and 50 ppm) in combination with 0.2 or 0.5% calcium chloride were tested. Additionally, a treatment without blanching and a blanching

treatment with water without additives were carried out. Immediately after each treatment, the slices were cooled down in a 1% calcium chloride solution at room temperature for 5 min, drained and dried in a cabin dryer at 65 °C with a perpendicular flow rate of 1.8 m/s. Samples were dried until they reached 5% water content. Samples were subsequently grinded in a mill (A11, Basic IKA, Germany) and sieved to obtain a particle size ≤ 250 µm. Analysis carried out in this section included: pH of the blanching solution, RS and FOS retention, color and pH of the flour.

Drying process evaluation

After optimization of the blanching process described above, different drying temperatures were tested that corresponded to 50, 65 and 80°C, respectively under the same conditions described above. For each corresponding drying temperature, a not blanched control sample was obtained. All treatments were carried out in triplicate. Analysis carried out included water content, RS, FOS and color.

Analytical determinations

Water content was determined in a vacuum oven until constant weight was obtained according to the 925.45-A method (AOAC, 1995). The pH of the blanching solutions and obtained flours was carried out according to the 981.12 method (AOAC, 1995) using a Thermo Orion (model 410, USA) potentiometer.

Peroxidase (POD) and polyphenol oxidase (PPO) activity

Peroxidase activity was determined according to Pedreschi *et al*. (2011). Briefly, 10 g of yacon roots were mixed with 40 mL of 0.05 M phosphate buffer (pH 6.5) and 0.4 g of polyvinylpyrrolidone and homogenized in an Ultra-turrax T25 (IKA works, Inc., Wilmington,

NC) at 10000 rpm for 2.5 min. The extract was centrifuged at 6000 rpm for 20 min at 4 °C. Then, 33 µL of supernatant, 850 µL of phosphate buffer, 33 µL of 0.25 M hydrogen peroxide and 83 µL of 0.5 M guaicol were placed in a 1 mL glass spectrophotometer cell and the absorbance was recorded every min during 6 min at 470 nm.

Polyphenol oxidase (PPO) activity was determined according to Ndiaye *et al*. (2009) with slight modifications. Briefly, 10 g of yacon roots or 2 g of yacon flour sample were mixed with 30 mL of 0.05 M McIlvaine buffer (pH 6.5) and homogenized in an Ultra-turrax T25 (IKA works, Inc., Wilmington, NC) at 10000 rpm for 2.5 min. The extract was centrifuged at 6000 rpm for 20 min at 4 °C. Then, 143 µL of supernatant, 570 µL of McIlvaine buffer and 283 µL of catechol were placed in a 1 mL spectrophotometer cell and the absorbance was recorded every min during 6 min at 420 nm. Both reactions were performed in a UV-vis spectrophotometer microplate Eon (BioTek Instruments, Inc. USA) with double orbital agitation at 30 °C. One unit of enzyme activity was defined as causing a change in absorbance of 1 min/g enzyme extract. The residual enzyme activity was calculated in the linear portion of the curve, ΔAbs vs. time (min), as follows: Residual activity (%) = (S/So) x 100.

Where S: ΔAbs/min of the sample after heat treatment and So: the ΔAbs/min of the sample without heat treatment.

Sugars and fructooligosacharides

Two grams of yacon flour or 10 g of yacon roots cut into small pieces were homogenized in an Ultra-turrax homogenizer (IKA) with 50 mL of 70 % ethanol (v/v) and immediately heated at 100 °C for 10 min. The mixture was centrifuged at 4000 rpm for 15 min and the supernatant was collected. The yacon residues were re-extracted four more times under the same conditions. The supernatants were combined and evaporated in a rotary evaporator at 50

°C. The residue was re-dissolved in 25 mL of deionized water, and the yacon aqueous extract was kept for further determination of sugars and FOS.

FOS and sugars were analyzed according to the Jaime *et al*. (2001) and Pedreschi *et al*. (2003) protocols with slight modifications. An enzymatic hydrolysis of the sample with inulinase from *Aspergillus niger* (Sigma Aldrich, St. Louis Mo. USA) was carried out to liberate sugars. A 0.2 mL inulinase solution in acetate buffer 50 mM, pH 4.5 (1/10, v/v) was added to 1.8 mL of extract. The solution was mixed and incubated at 60 °C for 180 min, and the total glucose and fructose released was determined by HPLC-IR using a Waters 2695 Separation Module (Waters, Milford, MA) equipped with an auto-injector, a refraction index detector (IR 410) and the Empower software. A NH2P-40 3E (3.0 x 250 mm, 4 µm) column and a guard column NH2P-50G 3A of 3.0 x 10 mm, 5 µm (Shodex, Japan) were used. The mobile phase was composed of acetonitrile: water (72.5:27.5, v/v) at a flow rate of 0.35 mL/min. Samples were filtered through a 0.22 µm Millipore filter, type GV (Millipore, Bedford, MA) prior to HPLC injection. Five µL of sample were injected and run for 45 min at 35 °C. Sugars were identified and quantified by comparing their retention times to known previously injected standards (glucose, fructose and sucrose). The initial amounts of glucose, fructose and sucrose in the samples were also determined by HPLC-IR, and the obtained amounts were subtracted from the released sugars by the enzymatic hydrolysis. The concentration of FOS was calculated according to Prosky & Hoebregs (1999) and Pedreschi *et al*. (2003). Results were expressed as g of FOS per 100 g of dried matter (DM). The identification of the FOS displaying different degree of polymerization (DP) was carried out according to the methods of Campos *et al*. (2009) and Pedreschi *et al*., (2003). Retention of FOS of different DP: 1-kestose (GF2), nystose (GF3), fructofuranosylnystose (GF4) and 1-F-(1-β-D-fructofuranosyl)-2-nystose (GF5) in processed yacon was calculated as area percentage change respect to fresh

yacon. Reducing sugars (RS) were determined with the DNS method (Miller, 1959) and were expressed as g fructose per 100 g DM.

Color parameters

Color in the different samples was determined with a Konica Minolta Chroma metre (CR-400; Konica Minolta, Tokyo, Japan), using CIE1976 $L^*a^*b^*$ color space (CIELAB). The instrument was standardized with a white ceramic plate ($L^* = 97$; $a^* = 0.14$, $b^* = 1.64$). The total color change (ΔE), Hue (h^*), Chroma (C), and browning index (BI) which represents the browning suffered during treatment (Palou *et al.*, 1999), were calculated according to the following equations:

$$\Delta E = ((L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2)^{1/2}$$

$$h^* = \tan^{-1}(b^*/a^*)$$

$$C = \sqrt{(a^{*2} + b^{*2})}$$

$$BI = [100\ (x - 0.31)]/0.172, \text{ where } x = (a^* + 1.75L^*)/(5.645L^* + a^* - 3.012b^*)$$

Statistical analysis

The results were reported as means ± standard deviation (SD) of three independent replicates. One-way analysis of variance (ANOVA) was used to compare the means and Tukey's test was used to assess statistical significant differences among treatments ($p < 0.05$). All statistical analyses were performed with Statgraphics® Centurion XV (StatPoint Technologies, Inc).

RESULTS AND DISCUSSION

Influence of blanching conditions on enzyme activity

Polyphenol oxidase (PPO) and peroxidase (POD) are the main enzymes involved in the fast browning of yacon roots during storage and/or processing (Lachman *et al.*, 2003). PPO and

POD activity measured corresponded to 12.66 ± 0.7 and 161.9 ± 7.6 U/g min respectively. However, Fante *et al*. (2013) reported values of PPO and POD for peeled yacon of 25.34 and 22.01 U g^{-1} min^{-1}, respectively. The difference could be attributed to the cultivar or composition of the sample (peel + flesh). Our results report a higher POD activity than PPO as also previously reported by Pereira *et al*. (2013). However, PPO is considered as the main enzyme involved in browning due to high content of polyphenols present in vegetables. Hydrogen peroxide, the substrate for POD either is not present or it is present in little amounts in fruits and vegetables (Mayer, 2006) but, the synergistic activity of PPO and POD is due to the generation of hydrogen peroxide during the oxidation of phenolic compounds in PPO-catalysed reactions (Tomás-Barberán & Espín, 2001).

Residual PPO and POD activity after the different blanching treatments tested is presented in Figure 1. PPO was more stable than POD in both treatments, but this difference was less pronounced when steam blanching was employed. Fante *et al*. (2013) reported values of 16.24 15.38 % residual activities of PPO and POD respectively after steam blanching of yacon slices. Previous studies reported that POD is more stable than PPO (Arthey & Dennis, 1992), being observed a contrary behaviour in yacon. Ndiaye *et al*., (2009) found for blanched mango slices that PPO was more stable than POD. The thermal stability of yacon PPO partially purified was relatively stable at temperatures of 60 and 70 ºC displaying progressive inactivation at incubation temperatures of 80 and 90 ºC; this behaviour was attributed to the presence of sucrose, maltose, glucose, fructose, and trehalose at high concentrations, as protectants of yacon PPO against thermal inactivation at 75 and 80 °C (Neves & da Silva, 2007).

The blanching treatments either in boiling water or steaming for 6 min of slices of 5 mm thickness allowed to eliminate more than 95% of the PPO and POD activities. However, some hours after treatment, a gradual browning of the yacon slices was observed from the external

part of the skin towards the centre of the slices. This behaviour might be due not only to the higher content of polyphenols present in the skin but to the higher content of oxidation catalyzing agents (Fe and Cu) present in the skin (Pereira *et al*., 2013). Thus, next blanching experiments included the use of additives (chelating, acids and or salts).

Influence of the use of chelating agents in the blanching solution

RS and FOS retention in the blanched and dried at 65˚C samples is presented in Table 1. RS retention varied within 70.1 ± 1.8 and 87.4 ± 10.4% with no statistical significant differences (p < 0.05%) among the different treatments. The values found are consistent with those reported in the literature. Bomben *et al. (*1975) and Bomben & Hudson (1977) reported solute losses within 9 to 40% of the initial content. Mukherjee & Chattopadhyay (2007) reported considerably higher solid losses for hot water blanching due to diffusion and leaching, and reported reducing sugar retention values of 48.5 and 53.5 % in potatoes blanched at 93 ˚C and 100 ºC respectively.

FOS retention varied within 68.2 ± 6.5 and 109.7 ± 0.7, with higher losses in samples exposed to an acid media (500 ppm) but the blanched samples in water solutions containing 4% NaCl, 0.5% $CaCl_2$ or the combination of both salts with 500 ppm AA did not significantly affect FOS losses. The pH of the acid blanching solutions ranged within 3.1 and 3.4 respectively, and the obtained flours within the range of pH of 4.5 and 5.5. Extremely low values of FOS were found in the blanching solution (0.01 – 0.02 g/100 g of yacon), thus the FOS decrease is mainly due to the hydrolysis provoked by the blanching treatment in boiling water under acid conditions. However, treatments that combined AA and NaCl or $CaCl_2$ did not present losses attributed to hydrolysis even though the pH values were similar to the ones of the acid media, indicating a protective effect of the salts. Salts can affect the texture of the tissues due to Ca or Mg induced crosslinking between carboxyl groups in pectin molecules present in cell wall

and middle lamella. Calcium salts may be added to the blanching solution to form insoluble calcium pectate and thus increase the firmness of the product. Different salts might be needed depending on the type of tissue (for example, calcium hydroxide for cherries, calcium chloride for tomatoes, and calcium lactate for apples) and related to the differences in the proportion of demethylated pectin in each product (Ramesh, 2007).

Blanching under acid conditions (500 ppm AA) provoked significant losses ($p < 0.05$) of GF3, GF4 and GF5 but not GF2 (Figure 2). The trend in FOS retention corresponded to GF2 > GF3 > GF4 = GF5, respectively; additionally, samples blanched in AA/$CaCl_2$ (500 ppm/0.5%) did not display changes in the FOS profile (chromatograms are presented in Supplementary Figure 1). The FOS profile for the samples blanched in solutions containing CA, LA, AA + CA, AA + LA were similar to the FOS profile with AA, while the FOS profile for the treatments that included NaCl, $CaCl_2$, AA + NaCl were similar to the treatments that included AA/$CaCl_2$ (data not shown). FOS with a DP > 6 (GF6, GF7 or higher) were not determined because they are present in very low concentrations. The degradation path of oligomers consists of two ways: oligomers are degraded and formed at the same time or the amount of monomer only increases (Matuzek *et al*., 2009).

RS and FOS retention of the blanching treatments that included combinations of AA/$CaCl_2$ are presented in Table 2. RS retention varied within 62.7 ± 13.6 and 67.3 ± 5.1 for $CaCl_2$ concentrations of 0.2%, while for $CaCl_2$ concentrations of 0.5%, the RS retention varied within 85.0 ± 5.4 and 92.1 ± 9.8%. In these treatments, non-significant losses of FOS ($p < 0.05$) were found. FOS hydrolysis at high temperature in acid conditions has been extensively reported (Blecker *et al*., 2002; Courtin *et al*., 2009). Vega & Zuniga-Hansen (2015) reported that short chain FOS hydrolytic degradation due to the thermal treatment of acid food products. The final composition depends on the processing conditions, including pH, food

matrix, the DP of the oligosaccharides, the severity of the heat treatment (temperature, time) and the heat treatment method (batch or continuous).

Color parameters expressed in the CIE *L*a*b** system are reported in Table 3. Lightness *L** values were within 58.4 ± 4.1 and 78.6 ± 3.9, with non-significant differences ($p > 0.05$) observed between the samples blanched with acid solutions and/or saline but significantly higher ($p < 0.05$) than the non-blanched or blanched only with water samples. Additionally, acid and/or saline solutions had a positive effect on the ΔE value (43.9 ± 2.6 and 22.3 ± 0.7) being significantly lower ($p < 0.05$) than in the blanched in water sample and the non-blanched sample. The color total difference (ΔE) in CIE *L*a*b** represents the total color difference when a sample is subjected to a treatment compared to the untreated sample. The total color difference (ΔE) has been used in the determination of the color change in various foods during processing and storage (Choi & Nielsen, 2005).

The change in the values of the *h** angle did not display a defined trend, while the *C** values were lower in the blanched samples compared to the control. Values of *h** close to 90° are indicative of a yellowish color plus the low *C** values are indicative of a matt yellow color, being characteristic of yacon color. The value of the browning index (*BI*) represents the browning suffered during treatment and it is reported as an important parameter in processes that involve enzymatic and non-enzymatic browning reactions (Palou *et al.*, 1999). The addition of acid and/or salts had a significantly positive effect ($p < 0.05$) on the *BI* with values within 19.7 ± 2.6 and 28.2 ± 2.0 with respect to the control (*BI* = 47.5 ± 5.0) and the sample blanched only with water (*BI* = 31.8 ± 0.7) (Table 3). Samples blanched with different concentrations of AA/$CaCl_2$ are indicative of the $CaCl_2$ role on the inhibition of yacon browning (Table 3 and Supplementary Table 1). In fact, it is well known that calcium chloride works as a chelating agent or metal scavenger since it combines with metals such as iron and copper which can catalyse oxidation and also cause discolouration. Gómez *et al.*, (2010)

found that the application of an antibrowning pretreatment containing ascorbic acid or calcium chloride helped in maintaining the original color of apple after UV-C light exposure.

Influence of the drying temperature

Yacon slices blanched in a boiling water solution containing 100 ppm AA and 0.5 % $CaCl_2$ were dried at temperatures of 50 ˚C, 65˚C and 80 °C, respectively. In parallel, the drying process of the non-blanched samples was followed. The drying time and final water content corresponded 10.5, 9.5 and 7 h and 6.5 (8.2), 3.6 (3.9) and 2 (3.6) g/100g of DM for the corresponding drying temperatures of 50, 65 and 80 °C for the blanched and non-blanched samples, respectively (Table 4). The increase in drying air temperature increased the rate of heat transfer and consequently decreased the total drying time (Kaya *et al*., 2008). Blanching helps to reduce the water content for the same drying time and slices with higher texture are obtained which facilitate posterior unit operations (Padilha *et al*., 2009).

The drying temperature did not significantly influence ($p < 0.05$) the RS (34.5 ± 2.4 - 37.7 ± 1.4 g/100 DM) and FOS content (37.2 ± 0.3 - 42 ± 7.3 g/100 DM) of the obtained flours (Table 4). Our results demonstrate that temperatures as high as 80 °C did not affect the FOS content and profile since the pH of the yacon slices were within the 5.8 - 6.0 range, no hydrolysis occurred. Our results are in agreement with the results reported by Figueira *et al*., (2004) who reported non significant differences in the content of inulin in chicory roots (*Cichorium intybus* L.) dried at 60, 70 and 80 °C, respectively. However, Scher *et al*. (2009) studied the drying process of yacon slices previously peeled, steam blanched and dried at 70 °C and reported an increase in the RS content due to FOS hydrolysis; the difference with our results could be attributed to the method used to analyse FOS and to the raw material used. Scher *et al*. reported very low values of inulin (4.06 – 6.94 g/100 g DM). Color analysis of the blanched and non-blanched samples submitted to different drying temperatures is presented in Table 5. Increasing the temperature from 50 to 80 ºC had a positive effect on the *L** value

(from 52.49 ± 5.17 up to 75.90 ± 1.4), a decrease in the *a** value (from 3.97 ± 0.20 to -0.54 ± 0.44 indicative of absence of browning and a trend towards a yellow color). The Δ*E* decreased from 47.95 ± 4.54 to 26.35 ± 1.44; while *h** increased (from 77.76 ± 1.07 up to 91.84 ± 1.56) and *C** decreased (from 21.81 ± 0.83 up to 17.36 ± 0.98), being these changes indicative of a trend towards the yellowish color of the raw material. A significant decrease ($p < 0.05$) was also observed in the *BI* (from 47.51 ± 3.57 up to 24.54 ± 2.42). High drying temperatures significantly influence the color of the yacon flour, being more important the previous blanching treatment than the drying temperature itself. A high drying temperature would rapidly decrease water availability and thus minimizing enzymatic and non-enzymatic reactions.

CONCLUSIONS

Blanching of 5 mm yacon slices in acid solutions (AA, CA and LA) resulted in significant losses of FOS due to hydrolysis of GF3, GF4 and GF5 but GF2 remained constant. However, mixtures of AA/$CaCl_2$ even in acid conditions resulted in retention of FOS demonstrating the protective effect of salts against FOS hydrolysis. The drying temperature in the samples blanched with AA/$CaCl_2$ and without blanching did not affect the FOS and reducing sugar content. A high drying temperature of 80 ºC allowed to obtain a yacon flour with excellent color characteristics even without prior blanching, however, it might be subjected to the variety of the raw material. The present study allowed to determine the processing conditions to obtain a FOS rich yacon flour that can be further employed for the elaboration of prebiotic functional foods.

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Table 1. Influence of the blanching solution composition on the retention of RS and FOS, pH of the solution and flour obtained at 65 °C

Treatment	Retention of RS (%)	Retention of FOS (%)	pH	
			Solution	Flour
H_2O	92.0 ± 10.6a	105.4 ± 10.9a	6.8 ± 0.1	6.3 ± 0.1
AA, 500 ppm	72.4 ± 8.0a	68.2 ± 6.5c	3.4 ± 0.2	5.5 ± 0.0
CA, 500 ppm	75.7 ± 3.3a	71.4 ± 8.3c	3.2 ± 0.1	5.0 ± 0.2
LA, 500 ppm	70.1 ± 1.8ab	71.9 ± 16.2c	3.1 ± 0.1	4.5 ± 0.1
AA, 250 ppm + CA, 250 ppm	72.2 ± 2.8a	77.5 ± 13.5bc	3.2 ± 0.1	4.6 ± 0.3
AA, 250 ppm + LA, 250 ppm	69.5 ± 7.8a	87.4 ± 0.7abc	3.4 ± 0.4	4.5 ± 0.2
NaCl, 4%	71.1 ± 3.8a	99.4 ± 1.6ab	5.8 ± 0.4	6.1 ± 0.1
$CaCl_2$, 0.5%	73.0 ± 4.1a	109.7 ± 0.6a	5.2 ± 0.3	5.9 ± 0.1
AA, 500 ppm + NaCl, 4%	72.8 ± 5.9a	101.5 ± 4.1a	3.8 ± 0.0	5.5 ± 0.1
AA, 500 ppm + $CaCl_2$, 0.5%	87.4 ± 10.4a	96.3 ± 0.7ab	3.6 ± 0.2	5.5 ± 0.0

RS= Reducing sugars, AA = ascorbic acid, CA = citric acid, LA = lactic acid

Values in columns labelled with the same letter are not significantly different ($p > 0.05$)

Table 2. Influence of the ascorbic acid/calcium chloride concentration of the blanching solution on the retention of RS and FOS in the flour obtained at a drying temperature of 65 °C

Treatment	Retention of RS (%)	Retention of FOS (%)
AA, 500 ppm + $CaCl_2$ 0.2%	62.7 ± 13.6c	110.6 ± 5.6a
AA, 250 ppm + $CaCl_2$ 0.2%	63.6 ± 5.7c	103.2 ± 8.8a
AA, 100 ppm + $CaCl_2$ 0.2%	63.7 ± 4.1c	108.3 ± 9.5a
AA, 50 ppm + $CaCl_2$ 0.2%	67.3 ± 5.1bc	99.2 ± 4.9a
AA, 500 ppm + $CaCl_2$ 0.5%	85.0 ± 5.4ab	96.3 ± 0.7a
AA, 250 ppm + $CaCl_2$ 0.5%	86.0 ± 1.7ab	95.8 ± 7.5a
AA, 100 ppm + $CaCl_2$ 0.5%	92.1 ± 9.8a	95.3 ± 7.1a
AA, 50 ppm + $CaCl_2$ 0.5%	89.0 ± 7.8a	92.5 ± 6.8a

RS= Reducing sugars, AA = ascorbic acid

Values in columns labelled with the same letter are not significantly different ($p > 0.05$)

Table 3. Color of flours (dried at 65 ˚C) obtained from samples blanched in boiling water with different additives

Treatment	*L**	*a**	*b**	Δ*E*	*h**	*C**	*BI*
Control*	58.4 ± 4.1b	1.9 ± 0.2bc	21.9 ± 3.2 a	43.9 ± 2.6a	85.1 ± 1.1abc	22.0 ± 3.2a	47.5 ± 5.0a
H_2O	63.8 ± 2.0b	3.1 ± 0.0a	16.3 ± 0.7bc	35.9 ± 1.0b	79.3 ± 0.5d	16.8 ± 0.6b	31.8 ± 0.7b
AA, 500 ppm	74.2 ± 2.0a	1.8 ± 0.4bc	14.7 ± 0.8bcd	26.5 ± 1.6c	83.0 ± 1.8bcd	14.8 ± 0.8bc	23.2 ± 1.3cd
CA, 500 ppm	73.3 ± 3.3a	2.2 ± 0.5ab	12.6 ± 0.2cd	26.3 ± 3.1c	80.1 ± 2.0d	12.8 ± 0.3c	20.4 ± 1.8d
LA, 500 ppm	73.1 ± 4.0a	1.9 ± 0.6bc	12.2 ± 0.7d	26.4 ± 3.9c	81.2 ± 2.7cd	12.4 ± 0.7c	19.7 ± 2.6d
AA, 250 ppm + CA, 250 ppm	73.2 ± 4.1a	2.1 ± 0.4bc	15.3 ± 1.3bcd	27.7 ± 3.6c	82.3 ± 1.6bcd	15.4 ± 1.3bc	24.8 ± 2.5bcd
AA, 250 ppm + LA, 250 ppm	76.0 ± 2.5a	1.9 ± 0.3bc	15.4 ± 2.0bcd	25.3 ± 2.6c	83.1 ± 0.5bcd	15.5 ± 2.0bc	23.8 ± 3.6cd
NaCl, 4%	72.6 ± 0.5a	1.2 ± 0.2bcd	15.2 ± 2.0bcd	28.1 ± 1.0c	85.5 ± 1.2abc	15.2 ± 2.0bc	23.9 ± 3.2cd
$CaCl_2$, 0.5%	79.2 ± 0.2a	0.5 ± 0.3d	14.9 ± 1.5bcd	22.3 ± 0.7c	88.0 ± 1.3 a	15.0 ± 1.5bc	20.7 ± 2.1cd
AA, 500 ppm + NaCl, 4%	76.1 ± 1.5a	1.4 ± 0.3bcd	18.4 ± 0.8ab	26.9 ± 1.4c	85.6 ± 0.8abc	18.5 ± 0.8ab	28.2 ± 2.0bc
AA, 500 ppm + $CaCl_2$, 0.5%	78.6 ± 3.9a	1.1 ± 0.5cd	15.9 ± 1.5bcd	23.4 ± 3.4c	85.9 ± 2.1ab	16.0 ± 1.5bc	23.0 ± 3.0cd

*Not Blanched

AA = ascorbic acid, CA = citric acid, LA = lactic acid

Values in columns labelled with the same letter are not significantly different ($p > 0.05$)

Table 4. Influence of the drying temperature on the retention of RS and FOS of samples blanched with ascorbic acid/$CaCl_2$ at a concentration ratio of 100 ppm/0.5%) and a control sample

Treatment		Water content (%)	RS (g/100 g DM)	FOS (g/100 g DM)
50 °C	NB	8.2	35.3 ± 1.8a	40.6 ± 1.0a
	B	6.5	35.0 ± 7.5 a	42.0 ± 7.3 a
65 °C	NB	3.9	37.7 ± 1.4 a	37.2 ± 0.3 a
	B	3.4	37.4 ± 4.6 a	40.3 ± 5.0a
80 °C	NB	3.6	37.5 ± 4.4 a	40.9 ± 1.0a
	B	2.0	34.5 ± 2.4 a	38.1 ± 3.0a

NB = Not blanched, B = Blanched, RS= Reducing sugars

Values in columns labelled with the same letter are not significantly different ($p > 0.05$)

Table 5. Color parameters for the flours obtained from the different treatments: blanched, not blanched and dried at different temperatures

		L*	a*	b*	ΔE	h*	C*	BI
50 °C	NB	52.49 ± 5.17d	3.97 ± 0.20a	18.36 ± 0.88c	47.95 ± 4.54a	77.76 ± 1.07a	21.81 ± 0.83a	47.51 ± 3.57a
	B	62.53 ± 3.10c	1.05 ± 0.10c	21.74 ± 0.88a	40.06 ± 2.28b	87.24 ± 0.29c	21.77 ± 0.88a	42.40 ± 0.99b
65 °C	NB	70.17 ± 3.76b	2.10 ± 0.27b	21.09 ± 0.27ab	33.30 ± 3.22c	84.31 ± 0.66b	21.19 ± 0.29ab	36.89 ± 3.12c
	B	72.67 ± 2.24ab	1.07 ± 0.28c	19.89 ± 1.09b	30.53 ± 1.30cd	86.89 ± 0.90c	19.92 ± 1.08bc	31.96 ± 1.07d
80 °C	NB	73.34 ± 1.00ab	1.46 ± 0.21c	17.00 ± 0.46c	28.32 ± 1.02d	87.11 ± 0.62b	17.06 ± 0.47d	26.97 ± 1.29e
	B	75.90 ± 1.14a	-0.54 ± 0.44d	17.34 ± 0.99c	26.35 ± 1.44d	91.84 ± 1.56d	17.36 ± 0.98d	24.54 ± 2.42e

NB = Not Blanched, B = Blanched

Values in columns labelled with different letters are significantly different ($p < 0.05$)