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The quality of functional whole-meal durum wheat spaghetti as affected by inulin polymerization degree

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ABSTRACT

The use of inulin in pasta improves the nutritional value decreasing the glycemic index in the blood after pasta ingestion but it compromises the sensory characteristics in terms of elasticity, firmness, bulkiness and adhesiveness.

Thus, in this work, the impact of substituting whole-meal durum wheat flour with inulin on cooking quality, sensory and textural properties, digested starch and chemical composition of spaghetti was investigated. Two types of inulin at two different concentrations (2% and 4%) were adopted: inulin extracted from cardoon roots (CRI) (high polymerization degree) and commercial inulin (CHI) (low polymerization degree) produced from chicory. From the chemical point of view, the sample with 4% CRI showed the greatest total dietary fibres content and the lowest available carbohydrates content. A global acceptable quality was also recorded in all the other technological and sensory properties of enriched pasta with both types and both concentrations of inulin. The most feature of the work is that when CRI was added to the dough, better results were recorded, thus suggesting that for pasta enrichment, the selection of inulin with proper polymerization degree is a strategic factor for final product acceptance.

1. Introduction

Functional food can be any food consumed as part of an accustomed diet which, beyond basic nutritional functions, is demonstrated to have physiological benefits and/or reduces the risk of some diseases (e.g. cholesterol-lowering products), improves the general conditions of the body (e.g. pre- and probiotics) and can also be used for curing some illnesses (Menrad, 2003; Mark-Herbert, 2004; Siro, Kapolna, Kapolna, & Lugasi, 2008). Functional food can be either an unmodified 'natural food' or a food developed by adding, modifying or removing a component from the food (Rakhesh et al., 2015Rakhesh, Fellows, & Sissons, 2015). Pasta is a staple food eaten daily or weekly in quantities constituting a dominant moiety of the diet in many countries, it is regularly eaten in such quantities that constitutes a dominant portion of the diet worldwide (International Pasta Organization, 2014). Pasta is favored by consumers for its versatility, ease of transportation, handling, cooking and storage properties, availability in numerous shapes and sizes, high digestibility, good nutritional qualities and relatively low cost. Therefore, pasta can be used as carrier of specific compounds. It is traditionally manufactured from durum wheat semolina (Rakhesh et al., 2015). Recently, the development of enriched pasta with a high dietary fibre content would be a good way to increase the fibre intake and reduce the glycemic index (Padalino et al., 2015). Dietary fibre is rich in fruits, vegetables and whole grains, and consists of portions of plant foods that are edible and non-digestible by humans (Jones, Lineback, & Levine, 2004). The fibers can be soluble and insoluble. Among the soluble fibers, inulin plays an outstanding role. Inulin is an indigestible fructo-oligosaccharide which naturally occurring plant carbohydrates stored in various amounts in tubers, bulbs and tuberous roots of several edible fruits and vegetables and in particular large amounts in the tubers of Helianthus tuberosus (Jerusalem artichoke) and Cichorium intybus (chicory) (Apolinário et al., 2014; Drabińska, Zieliński, & Krupa-Kozak, 2016). Depending on species and age of the plants, inulin presents different degree of polymerization, from low fructose unit numbers (e.g. chicory with 20 units

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of fructose) until 100 units of some Asteracean plants (Cynara, Echinops, topinambur, etc.) (Raccuia & Melilli, 2004, 2010). In food, oligofructose is more commonly used as sweet-replacer and longer chain inulin is used mostly as fat replacer and texture modifier (Kelly, 2008). Both inulin and oligofructose are used as dietary fiber and prebiotics in functional foods. Its longer chain length makes inulin more useful for pharmaceutical purposes than oligofructose (Maartens et al., 2015). The addition of inulin could compromise sensory, technological and nutritional aspects of pasta and could not be accepted by consumers. Aravind, Sissons, Egan, and Fellows (2012) studied that two inulin types with different degrees of polymerisation and crystallinity have different levels of integration with the starch–gluten matrix during pasta preparation. Recently, Liu et al. (2016) investigated by scanning electron microscopy the effects of three types of inulin with different degrees of polymerization on the structure of protein component of wheat dough (gluten, gliadin and glutenin). Besides, Luo et al. (2017) observed that the gelatinization and retrogradation properties of wheat starch were largely dependent on degree of polymerization and inulin content.

The aim of this work was to evaluate the effects of the addition of inulin with different polymerization degrees on the chemical and sensory properties of spaghetti based on whole-meal durum wheat flour. Specifically, inulin extracted from cardoon roots and commercial inulin produced from chicory at two concentrations (2% and 4%) were used.

2. Materials and methods

2.1. Raw material

The whole-meal flour (*cv Senatore Cappelli*) was bought from Molino Riggi (Caltanisetta, Italy).

2.2. Location of the trial, plant material and crop management

Cynara cardunculus L. var. *altilis* DC, line CDL, was cropped in the experimental field of Assoro (EN. 37°30′54″ N; 14°16′26″ E, 279 m. a.s.l.) located in the internal hilly area of Sicily. Soil characteristics are 64% sand, 24% silt, 13% clay%, 1.5%, organic matter, 1.0‰ total nitrogen, 35 μg/g P_2O_5 and 403 μg/g K_2O.

Cultivated cardoon plants were sown on September 2012, using a density of 6 plant m^{-2}. During the two years of the experiment, the energy inputs for crop management were minimized. Crop water requirements were satisfied by rain and one irrigation per year in May (flowering) with 50 mm of water. In the first year, another irrigation (50 mm of water) was carried during the establishment of the crop. Each year, plants were fertilized with N at 50 Kg ha^{-1} (October) and two manual weedings were carried out in October and December. In the second year, the crop regrowth was naturally carried out by rainfall.

Roots were collected (up to a depth of 40 cm) in May 2014 at Assoro before plant flowering. The crop was two years old. The harvest time was chosen on the basis of inulin metabolism (synthesis and breakdown of the polymer) in cardoon, because in previous studies it was demonstrated plants maximize yields in long polimerisation degree (DP) inulin before flowering, after that inulin breakdown follows to supply energy for heads development and achenes ripening (Melilli et al., 2014; Raccuia & Melilli, 2010).

2.3. Inulin extraction and purification

In the laboratory, the moisture content of a representative sample of roots was measured after drying the plant material to a constant weight in a thermo-ventilated drying oven at 105 °C. Fresh roots (consisting of both primary and secondary roots) was washed in cold tap water, scraped and ground to a fine powder. 100 g of the original homogenate was diluted tenfold with water and put in a boiling water bath for 30 min. After cooling to room temperature the extract was filtered and centrifuged at 3000*g* for 5 min. The inulin extracted was precipitated at 0 °C overnight. The supernatants was removed and inulin was washed with distilled water and precipitated at 0 °C overnight. The washing process was repeated until inulin was white. The colour was determinate by colorimeter Minolta CR 400. Values of L* upper than 85 has been accepted for purification. Inulin was lyophilized in petri dishes and used for pasta production (called CRI, high DP). On lyophilized inulin the moisture content was determined in a thermo-ventilated oven at 105 °C. The moisture content resulted less than 0.5 g 100 g^{-1} of fresh weight.

To test the effect of the degree of polymerization during the pasta production, commercial inulin from *Chicory intibus* was purchased by Orafti®. The mean degree of polymerization was 20–25 fructose units (called CHI, low DP).

2.4. Inulin characterization

A representative sample of fresh roots was washed in cold tap water, scraped and ground to a fine powder with a mortar and pestle under liquid nitrogen. One gram of the original homogenate was diluted fivefold with water and put in a boiling water bath for 30 min. After cooling to room temperature the extract was centrifuged at 3000*g* for 5 min. A part of this fraction was diluted 10-fold with distilled water to analyse free sugars (glucose, fructose, and sucrose) and another fraction (500 μL) was hydrolysed at 70 °C for 2 h using 5 μL of 3 N HCl to analyse total fructose. Both the fractions were analysed using high-performance anion exchange chromatography with pulsed amperometric detection (HPAEC PAD) (Thermofisher 3000), consisting of a metal-free isocratic pump, a pulsed amperometric detector, a metal-free injection valve with a 20 μL injection loop, and a CarboPac PA10 column (4 × 250 mm) with the guard column. The detection cell contained a gold working electrode (1.0 mm in diameter) and an Ag/AgCl reference electrode; the counter electrode was a titanium cell body across the 25 mm thin-layer channel from the working electrode.

The column was regenerated with 1 M NaOH for 10 min and equilibrated for 20 min after every run. Pulsed amperometric detection was carried out with the following waveform: t = 0.00 s (E = +0.05 V), t = 0.49 s (E = +0.60 V), and t = 0.62 s (E = −0.60 V). The integration was at 0.28 s (beginning) and 0.48 s (end). The response time was 1 s, and the electric signal was integrated in nanocoulomb (nC). All experiments were carried out at 30 °C under the following elution conditions: 90 mM NaOH with 50 mM Na-acetate for 1 min followed by a linear gradient from 50 to 500 mM Na acetate in 90 mM NaOH over a 60-min period with a flow-rate of 1 mL/min. Quantification was performed on the peak areas with the external standards methods for α-glucose, fructose, and sucrose (SIGMA, Steinhem, Germany). The carbohydrate standard solutions to be injected were prepared fresh daily. The maximum DP was recorded counting the peaks over a threshold of 10 nC of the chromatograms obtained in runs of 120 min under the following elution conditions: 90 mM NaOH with 50 mM Na-acetate for 1 min followed by a linear gradient from 50 to 500 mM Na acetate in 90 mM NaOH over a 120-min period with a flow-rate of 0.8 mL/min.

Inulin content (I) and the average chain length (mean DP) were calculated as suggested by Baert (1997): I = (F + G) − (f + g + s), mean DP: (F − f − 0.525s)/(G − g − 0.525s) where F and G are total fructose and glucose after acid-hydrolysis and f, g, and s the reducing free sugars fructose, glucose, and sucrose before acid-hydrolysis.

All the analyses were performed in duplicate and are reported on a dry matter (DM) basis. Inulin is reported in g kg^{-1} DM.