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The use of dry Jerusalem artichoke as a functional nutrient in developing extruded food with low glycaemic index

Ana Radovanovic [a], Valentina Stojceska [b,*], Andrew Plunkett [c], Slobodan Jankovic [d], Dragan Milovanovic [d], Snezana Cupara [a]

[a] University of Kragujevac, Faculty of Medical Sciences, Pharmacy Department, Kragujevac, Serbia
[b] Brunel University, School of Engineering, Design and Physical Science, Uxbridge, Middlesex UB8 3PH, UK
[c] The Manchester Metropolitan University, Department of Food and Tourism Management, Hollings Campus, Manchester, UK
[d] University of Kragujevac, Faculty of Medical Sciences, Pharmacology and Toxicology Department, Kragujevac, Serbia

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ABSTRACT

This study considers the use of dry Jerusalem artichoke (JA) as a functional nutrient in developing food products with enhanced nutritional characteristics and low glycaemic index (GI). Three different formulations based on buckwheat and JA were developed and processed using extrusion technology. Nutritional properties including the levels of total dietary fibre (TDF), protein, inulin, total carbohydrates and lipids were analysed. A clinical study was performed on ten healthy volunteers (aged between 21 and 56) to determine the level of GI and glycaemic load (GL).

The results revealed that JA significantly ($P < 0.05$) increased the levels of TDF and inulin whilst decreasing carbohydrates, lipids and proteins. The resulting products had a significant ($P < 0.05$) effect on IAUC between reference food and extruded products, GI and GL. Samples containing 80% of Jerusalem artichoke were considered as a low GI food whilst samples containing 30% and 60% of Jerusalem artichoke as a medium GI food. A similar trend was seen in terms of GL.

1. Introduction

Over the last decades, consumer demands for functional foods as an opportunity to improve food product quality has increased enormously. The main characterisation of functional food is fortification with dietary fibre, micronutrients, antioxidants, vitamins or minerals that contributes health benefit effects in certain disorders.

One of the promising functional constituents that could be used for developing a functional food is inulin. It has a great potential to be considered as a low glycaemic index (GI) ingredient that could provide a number of health benefits such as managing increased risk of chronic diseases (diabetes, cardiovascular diseases, obesity, stroke and cancer), improving digestive health (prevents constipation), reducing cholesterol and lipids (decrease cardiovascular disease) and enhancing mineral absorption from colon with its prebiotic role (prevents osteoporosis) (Barclay et al., 2008; Brand-Miller, Holt, Pawlak, & McMillan, 2002; Knudsen & Hessova, 1995; Watzl, Girrbach, & Roller, 2005).

The main sources of inulin are Jerusalem artichoke (JA) (*Helianthus tuberosus L. Heliathus, Asteraceae*) and chicory root (*Cichorium intybus var. sativum*). JA is also a good source of minerals (calcium, iron, selenium, potassium, phosphorus) and vitamins (vitamin B complex, vitamin C and β-carotene) (Kays & Nottingham, 2007). Inulin from JA is a non-starch carbohydrate known as a fructan which is considered as a functional ingredient with similar characteristics to dietary fibre. Because of its desirable textural and nutritional properties inulin from JA has been used as a prebiotic (Rubel, Pérez, Genovese, & Manrique, 2014), a source of low GI food (Radovanovic, Cupara, Stojceska, & Plunkett, 2012) and a fat/sugar replacer and texturizer (Choque Delgado, Tamashiro, & Pastore, 2010).

The present work investigated the possibility of the use of dry JA as a source of inulin in developing low GI extrudates. In order to develop a low GI food it is also essential to consider the type of food processing, moisture content and degree of starch gelatinization (Bjorck, Liljeberg, & Ostman, 2000; Foster-Powell, Holt, & Brand-Miller, 2002). Extrusion technology is increasingly used in the food industry for producing different types of food products such as breakfast cereals and ready-to-eat snacks. It is a high temperature, high pressure, short time and continuous processing technique that enable manufacturers to produce highly nutritious

* Corresponding author. Tel.: +44 1895267328; fax: +44 1895269803.
E-mail address: Valentina.Stojceska@brunel.ac.uk (V. Stojceska).

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food products with incorporation of different types of ingredients, flours and starches. It is a very efficient and promising technology that could be used in developing new generation of functional foods. A number of different ingredients sourced from vegetables, cereals and fruits have been used to develop a range of extruded products with improved nutritional characteristics including dietary fibre, proteins, antioxidants, phenolic compounds and iron (Potter, Stojceska, & Plunkett, 2013; Stojceska, Ainsworth, Plunkett, & İbanoğlu, 2010; Stojceska, Ainsworth, Plunkett, İbanoğlu, & İbanoğlu, 2008). Under optimal conditions the extrusion technology is an appropriate method for producing high quality ready-to-eat snacks. Apart from the formulation the quality of the final products also depends extensively on the extruder type, screw configuration, feed moisture, barrel temperature, screw speed and feed rate. Therefore, selecting and combining appropriate ingredients, process conditions and extruder types are important factors in producing high quality extruded snack products. The primary objective of this study was to develop food products with enhanced nutritional quality by incorporation of different levels of dry JA. The secondary objective was to assess the glycaemic effect of the resulting extrudates. Although, JA has been used in various studies, to the best of authors' knowledge no similar paper in this area has been published before.

2. Materials and methods

The ingredients used in the preparation of the samples were: buckwheat (purchased from the local shops in Manchester) and Jerusalem artichoke (JA) tubers (collected from the Sumadija region, Serbia).

The JA's tubers were peeled and chopped in small pieces then dried for 24 h at 40 °C in a cabinet drier (Model UOP8-G, Armfield, Hampshire, England) and milled into a fine powder (Retsch ZM200 centrifugal mill: Retsch UK Ltd). Ingredients (JA and buckwheat) were weighed on Weighmaster scales (Weigh-master Limited, Leicester, UK), sieved and mixed in a Hobart NCM mixer (Process Plant and Machinery Ltd, UK). Four different samples were prepared as follows:

Sample 1: buckwheat flour and 30% of JA (JA30)
Sample 2: buckwheat flour and 60% of JA (JA60)
Sample 3: buckwheat flour and 80% of JA (JA80)
Sample 4: only buckwheat flour (JA00) was used as a control sample

The samples were packed in polyethylene bags and stored at room temperature for 24 h before extrusion.

2.1. Extrusion trials

The moisture content of the samples was determined using the air oven method (AOAC, 1984) with extrusion moisture being adjusted by pumping water into the extruder during runs by means of a Watson Marlow 505L peristaltic pump (Watson Marlow Bredel). A twin-screw volumetric feeder (Rospen, Gloucestershire, UK) was used for feeding the dry mixture to the extruder.

The extrusion trials were performed using a Werner and Pfleiderer Continua 37 twin-screw co-rotating extruder (Stuttgart, Germany), fitted with a circular die with a diameter of 4 mm, under the following process conditions: feed rate of 16–24 kg/h, water feed of 8.2–22%, screw speeds of 330–332 rpm with the barrel temperatures being set in two zones 80 °C and 120 °C at the beginning and end of the barrel, respectively. The process conditions were optimised prior to the main extrusion trials. Pressure, material temperature and torque were manually recorded during extrusion runs after steady state conditions were reached, as indicated by constant torque, temperature and screw speed readings. Samples then palletized, collected on trays before being cooled and stored in polyethylene bags at room temperature for further analysis and sensory evaluation.

The sensory analysis of the four samples was performed using staff members of the Manchester Metropolitan University who were asked to assess the snacks for flavour acceptability. Preference was indicated by placing a vertical line a 10 cm horizontal scale numbered with 1 (dislike a lot) at one end and 10 (like a lot) at the other in accordance with their opinion.

2.2. Nutritional analysis

2.2.1. Total dietary fibre (TDF)

The TDF content of extrudates was determined using a combination of enzymatic and gravimetric methods (Sigma–Aldrich, Inc., Saint Louis, Missouri, US) (AOAC, 1997). Milled and dried samples were gelatinized with heat stable α-amylase and then enzymatically digested with protease and amyloglucosidase to remove protein and starch present in the sample. Ethanol was added to precipitate the soluble dietary fibre. The residue was then filtered and washed with ethanol and acetone. After drying, the residue was weighed. Half of the samples were analysed for protein and the others ashed. Total dietary fibre was calculated as a weight of the residue less the weight of the protein and ash. This methodology does not include nondigestable oligosaccharides and some resistant starches.

2.2.2. Carbohydrates

Total carbohydrate level was measured using the anthrone reagent method using glucose as a standard (Hedge & Hofreiter, 1962). Milled and dried samples were hydrolysed with 5 ml of 2.5 N HCl, neutralized with sodium carbonate then mixed with 4 ml freshly prepared anthrone reagent. A standard graph was drawn of the concentration of standard on the *X*-axis versus absorbance on the *Y*-axis. The amount of carbohydrate present was calculated from the graph as follows: mg of glucose × 100/volume of test sample.

2.2.3. Inulin

The inulin level of the finished products was measured using the method of Sadasivam and Manickam (2007). Samples were extracted using boiling water and hydrolysed with sucrase and fructanase. Calculations of inulin were based on fructose measurement. Glucose results of the hydrolysates were not used for inulin calculations because of possible interference with the measurement of the sucrase and the fructanase hydrolysates, occurring from glucose released by the hydrolysis of maltose or by partial hydrolysis of other compounds such as maltodextrins, starch, lactose, or maltitol.

2.2.4. Protein

Protein content was estimated from the crude nitrogen content of the sample determined by the Kjedahl method (Nx 6.25) (AOAC, 1984).

2.2.5. Lipids

Lipids content was determined following the method of Trajković, Baras, Mirić and Šiler (1983).

2.3. Study subjects

The GI and GL produced by the extrudates were determined according to the FAO/WHO protocol (FAO/WHO, 1998). The clinical study was performed on 10 healthy volunteers of both genders (4 males and 6 females), aged between 21 and 56 years all of which