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Spaghetti from durum wheat: Effect of drying conditions on heat damage, ultrastructure and in vitro digestibility

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ABSTRACT

The effects of low (LT) or high (HT) temperature drying on ultrastructural, molecular and *in vitro* digestibility properties of cooked spaghetti were studied. Starch swelling and denaturation/aggregation of proteins occurring at diverse stages, LT or HT drying and cooking, resulted in different *in vitro* digestibility of spaghetti. For the first time, these differences were assessed in terms of the release of free AA and simple sugars. Indeed, at the end of *in vitro* digestion, the total amount of released maltotriose, maltose and glucose significantly differentiated digestates of LT and HT spaghetti (12.6 and 15.9 g 100 g^{-1}). In the same samples, diverse amounts (16.3 and 12.5 g 100 g^{-1} protein) of free amino acids were found. Chemical artifacts occurring at protein level impaired release of lysine in cooked HT spaghetti after *in vitro* digestion. These results increase the knowledge on digestibility of LT and HT cooked spaghetti.

1. Introduction

Dried pasta represents a basic food worldwide; it is prepared from dough obtained by mixing water with semolina from durum wheat (*Triticum turgidum* L. var. *durum*). The dough is continuously kneaded and extruded through a die that determines the shape of the final product. At industrial scale, pasta is finally dried to about 12% moisture according to different time/temperature/humidity cycles, which have been largely performed in Italy at low temperature (LT, 60–70 °C; 14 h) until the 1970s. More recently, adoption of high temperature (HT, >70 °C; 8 h) drying has reduced the processing time and generally improved cooking properties of pasta (Cubadda, Carcea, Marconi, & Trivisonno, 2007; Petitot, Abecassis, & Micard, 2009a; Petitot et al., 2009b). The phenomena involved in determining the behaviour of pasta components have been elucidated by investigating the ultrastructure of dried and cooked pasta by means of transmission electron microscopy and scanning electron microscopy (Cunin, Handschin, Walther, & Escher, 1995). As a result of these investigations, the structure of dried and cooked pasta has been generally described as a compact matrix with starch granules entrapped in a coagulated protein network, which especially forms and organises when HT drying is applied to pasta dried under low moisture (<15%) conditions (Bruneel, Pareyt, Brijs, & Delcour, 2010; Cunin et al., 1995). Under such conditions, the cooked pasta achieves higher firmness, lower stickiness and minimally loses solids into cooking water (Petitot et al., 2009a, 2009b; Zweifel, Handschin, Escher, & Conde-Petit, 2003).

Due to the presence of reducing sugars and proteins, pasta is a food system easily prone to Maillard Reaction (MR), which can be enhanced by several biochemical and technological factors occurring in pasta production (De Noni & Pagani, 2010). Consequently, the heat damage of dried pasta involves protein glycosylation and formation of advanced glycation end products (AGEs) (De Noni & Pagani, 2010), which may affect protein digestibility (Seiquer et al., 2006). In this regard, the effect of drying treatments in modifying protein breakdown during digestion by formation of AGEs should be considered.

The molecular phenomena responsible for pasta (ultra)structure, especially during HT drying, could also affect the kinetics and degree of protein and starch breakdown in the gastrointestinal tract. Starch degradation during *in vitro* digestion of pasta was demonstrated to be affected by both its physical modification (mainly gelatinisation) and the compact protein matrix surrounding the starch granules, which may prevent amylolysis (Casiraghi, Brighenti, & Testolin, 1992; De Zorzi, Curioni, Simonato, Giannattasio, & Pasini, 2007). The size and shape of pasta as well as the spaghetti particle size have been reported to affect *in vitro* starch digestion by changing the surface-to-volume ratio and hence access by α-amylase (Aravind, Sissons, & Fellows, 2011). The influence of matrix modifications determined by processing conditions on the digestibility of pasta protein has been studied

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as well, and HT drying was shown to decrease the *in vitro* digestibility of proteins (De Zorzi et al., 2007; Petitot et al., 2009a, 2009b). Moreover, resistance of pasta proteins to digestion was shown to address sensitisation of humans to wheat proteins (De Zorzi et al., 2007; Petitot et al., 2009b; Simonato et al., 2001).

The overall effect of drying parameters on the digestibility of pasta was assessed by different *in vitro* digestion models and by evaluating different products arising from breakdown of pasta components (De Zorzi et al., 2007; Petitot et al., 2009b). Recently, a static protocol for *in vitro* digestion has been drafted and shared within the COST Action FA1005 (Dupont et al., 2011). Based on this protocol, the aim of this work was to assess the digestibility of cooked spaghetti dried under LT or HT conditions by measuring the release of amino acids and sugars in the digestates. The ultrastructure and the characteristics of starch and proteins of spaghetti before and after cooking were evaluated as well, with the aim to achieve a more detailed view of factors affecting their *in vitro* digestibility.

2. Materials and methods

2.1. Spaghetti production

Spaghetti were processed with a continuous pilot-scale plant (50 kg h^{-1}, Braibanti, Milan, Italy). Durum wheat semolina (protein content 12.0 g 100 g^{-1} db; extraction rate 70%; Molino Grassi, Parma, Italy) was mixed with tap water at a semolina-to-water ratio of 10:2.67 to obtain a dough moisture of 32%, and mixed for 10 min. Spaghetti were extruded through a Teflon die (diameter 1.7 mm) at 10–11 MPa, 20 rpm and about 40 °C, and then dried in a pilot-scale drier (50 kg h^{-1}, Braibanti, Milan, Italy) until 12% moisture was reached. Drying at low (<62 °C) or high (<93 °C) temperature was applied to the pasta; the related time/temperature/moisture profiles are depicted in Fig. 1.

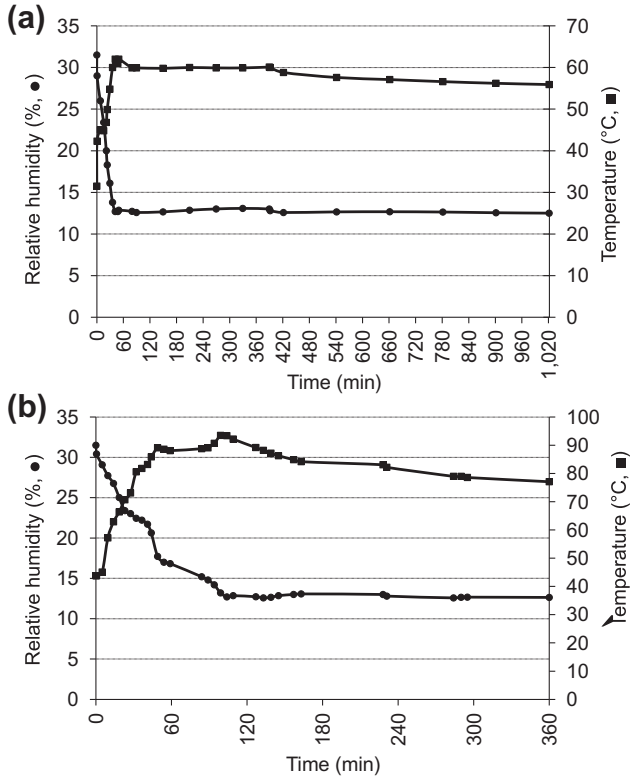

Fig. 1. Drying conditions of spaghetti processed in a semi-pilot plant according to low-temperature (A) and high-temperature (B) cycles.

2.2. Cooking of spaghetti

Dried spaghetti were cooked according to D'Egidio, Mariani, Nardi, Novaro, and Cubadda (1990) with minor modifications. In detail, dried spaghetti were cut to the same length (about 8 cm). Ten grams of spaghetti were then put into 100 mL boiling tap water without salt added. Optimal cooking times were 10.0 and 11.0 min for LT and HT dried spaghetti, respectively. The cooking time was determined by observing the disappearance of the white core of the pasta squeezed between two glass plates. Spaghetti were let to drain for 9 min and promptly submitted to analyses or freeze dried.

Water absorption was measured as the weight increase of spaghetti before and after cooking, and is expressed as percent weight gain with respect to the weight of uncooked spaghetti.

2.3. Pasting properties of spaghetti

The pasting properties of uncooked and cooked spaghetti were measured by a Brabender Micro-Visco-AmyloGraph (Brabender OHG, Duisburg, Germany) on 15 g of finely ground sample dispersed in 100 mL of distilled water, according to Bonomi et al. (2012). The following indices were considered: pasting temperature; peak viscosity (maximum paste viscosity achieved during the heating cycle); breakdown (decrease in viscosity during the first holding period, corresponding to the peak viscosity minus the viscosity after the holding period at 95 °C); setback (increase in viscosity during cooling, corresponding to the difference between the final viscosity and the viscosity reached after the first holding period). Measurements were performed in triplicate.

2.4. Analysis of SDS-soluble, DTE-soluble and unextractable proteins

Proteins were extracted in triplicate from semolina, uncooked and cooked freeze dried spaghetti according to a modified method of Morel, Dehlon, Autran, Leygue, and Bar-L'Helgouac'h (2000) and described in Petitot et al. (2009b). The extraction procedure consisted of two successive extractions. The first step extracted SDS-soluble proteins and the second one extracted DTE-soluble proteins from the pellet of the first extraction. The remaining fraction that was extracted neither in SDS nor in DTE followed by sonication constituted the insoluble fraction or unextracted proteins. It represented proteins linked by covalent linkages other than disulfide bonds. The protein quantification in each extract (semolina, raw and freeze dried cooked pasta) was examined using total area from the SE-HPLC profile as described in Petitot et al. (2009b). The percentages of extracted proteins were calculated considering the semolina protein as 100% extractable. Assays were performed in triplicate.

2.5. Ultrastructural observations

Both uncooked and freeze-dried cooked spaghetti strands were mounted on aluminium stubs and sputter-coated with gold. On each stub, four cross-sectioned pieces (4–6 mm length; selected at random) of spaghetti were mounted. Pasta ultrastructure was imaged in the scanning electron microscope (SEM) LEO438 VP (LEO Electron Microscopy Ltd., Cambridge, UK), under high vacuum conditions (10^{-4} Pa) at an accelerating voltage of 15 kV.

2.6. In vitro static gastrointestinal digestion

To evaluate the digestibility of spaghetti, an *in vitro* static digestion protocol developed within the COST Action FA1005 was adopted (Dupont et al., 2011). In detail, simulated salivary (SSF), simulated gastric (SGF) and simulated duodenal (SDF) fluids were