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Dietary fiber, fructooligosaccharides, and physicochemical properties of homogenized aqueous suspensions of yacon (*Smallanthus sonchifolius*)

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ABSTRACT

Yacon roots are a promising source of inulin-type fructans (35 g/100 g dry matter) with a total amount of dietary fiber of about 45 g/100 g dry matter. The polydispersity of the particle size distribution of yacon aqueous suspension was reduced with increasing the degree of homogenization due to two phenomena: aggregation of particles, and disruption of large particles. Non-homogenized yacon suspensions exhibited large cell clusters that were disrupted into small cell clusters, single cells, and aggregates. The most concentrated suspension exhibited mainly aggregates.

The volume fraction of the suspensions decreased significantly with increasing the degree of homogenization. This was attributed to a denser packing of small particles and aggregates in between large particles thus allowing the water within the structure to be released.

Yacon suspensions exhibited high elastic modulus (750 Pa) at low water insoluble solids content (0.9% WIS). Additional results suggested that inulin-type fructans contributed to the elastic properties of yacon suspensions.

The yacon suspensions studied in this work can be considered as semi-concentrated suspensions, i.e. the plot elastic modulus of the suspensions versus concentration exhibited a region immediately after the transition region. Particle interactions seem to be of great importance in this region in the particular case of yacon suspension since the elastic modulus (G') reached 750 Pa at low water insoluble solids content ($<1\%$).

1. Introduction

The food industry is currently interested on improving the nutritional benefits of products without compromising their technological properties. For example, there is an increase interest on using dietary fibers to fortify formulations or to replace components such as fat in food. Therefore, it is interesting to study new sources of dietary fiber as well as their physicochemical properties for future industrial application. It is for this reason that some studies have been performed on the physicochemical and sensory properties of various fruits and vegetables in attempts to understand the behavior of dietary fiber when added to a food product (Bayod, Willers, & Tornberg, 2008; Bengtsson, Montelius, & Tornberg, 2011; Castro, Bergenståhl, & Tornberg, 2012; Lopez-Sanchez et al., 2011; Valencia et al., 2003).

Moreover, processes such as heating, pumping, and homogenization are often included in this type of works in order to study the impact of processing on the physicochemical properties of fibers. This helps us to understand changes occurring at industrial scale. Some of these changes are related to particle properties, concentration, and chemical composition. Concentration of water insoluble solids (WIS) has a great influence of the rheological properties of fiber suspensions (Pelegrine, Silva, & Gasparetto, 2002; Valencia, Sanchez, Ciruelos, & Gallegos, 2004). For example, the elastic modulus (G′) of parsnip, apple, carrot, tomato, and potato suspensions increased significantly with WIS content. Moreover, in the particular case of parsnip suspensions the elastic modulus as a function of WIS exhibited three regions of different rheological behavior i.e. dilute regime, transition region (at volume fraction of 19%) and concentrate regime. Additionally, it has been shown in these fiber studies that homogenization introduces significant changes in the particle size distributions and particle shape (Bayod & Tornberg, 2011; Bengtsson & Tornberg, 2011; Castro et al., 2012).

The changes in particle properties produced by homogenization can also influence the rheology of the fiber suspensions. These changes may be greater in some fibers than in others because not all cells are disrupted to the same extent when homogenized. This seems to depend on the insoluble pectin present in the cell structure (Hanna Bengtsson & Tornberg, 2011). In addition, the way how the cell clusters are disrupted e.g. through the cell wall or through the middle lamella, seems to have an effect on the rheological properties of the fiber suspensions (Day, Xu, Oiseth, Hemar, & Lundin, 2010; Lopez-Sanchez et al., 2011).

The different polysaccharides that constitute the dietary fiber also have various roles in the physicochemical properties of fiber

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suspensions. One group of polysaccharides that has received a great deal of attention in recent years especially in the food industry is the inulin-type fructans. Inulin-type fructans are used to replace fat in meat products due to their ability to form a stable gel network and mimic some of the textural properties of fat (Bodner & Sieg, 2009; Izzo & Franck, 1998). Inulin and its hydrolysates (oligofructans with degree of polymerization from 2 to 8) are also added to dairy products such as yogurt in order to improve textural properties and sensorial acceptance. Additionally, the partial replacement of sucrose with oligofructans in yogurt formulations it is also possible (Yi, Zhang, Hua, Sun, & Zhang, 2010).

Like starch, inulin-type fructans are storage polysaccharides found in some plants. In contrast to starch, inulin-type fructans are not hydrolyzed by the enzymes of the small intestine. Instead, they are metabolized by the intestinal microflora to form short chain fatty acids, L-lactate, CO_2, hydrogen and other metabolites. Therefore, inulin-type fructans are considered to have prebiotic effects (Nair, Kharb, & Thompkinson, 2010; Sabater-Molina, Larque, Torrella, & Zamora, 2009). Inulin-type fructans can also reduce the risk of many diseases, promote good gastrointestinal health, increase calcium and magnesium absorption, and reduce the risk of colon cancer and tumor growth (Cherbut, 2002; Nair et al., 2010; Roberfroid, 2007; Sabater-Molina et al., 2009). All these benefits were strong arguments for the inclusion of inulin-type fructans in the concept of dietary fiber. Thus, it has been proposed to modify standard methods for total dietary fiber determination in order to include inulin-type fructans (Quemener, Thibault, & Coussement, 1997; Steegmans, Iliaens, & Hoebregs, 2004).

Yacon roots have these beneficial properties due to their fructooligosaccharide content, which is an inulin-type fructan. The yacon (*Smallanthus sonchifolius*) is a perennial herb grown in many Andean countries and it is commonly eaten raw (Ecuador, Peru, Bolivia, and Argentina). The color of the flesh can vary between white, cream, white with purple striations, purple-pink, and yellow (Cazetta, Martins, Monti, & Contiero, 2005; Hermann & Heller, 1997; Pedreschi, Campos, Noratto, Chirinos, & Cisneros-Zevallos, 2003). Nevertheless, the physicochemical properties of yacon aqueous suspensions have not previously been studied.

In this work, we investigated the physicochemical properties of yacon aqueous suspension at different concentrations and different degrees of homogenization. The total dietary fiber and fructooligosaccharide content in yacon roots was determined, followed by a study of the physicochemical properties of aqueous suspension considering particle size distribution, volume fraction, cell microstructure, and rheological properties.

2. Material and methods

2.1. Preparation of yacon paste and yacon suspensions

Yacon roots were purchased from three localities in Bolivia: Colomi (C), Tiquipaya (T) and Luriby (L). The samples were named after the color of their flesh (yellow and purple) and locality of provenance: yellow-C, yellow-T, purple-C and purple-L. The roots were washed, peeled under distilled water to avoid oxidation, and cut into 1×1×1 cm cubes. The cubes were immersed in 5 g/l ascorbic acid solution for 1 min. Approximately 300 g of the material was minced in a Grindomix® GM200 knife mill (Retsch, Germany) at 7000 rpm for 45 s to obtain yacon paste. Potassium sorbate (1.5 g/l), sodium benzoate (0.8 g/l) and ascorbic acid (3 g/l) were added to the paste as preservatives. The yacon paste was stored at −20 °C in plastic containers with a capacity of 1 Kg until use. The yacon paste was thawed at room temperature prior to the analysis. Unless otherwise stated, only results obtained from yacon "yellow-C" are reported.

Yacon suspensions with 70, 80 and 100% paste (w/w) were prepared by suspending yacon paste in distilled water. The suspensions were homogenized from 1 to 10 passes at 90 bar using a ball-valve lab-scale homogenizer (Tornberg & Lundh, 1978). An amount of each sample was reserved after each pass for further analysis.

2.2. Determination of dry matter, water insoluble solids, soluble solids, and pH in yacon paste and suspensions

Three grams of sample were dried in a vacuum oven at 70 °C for 16 h and then weighed. The results are expressed as g dry matter (DM) /100 g sample. The water insoluble solids (WIS) were determined by suspending 20 g of sample in 100 ml distilled water. The mixture was centrifuged at 3000 ×g for 20 min at 20 °C (Allegra X-15R, Beckman Coulter Inc., USA). The supernatant was filtered (paper filter 1 F, Munktell Filter AB, Sweden) in order to recover any residues still in suspension and then discarded. Any material recovered during filtration was added to the pellet. The pellet was washed repeatedly with distilled water and filtered again until the washing liquid had a refractive index of about zero. Finally, the residue was dried in an oven at 105 °C for 16 h and then weighed. The results are expressed as g WIS/100 g sample.

The content of soluble solids was measured in the continuous phase with a refractometer (Atago N1, Japan) and expressed as °Brix. The refractometer was calibrated with distilled water at 20 °C prior to the measurement. The pH was measured with a PHM210 pH-meter (MeterLab, France) previously calibrated with two buffers (pH 7 and pH 4) at 20 °C.

2.3. Content and composition of total dietary fiber

2.3.1. Separation of yacon paste into soluble and insoluble fractions

The paste was separated into soluble and insoluble fractions using a mild procedure described by Bengtsson and Tornberg (2011). The yacon paste was mixed with distilled water to give a suspension containing 2% dry matter and then centrifuged at 3000 ×g for 20 min at 20 °C (Allegra X-15R, Beckman Coulter Inc., USA). Pellet and supernatant were collected separately. Both fractions were freeze dried and then milled in a centrifugal miller (Retsch ZM1, Germany) equipped with a 0.5 mm sieve to obtain the insoluble (pellet) and soluble (supernatant) fractions as powders.

2.3.2. Determination of total dietary fiber content in the soluble and insoluble fractions

The mono-, di-, and oligosaccharides were removed from the powders by washing 0.5 g of sample three times with 25 ml of 80% ethanol (Theander, Aman, Westerlund, Andersson, & Pettersson, 1995). The mixture was placed in an ultrasonic water bath for 15 min and then centrifuged at 3000 ×g for 15 min at 20 °C. The upper phase was discarded. The pellet was collected and dried at 40 °C for approximately 16 h. The formation of a compact residue during drying was avoided by breaking the pellet with a glass rod occasionally during the first 8 h. The starch was removed by enzymatic hydrolysis with amylase and amyloglucosidase as described by Theander et al. (1995). The resulting residue was dried in an oven at 40 °C for approximately 16 h. A glass rod was used to break the pellet during drying to avoid the formation of compact residue.

The total dietary fiber (TDF) was determined using the method described by Theander et al. (1995). The method determines the TDF as the sum of neutral sugar residues (PR), uronic acid residues (UA), and Klason lignin (K),

$$\mathrm{TDF} = \mathrm{PR} + \mathrm{UA} + \mathrm{K} \tag{1}$$

The total dietary fiber (TDF) in yacon was calculated as the sum of the fiber content in each fraction,

$$\mathrm{TDF} = \mathrm{TDF}_{\mathrm{soluble fraction}} + \mathrm{TDF}_{\mathrm{insoluble fraction}} \tag{2}$$