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Inulin-enriched pasta: effects on textural properties and starch degradation

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Abstract

The effects of inulin addition on the cooking properties, texture and nutritional characteristics of durum wheat pasta were determined. Inulin was shown to influence the swelling index and firmness, but not the adhesiveness and elasticity of pasta products. Addition of inulin to pasta also had a nutritional advantage, showing a slower release of sugars during in vitro starch digestion, and thus reducing the predicted glycaemic index by up to fifteen per cent. The results suggest that by using non-starch polysaccharides it is possible to enhance the nutritional quality of pasta, without deleteriously affecting its cooking and textural properties.

Keywords: Pasta; Dietary fibre; Glycaemic index; Diabetes; Non-starch polysaccharides

1. Introduction

Pasta, a traditional food with origins from the first century BC (Agnesi, 1996), is popular for its ease of cooking and its nutritional qualities. In particular, pasta is regarded as low glycaemic index food product (Björk, Liljeberg, & Ostman, 2000; Jenkins et al., 2000; Jenkins, Wolever, & Jenkins, 1988; Jenkins et al., 1983). The glycaemic index provides a means of quantifying the effect of ingestion of a food product on the blood glucose level when compared with a standard white bread or glucose. (Granfeldt & Björk, 1991; Granfeldt, Liljeberg, Drews, Newman, & Bjorck, 1994; Wolever, 1990). In the case of pasta, digestion of the carbohydrates within its matrix is relatively slow. This in turn results in a slow and progressive starch breakdown and hence sugar production in the body, leading to low postprandial blood glucose and insulin responses (Granfeldt et al., 1994; Jenkins et al., 1983).

Although pasta is traditionally manufactured using only durum wheat flour, it is possible to use non-durum wheat ingredients to produce specifically-labelled blended pasta. It is also feasible to incorporate dietary fibre ingredients into pasta which may increase its nutritional value to the consumer compared to conventional pasta. Incorporation of hydrocolloids into foods has shown beneficial regulation effects on post-prandrial blood glucose, insulin and fasting plasma cholesterol (Blake, Hamblett, Frost, Judd, & Ellis, 1997; Brennan, Blake, Ellis, & Schofield, 1996; Brennan, Roberts, Low, & Ellis, 1993; Eastwood & Morris, 1992; Ebling et al., 1988; Slaughter, Ellis, & Butterworth, 2001; Slaughter, Ellis, Jackson, & Butterworth, 2002; Wood, 2001).

One of these ingredients used by the food industry is inulin, a non-digestible fructo-oligosaccharide (Tungland, 2000). Inulin has traditionally been used as a fat-replacer in dairy foods and has been shown to have positive effects on the rheology and stability of products (El-Nagar, Clowes, Tudorica, Kuri, & Brennan, 2002). There are not many reports on the effects of inulin incorporation into cereal products, and pasta in particular. Information is required regarding the characteristics and the processing parameters needed for the successful incorporation of dietary fibres into consumer-acceptable

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pasta products. The current report discusses the effects of inulin addition on the cooking properties, textural and nutritional characteristics of pasta products.

2. Materials and methods

2.1. Pasta production

Pasta (spaghetti) was made from commercial durum semolina flour, water and inulin (FRUTAFIT HD from Calleva Limited, UK) using a single-screw extruder (La Monferrina pasta machine, Model 6, Italy). Inulin was added at 2.5%, 5%, 7.5% and 10% (g/100 g of flour) and frozen at −20 °C until required for analysis. Pasta without inulin (control) was also made.

2.2. Pasta assessment

Pasta was cooked for 7 min in boiling distilled water, drained and analysed for dry matter, swelling index, cooking loss, total starch, and protein content, as described by Tudorica, Kuri, and Brennan (2002). Textural analysis of the cooked pasta was determined using a TA.XT2 Texture Analyser (Stable Micro System, Reading, UK) with a 25 kg load cell (Tudorica et al., 2002). Adhesiveness of the spaghetti was assessed using a 35 mm cylinder probe (P/35); pasta firmness was measured using a craft blade rig, and elasticity was determined using spaghetti tensile grips (A/SPR).

2.3. In vitro digestion of pasta

In vitro digestion was performed using the multi-enzymatic method of Brighenti, Pellegrini, Casiraghi, and Testolin (1995), slightly modified. Duplicate samples of product (4 g of cooked pasta) were mixed with 20 ml sodium potassium phosphate buffer (pH 6.9). Thereafter, the pH was adjusted to 1.5 (using 8 M HCl), and 5 ml pepsin solution (pepsin 115 U/ml, EC 3.4.23.1, Merck) was added to the samples, followed by incubation at 37 °C for 30 min. Before addition of porcine pancreatic alpha amylase solution (amylase = 110 U/ml buffer, Sigma Chemicals), the pH was readjusted to 6.9 with 10% NaOH and the sample brought to 49 ml with sodium potassium phosphate buffer (pH 6.9). Then 1 ml of α-amylase solution was added and the mixture transferred in dialysis tubes. Each tube was placed into a beaker containing 450 ml potassium phosphate buffer and stirred during the incubation (5 h at 37 °C).

A sample blank and a maltose blank were run with each sample digestion.

Every 30 min for 5 h, aliquots of 1 ml from dialysate were withdrawn in triplicates for analysis of reducing sugar content using the 3,5-dinitrosalicylic acid (DNS) method. A standard curve, using maltose, was prepared. The withdrawn dyalysate was replaced each time with sodium potassium phosphate buffer.

The following parameters were calculated:

- *Extent of hydrolysis* as the proportion of starch digested to maltose: mg maltose equivalents × 0.95 × 100/mg starch [Holm and Bjorck, 1988];
- *sugar diffusion index* (*SDI*). $\mathrm{Diff}_{\mathrm{maltose}}/\mathrm{Diff}_{\mathrm{sample+maltose}}$;
- *digestion index* (*DI*). $(A_{\mathrm{sample}} - A_{\mathrm{blank}}) \times 500 \times 0.95 \times \mathrm{SDI} \times 100/(A_{\mathrm{maltose}} \times \mathrm{St})$;
- *predicted glycemic index* (*GI*). $105.52 \times \text{fibre/carbohydrate} - 76.46 \times \text{protein/carbohydrate} + 1.23 \times \mathrm{DI}_{\mathrm{at\ 150\ min}} + 69.41 \times \mathrm{SDI}_{\mathrm{at\ 270\ min}} - 83.87$ (Brighenti et al., 1995; Giacco et al., 2001).

2.4. Statistical analysis

Results from all the tests were obtained as means ± SD. Analysis of variance (one way ANOVA), followed by Tukey's test with Minitab 13.1 software (Minitab Inc., USA), were used for statistical analysis.

3. Results and discussion

Cooking properties of the durum wheat control pasta and the inulin-enriched pasta samples are shown in Table 1. Compared to the control, pasta containing inulin showed a significant increase in dry matter content ($p < 0.05$), and a significant lowering in swelling index (2.5% addition excepting). Although the mean values for cooking losses of pasta containing inulin were higher than the control, the values were not significantly different. Water absorption capacity of pasta significantly decreased as the amount of inulin in the formulation

Table 1
Cooking characteristics of control and inulin-enriched pasta products

Level of inulin addition	Dry matter (g/100 g)	Swelling index	Cooking losses (%)	Water absorption (%)
0% (Control)	29.79 ± 0.08^{c}	2.36 ± 0.09^{a}	7.93 ± 0.89^{a}	101.10 ± 3.01
2.5%	$31.75 \pm 1.42^{b,c}$	$2.15 \pm 0.14^{a,b}$	8.23 ± 0.79^{a}	80.36 ± 4.21^{a}
5.0%	$34.13 \pm 0.73^{a,b}$	$1.93 \pm 0.06^{b,c}$	8.38 ± 0.42^{a}	82.68 ± 2.79^{a}
7.5%	35.29 ± 1.68^{a}	1.84 ± 0.14^{c}	8.85 ± 0.96^{a}	74.46 ± 3.21^{a}
10.0%	35.08 ± 1.05^{a}	$1.85 \pm 0.08^{b,c}$	8.89 ± 1.35^{a}	77.43 ± 4.65^{a}

Values represent means of four replicates ± SD.
Within the same column, the values with the same superscript are not significantly different ($p > 0.05$).

increased ($p < 0.05$). Both the decreased swelling index combined and the reduced water absorption exhibited in the inulin pasta samples may be explained by the characteristics of inulin. Being highly hydrophilic, it is likely that the inulin preferentially absorbs the water, inhibiting starch swelling, and absorption of water, which in turn may alter the structure of the pasta produced (Tudorica et al., 2002).

Texture is of paramount concern to consumers of pasta, with sticky pasta being generally unacceptable. Textural characteristics of the cooked pasta samples are listed in Table 2. Results clearly illustrate that the addition of inulin to the pasta formulation does not significantly affect pasta stickiness, since the figures for stickiness of inulin-containing pasta were not significantly different from the control. Elasticity of inulin pasta samples also appeared similar to the control sample. However, the firmness of pasta containing inulin appeared to be generally lower than the control pasta, and the results showed a trend of decreasing firmness as the inulin content was increased. These results are similar to those reported in our previous paper (Tudorica et al., 2002). Pasta firmness can be related to the hydration of the starch granules during the cooking process and the subsequent embedding of gelatinising starch granules in a matrix of partially denatured protein. As such, the decrease in firmness and swelling index may be associated with a reduction in starch gelatinisation in the pasta.

Nutritional quality of inulin-enriched pasta, in terms of its digestibility, was determined by an in vitro method, which monitored the amount of reducing sugars released over a 5 hour period. The results give a good indication of the rate of starch degradation and allow the calculation of a predictive glycaemic index of pasta samples. The values of reducing sugars released during in vitro digestion of pasta sample are presented in Fig. 1 and suggest that the rate of digestion of pasta declined with increasing inulin addition. Fig. 2 illustrates the extent of starch digestion, expressed as the proportion of starch digested to maltose, taking into account the amount of starch present in the sample. As in Fig. 1, there is a trend to decreased starch digestion with increasing inulin levels. A predictive glycaemic index value for each pasta sample was obtained by using the formula proposed by Brighenti et al. (1995) which takes into account the amount of sugars released, rate of starch degradation and also the chemical composition of the sample (formulae given in Section 2). This eliminates

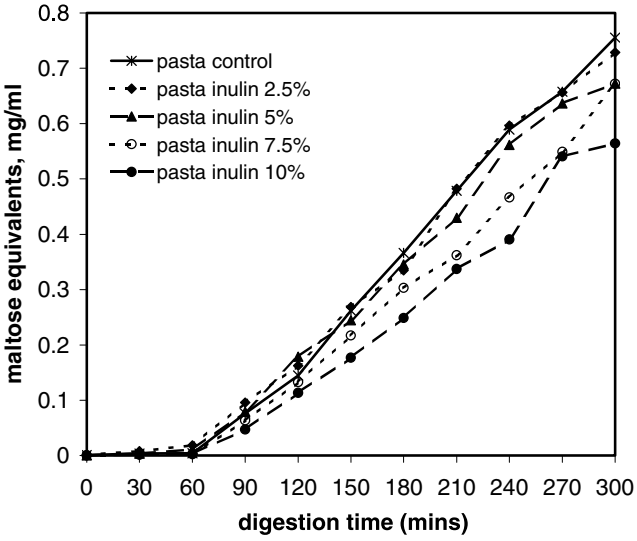

Fig. 1. Amount of reducing sugars (maltose equivalents) in dyalisate released during in vitro digestion (values represent means of duplicate samples).

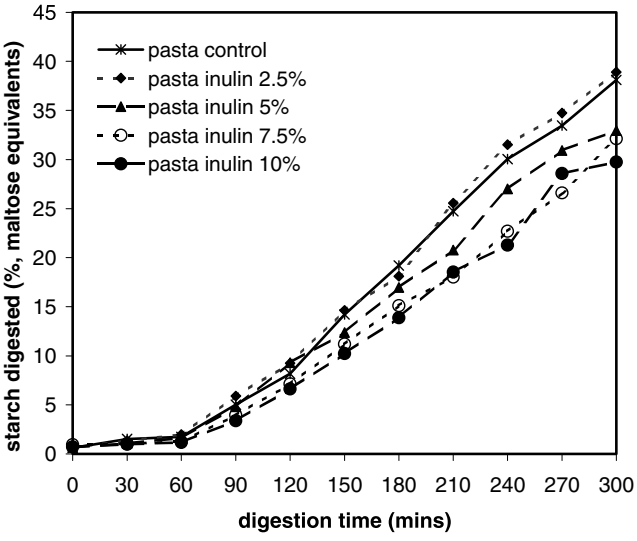

Fig. 2. Extent of hydrolisis of pasta expressed as the proportion of starch degraded to maltose products (values represent means of duplicate samples).

Table 2
Textural characteristics of cooked control and inulin-enriched pasta products

Level of inulin addition	Elasticity peak +ve force (N)	Adhesiveness area (N*s)	Firmness peak +ve force (N)
0% (Control)	0.17 ± 0.02^{a}	3.06 ± 0.48^{a}	1.61 ± 0.17
2.5%	$0.13 \pm 0.02^{a,b}$	3.12 ± 0.57^{a}	1.36 ± 0.09^{a}
5.0%	0.16 ± 0.02^{a}	3.72 ± 0.45^{a}	$1.26 \pm 0.10^{a,b}$
7.5%	$0.13 \pm 0.02^{a,b}$	2.96 ± 0.51^{a}	$1.19 \pm 0.09^{a,b}$
10.0%	0.12 ± 0.01^{b}	3.34 ± 0.53^{a}	1.08 ± 0.11^{b}

Values represent means of 20 replicates ± SD.
Within the same column, the values with the same superscript are not significantly different ($p > 0.05$).

Table 3
Predictive glycaemic index of control and inulin-enriched pasta products

Level of inulin addition	Glycaemic index (GI)	% GI decrease from control pasta
0% (Control)	44.1 ± 2.81^{a}	–
2.5%	43.1 ± 2.25^{a}	2.3
5.0%	41.4 ± 0.55^{a}	6.2
7.5%	40.8 ± 0.70^{a}	7.4
10.0%	37.5 ± 3.28	15

Values represent means of duplicate samples ± SD.

Within the same column, the values with the same superscript are not significantly different ($p > 0.05$).

any variation that could be solely attributed to replacement of starch with inulin.

Table 3 shows the calculated values for predictive glycaemic index of the inulin-enriched pasta compared to the control samples. Although the calculated values for the predictive glycaemic index of inulin-containing pasta were not significantly different from the control ($p > 0.05$), a general trend was observed with a reduction in GI proportional to the amount of inulin used in the formulation. These results, indicating a reduced rate of starch digestibility in the presence of inulin, could be related to the observations regarding cooking properties. As the swelling index and the water absorption values were lower for inulin-containing pasta than for the control, a possible explanation could be that higher levels of inulin inhibit the swelling and gelatinisation of the starch, and hence reduce starch digestibility.

Previous research by Tudorica et al. (2002), using a simplistic amylase digestion procedure, related the reduction in glucose production in non-starch polysaccharide-enriched pasta to both the type and quantity of non-starch polysaccharide used, with the solubility of the fibre appearing to affect starch degradation rate. Work conducted on guar (galactomannan)-enriched breads, using a similar in vitro digestion method (Brennan et al., 1993, 1996) showed a similar effect on starch degradation due to the inclusion of the soluble galactomannans. This observation appears to be associated with the non-starch polysaccharides forming a barrier around starch granules, protecting them from enzymic degradation (partly supported by the observations of Tudorica et al., 2002).

The theory of thermodynamic incompatibility (Tolstoguzov, 2003) may help to explain this interaction between the starch and non-starch polysaccharide in the pasta matrix. The reduction in starch degradation within the samples containing inulin would result from the inulin preferentially hydrating, aggregating, and forming a matrix, encasing starch granules in a semi-solid gel (Tolstoguzov, 2003). This encasing of the starch granules would possibly limit water movement to the starch granules in the pasta, reducing gelatinisation events. Reduction in water movement may also interfere with the accessibility of starch-degrading enzymes to the partially gelatinised starch granules.

4. Conclusions

The current study serves to extend the research reported by Tudorica et al. (2002). Results presented in this paper support the idea that non-starch polysaccharides can inhibit starch degradation and hence alter the amount of sugars released during the digestion of carbohydrate-rich foods, with little influence on the textural attributes of the final product. As such, there exists the potential to regulate glycaemic response of simple cereal foods by the incorporation of these ingredients without compromising their quality. Further work is required to clearly identify the causal relationship between non-starch polysaccharide inclusion in more complex cereal-based foods and the degradation of starch and hence the reduction in glucose release. This is of paramount concern when considering the regulation of blood glucose levels within both normal and diabetic patients.

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