

Influence of Arabinoxylans and Endoxylanases on Pasta Processing and Quality. Production of High-Quality Pasta with Increased Levels of Soluble Fiber

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ABSTRACT

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As part of a general study aiming to clarify the role of arabinoxylans (AX) in pasta processing and quality, AX were modified by the addition of endoxylanases during pasta processing. The influence on processing parameters and quality were determined. Pasta (800 g) was produced from two commercial semolinas (semA and semB) using dosages of *Bacillus subtilis* (XBS) and *Aspergillus niger* (XAN) endoxylanases of 0–0.225 Somogyi units/g of semolina. Increased dosages resulted in a drop of extrusion pressure. The endoxylanase treatments had no great effect on the resulting pasta quality (color of dry products and surface condition,

viscoelastic index, and resistance to longitudinal deformations of cooked products). High dosages of XAN and XBS resulted in high levels of solubilized AX (as an extra source of soluble dietary fiber) of low molecular weight which were expected to easily leach out during the cooking process of pasta. Surprisingly, only low levels of AX were found in the cooking water, even with extremely high dosages of endoxylanases used and cooking beyond optimum time. A method is provided to obtain high-quality pasta with increased levels of soluble fiber.

Arabinoxylans (AX) consist of a backbone of 1,4 linked β -D-xylopyranosyl units partially substituted with α -1-2 or α -1-3 L-arabinofuranosyl side chains (Perlin 1951). They can either be water-extractable (WE-AX) or water-unextractable (WU-AX). The reported total AX content in semolina, the milling product of durum wheat (*Triticum durum* Desf.), which is commonly used for the production of pasta, is 0.58–3.02% (dry basis), respectively (Bains and Irvine 1965; Lintas and D'Appolonia 1973; Lempereur et al 1997) and 0.28–0.36% (dry basis) for WE-AX (Lintas and D'Appolonia 1973; Roels et al 1999). Durum wheat AX contains a higher proportion of arabinose than common wheat AX, (*T. aestivum* L.), indicating a more branched structure (Medcalf and Gilles 1968; Medcalf et al 1968; Ciaccio and D'Appolonia 1982; Roels et al 1999).

Endoxylanases are AX-hydrolyzing enzymes, able to transform both WU-AX and WE-AX. The use of endoxylanases is widespread in the breadmaking industry) and extensive studies have focused on their importance in the process. In breadmaking, some endoxylanases have a beneficial effect on bread volume (Kulp 1968; McCleary 1986; ter Haseborg and Himmelstein 1988; Rouau et al 1994; Courtin et al 1999). Courtin et al (1999) provided evidence that WU-AX have a negative effect on bread volume and that enzymic solubilization without a large reduction of the molecular weight (MW) of the solubilized AX is of primary importance for optimal endoxylanase functionality.

Only limited research has been conducted on the effects of endoxylanases in the pasta-making process, hence the necessity to clarify the role of AX and endoxylanases in pasta quality. Attempts in the past indicate that AX and endoxylanases may have a specific role during the mixing stages (Bains and Irvine 1965; Ingelbrecht et al 2000) and on the quality of the end product (Sheu et al 1967; Fardet et al 1998). Endoxylanase-treated bread doughs have a lower dough consistency than untreated bread dough (McCleary 1986). Thus, endoxylanases may facilitate dough preparation with less water. They are equally effective in reducing the consistency of low-moisture (35%) pasta doughs. Under controlled conditions,

the use of less water in endoxylanase-containing doughs resulted in dough consistencies comparable to those of untreated doughs (Ingelbrecht et al 2000). Recently, Qi Si et al (*unpublished*) presented endoxylanases as a possible tool to improve the quality of common wheat pasta and noodle products. Minor effects on some quality parameters were observed.

AX are an important source of dietary fiber in refined cereal-based products (Theander et al 1993). Recently, De Vries et al (1999) defined dietary fiber as the remnants of edible plant cell polysaccharides, lignin, and associated substances resistant to (hydrolysis) digestion by human alimentary enzymes. The importance of dietary fiber has been well documented (Trowell 1972; Burkitt 1973; Leveille 1976; Kahlon and Chow 1997; Kritchinsky 1997; Weber and Chaudhary 1987; Meister and Raso 1997). A diet rich in insoluble fibers is associated with smaller reductions of blood lipids than one rich in soluble dietary fibers (Jenkins et al 1993). Soluble dietary fiber can lower cholesterol levels (Haskell et al 1992; Ripsin et al 1992; Ink and Hurt 1987; Glore et al 1994) and influence human glycemic response (Ink and Hurt 1987; Yokoyama et al 1997; Nutall 1993). In the past, attempts have been made to increase the levels of dietary fiber in pasta by adding high-fiber material from sources other than durum wheat. Low glycemic responses in diabetics have been obtained with pastas formulated with guar gum (Gatti et al 1984; Briani et al 1987; Carra et al 1990). Addition of fiber-rich durum bran to semolina for pasta production gave a tasteful product, but resulted in increased cooking losses and reduced firmness of the cooked pasta (Kordonowy and Youngs 1985). Dougherty et al (1988) added oat fibers in the pasta dough recipe. However, even with an extra addition of vital wheat gluten, a product of lower quality was obtained. Pasta quality improvements were obtained with xanthan gum, whereas durum wheat WE-AX incorporation gave no difference in quality and pea fiber incorporation and whole-wheat pasta yielded lower quality products (Edwards et al 1995). Incorporation of barley β -glucan in pasta products yields products with a higher fiber content and modest quality (Knuckles et al 1997; Marconi et al 2000) but which result in lower glycemic responses (Yokoyama et al 1997).

Addition of endoxylanases during pasta-making is expected to result in a product with a higher soluble dietary fiber content. High dosages of endoxylanase can lead to an extensive breakdown of AX (Ingelbrecht et al 2000). However, an aspect which certainly has to be taken into account is whether or not the solubilized AX are leached out during the pasta-cooking process and hence are lost as a dietary fiber source for the consumer.

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It was shown previously that pasta made from germinated durum wheat semolina, containing significant levels of α -amylase, resulted in higher levels of solids in the cooking water. For pastas made from both sound and germinated wheat semolinas, such losses consist of simple sugars and high MW dextrans (>250,000) (Kruger and Matsuo 1982). Recently, Ingelbrecht et al (2001) showed that the smaller MW nonstarch polysaccharide (NSP) component: arabinogalactan peptide (AGP) leached more easily from pasta during cooking than the higher MW NSP component AX.

The aim of the present study was to analyze the effects of endoxylanases on pasta production and quality of the dried and final cooked product.

MATERIALS AND METHODS

Chemicals

All reagents were of at least analytical-grade. Specialty chemicals were heat-stable α -amylase (Termamyl 120 LS, Novo Nordisk, Bagsvaerd, Denmark) and amyloglucosidase (Boehringer Mannheim, Mannheim, Germany). For both enzymes, units were as defined by the respective suppliers. β -D-Allose was obtained from Sigma-Aldrich (St. Louis, MO).

Semolinas

Durum wheat semolinas were from an industrial blend of durum wheats harvested in 1999 (semA) and 1998 (semB), and were regular raw materials for commercial pasta production at NV Soubry (Roeselare, Belgium). Samples were stored at 4°C until used. Protein contents ($N \times 5.7$) were determined by a Kjeldahl procedure as 15.8 and 14.3% (dry basis), respectively. Ash (dry basis) contents were 0.79% for semA and 0.93% for semB. Moisture contents were 10.0 and 11.8% for semA and semB, respectively. Analyses were conducted according to Accepted Methods (AACC 2000).

Activity of the Endoxylanase Preparations

Enzyme solutions in deionized water were prepared just before addition with the pure endoxylanases XBS (from *Bacillus subtilis*, optimum pH 6.0; Puratos NV, Groot-Bijgaarden, Belgium) and

XAN (from *Aspergillus niger*, optimum pH 4.7; Puratos). Activities were determined according to a method by Somogyi (1952), with modifications as outlined in Megazyme (Bray, Ireland) product sheet 9/95. One Somogyi unit is the amount of enzyme that releases 1 μ mol of xylose reducing sugar equiv/min at 40°C from wheat AX (Megazyme) (1.0% w/v) in sodium phosphate (0.1M, pH 6.0).

Pasta Production

Pasta (spaghetti) was produced by mixing 800 g of semolina using a minipress (Sercom, Montpellier, France) and slowly adding (30 sec) deionized water to give a total moisture content of 33.8%. Endoxylanase additions (0–1.3 units/g of semolina) replaced part of the water needed. After 20 min of further mixing (120 rpm, direction of the mixing screw is reversed every 10 sec), the resulting dough was extruded (44°C, under partial vacuum: 150 mm Hg) to give pasta strands with a diameter of 1.45 mm. Extrusion pressure was recorded at the end of the extrusion screw, right before the die. Pasta was dried to \approx 12.5% moisture using a cycle at 70°C in a dryer (Secasi-Eurotherm, Chessell, France) (Fig. 1). Samples were stored at 20°C for at least four days before analysis. All pastas were produced at least in duplicate.

Color of Dried Pasta

Pasta color results from a desirable yellow component (measured by the index b^*) and the undesirable brown ($100-L^*$) and red (a^*) components (Laignelet et al 1972). International colorimetric indices L^* , a^* , and b^* were determined on the dry, uncooked pasta (CR310, Minolta, Osaka, Japan) colorimeter as in Abécassis et al (1994). Brown index was expressed as $100-L^*$, red index as a^* , and the yellow index as b^* . Indices were determined at least in triplicate.

Cooked Pasta Quality Assessment

Surface condition and firmness of the cooked pasta. Pasta strands (50 g), broken to a length of \approx 15 cm, were cooked in 1.5 L of salted (NaCl at 7 g/L) mineral water (as recommended by AFNOR Standard NF-V 03-714). The optimal cooking time (T) was defined as that needed to gelatinize starch at the center of the pasta strands (Abécassis et al 1994).

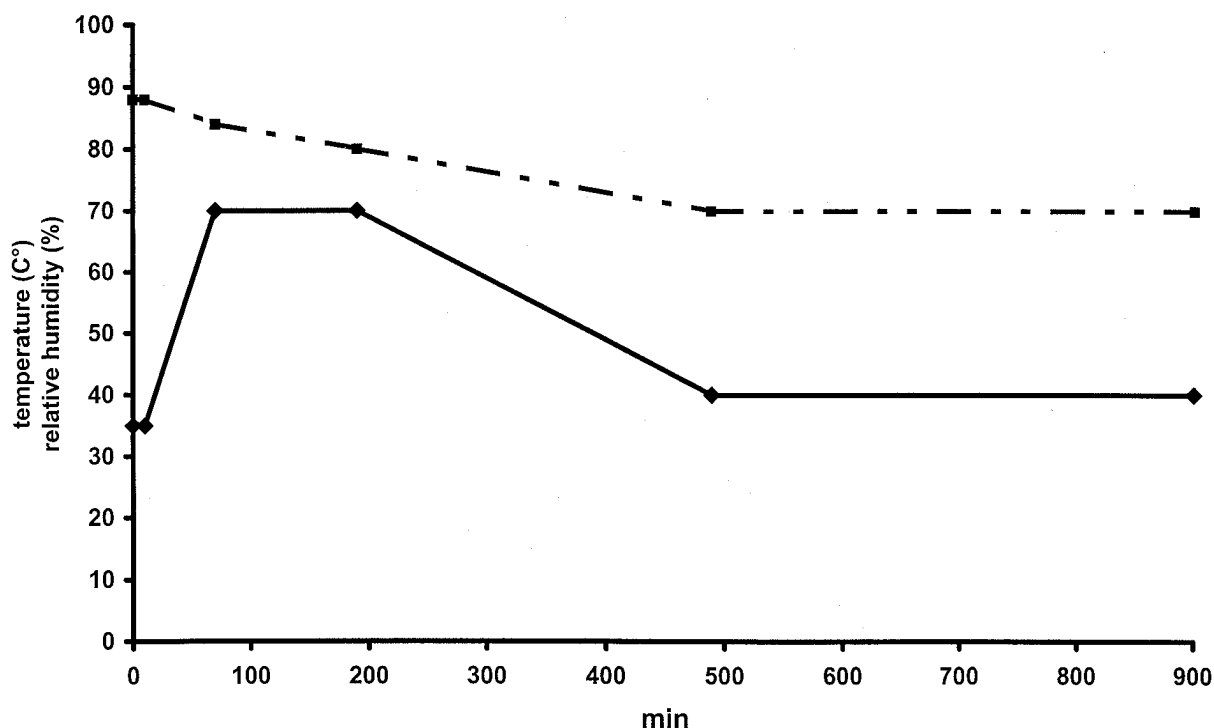


Fig. 1. Pasta drying profile: relative humidity (%) (■) and temperature (°C) (◆) vs. time.

As outlined by Abécassis et al (1994), scores of 1–9 (1 = very bad, 9 = excellent) were assigned by a trained panel (four participants) with photographs as reference, taking into account the general appearance, degree of swelling, and stickiness of the cooked pasta samples at T + 6 and T + 11 min. For determinations of cooking time and surface condition, analyses were performed at least in duplicate for each pasta production.

The viscoelastic index (VI) was assessed with a viscoelastograph (Chopin, Paris, France) at T + 1, T + 6, and T + 11 min as in Abécassis et al (1994) and is a measure of pasta firmness. Analysis was performed at least 5×.

Resistance to longitudinal deformations of the cooked pasta. Pasta (15 strands of 15-cm length) was cooked to optimal cooking time (T) and T + 11 in 2 L of deionized water (containing 1 g of NaCl). After 5 min of cooling, elastic modulus (g/mm) and maximal breaking strength (g) and distance (mm) were determined with a texture analyzer (TA-XT2i, Stable Micro Systems, Surrey, UK) using the spaghetti and noodle tensile rig A/SPR. The initial distance between the probes (0.5 mm) was gradually increased to 100 mm at a speed of 3 mm/sec. The elastic modulus (Hookean modulus) was recorded as the gradient (g/mm) in the linear region between trigger force 5 and 10 g. Analysis of the 15 strands was performed in duplicate.

Inactivation of Enzyme-Treated or Control Pastas

Dried pasta (100 g) was boiled in ethanol (95%, under reflux) for 2 hr. After cooling, the ethanol was removed by vacuum-rotary evaporation (45°C) and the material was air-dried. The material was crushed with mortar and pestle until it passed a 250-µm sieve (inactivated pasta).

Determination of Carbohydrate Contents

For the determination of the water-extractable carbohydrates in inactivated pasta, 2 g of inactivated material was extracted with 20 mL of deionized water (15 min, 4°C). After centrifugation (3,000 × g, 15 min, 4°C), supernatant (2.5 mL) was hydrolyzed (60 min, 110°C) with 2.5 mL of 4M trifluoroacetic acid (TFA). Both the extraction and the hydrolysis and derivatization were in duplicate. For the determination of total carbohydrate content of inactivated pastas, 50 mg was hydrolyzed (120 min, 110°C) with 5 mL of 2M TFA. After cooling, the hydrolysate was centrifuged (3,000 × g, 15 min). All analyses were at least in duplicate.

In both cases, alditol acetates were prepared according to the method of Englyst and Cummings (1984) and were separated (Supelco SP-2380, Bellefonte, PA) column (30 m, 0.32 mm i.d., 0.2 µm film thickness) in a Chrompack 9011 chromatograph (Middelburg, The Netherlands) equipped with a flame-ionization detector. The carrier gas was He. Separation was at 225°C with injection and detection temperatures of 275°C and β-D-allose as internal standard (1.0 mL added, with a concentration of 1.0 mg/mL).

The xylose (Xyl), arabinose (Ara), and galactose (Gal) data led to calculation of the AX and arabinogalactan (AG) contents and the A/X ratio (the arabinose to xylose ratio or substitution degree of AX), using the formulas as in Ingelbrecht et al (2000): $AX = [\%Xyl + (\%Ara - (0.7 \times \%Gal))] \times 0.88$; $AG = [\%Gal \times 0.90 + (\%Gal \times 0.7) \times 0.88]$ and $A/X = [\%Ara - (\%Gal \times 0.7)]/\%Xyl$. The A/G ratio (the arabinose substitution degree of AGP) was assumed to 0.7 (Ingelbrecht et al 2000), which allowed of Ara to be assigned to AGP. Conversion factors (0.88 and 0.90) were used for calculation of polymeric material contents, consisting of pentose or hexose monomers. AG contents are a good estimation of the content of AGP because it can reasonably (based on gel-permeation behavior) be assumed that, much as *T. aestivum* L., the peptide component is only a minor proportion of the structure (Fincher et al 1974).

Purification of NSP

Inactivated pasta (80 g) was extracted with deionized water (1:5 w/v, 15 min, 4°C). The suspension was centrifuged (8,000 × g,

15 min, 4°C), and the supernatant boiled for 10 min. Following a Termamyl treatment (3,000 units, 30 min, 90°C) and a centrifugation step (3,000 × g, 15 min, 15°C), samples were treated with amyloglucosidase at pH 4.5 (50 units, 12 hr, 60°C), centrifuged (8,000 × g, 40 min, 15°C), and the supernatant was boiled (10 min). After a last centrifugation step (8,000 × g, 40 min, 15°C) to remove the denatured proteins, the supernatant was dialyzed (48 hr, 4°C) and freeze-dried to obtain the NSP material.

Enzymically degraded AX and AGP have a similar precipitation behavior in ethanol solutions (Courtin et al 1998); therefore, no further separation between AX and AGP was performed.

Gel-Permeation Chromatography

NSP material (6.0 mg) was solubilized in 0.3% NaCl (3.0 mL) and centrifuged (10,000 × g, 10 min). The solution was filtered (0.45 µm) and separated on a Shodex SB-804 HQ (Showa Denko K.K., Tokyo) GPC column (300 × 8 mm) by elution with 0.3% NaCl (0.5 mL/min). The eluate was monitored using a refractive index detector (VDS Optilab, Berlin, Germany). Molecular weight markers (Shodex P-82 pullulan standards, Showa Denko K.K., with MW of 78.8, 40.4, 21.2, 11.2, 4.73, 2.28, 1.18, and 0.59×10^4) allow calculations of MW.

Cooking Losses

Pasta (25 g) was cooked to optimal cooking time (T) and T + 11 min in 1.0 L of deionized water (containing 0.5 g of NaCl). After draining and cooling, the cooking water was freeze-dried. Carbohydrate composition, ash, moisture contents, and protein content were determined as outlined above. From these data and comparison with the corresponding analytical data on the uncooked dry pasta, the relative losses in the cooking water of dry matter, AX, AG, glucose, proteins, and ash were calculated.

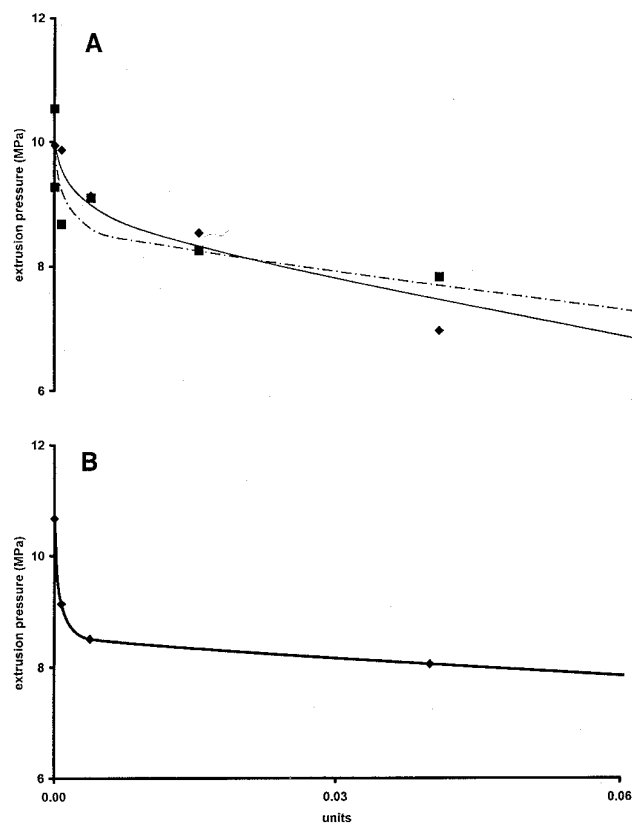


Fig. 2. Influence of dosages of *Bacillus subtilis* (XBS) and *Aspergillus niger* (XAN) endoxylanases on extrusion pressure (bar) during pasta production using two commercial semolinas (semA and semB). Somogyi units/g of semolina.

Statistical Analysis

The results obtained were analyzed using the analysis of variance (ANOVA) procedure of SAS system for Windows 8.1 including Tukey's studentized range test for pairwise comparisons.

For the quality characteristics of the pastas (colorimetric indices, optimal cooking time, surface condition, viscoelastic index, elastic moduli, maximal force, and maximal distance before breakage), we tested whether significant differences (Tukey's studentized range

test for pairwise comparisons) existed within a group of pasta samples produced with the same semolina and endoxylanase.

RESULTS AND DISCUSSION

Pressure During Extrusion

Increasing levels of endoxylanase, added before pasta dough mixing, resulted in lower extrusion pressures (Fig. 2A and B). For the highest dosages (0.225 units), pressure was reduced almost by

TABLE I
Colorimetric Indices^a of Dried Pastas Produced from Two Commercial Semolinas (SemA or SemB) with Different Levels of *Bacillus subtilis* (XBS) and *Aspergillus niger* (XAN) Endoxylanases

	SemA			SemB		
	100-L*	a*	b*	100 L*	a*	b*
Control	40.6 (0.5)a	0.3 (0.6)a	37.5 (0.9)a	40.9 (0.6)b	1.2 (0.1)a	33.3 (0.2)a
Control + XAN						
7.50 × 10 ⁻⁵ units ^b	40.9 (0.5)a	0.2 (0.4)a	36.5 (0.3)ab	nd ^c	nd	nd
7.50 × 10 ⁻⁴ units	40.4 (0.9)a	0.4 (0.1)a	35.8 (0.7)b	41.1 (0.3)ab	1.4 (0.2)a	32.8 (0.4)a
3.75 × 10 ⁻³ units	40.3 (0.2)a	0.7 (0.3)a	36.4 (1.2)ab	41.1 (0.1)ab	1.6 (0.1)a	32.9 (0.1)a
1.50 × 10 ⁻² units	41.2 (0.3)a	0.1 (0.1)a	36.1 (0.5)ab	nd	nd	nd
4.00 × 10 ⁻² units	40.7 (0.3)a	0.4 (0.1)a	36.0 (0.6)b	41.5 (1.1)ab	1.2 (0.6)a	32.2 (1.0)a
0.225 units	41.1 (0.6)a	0.4 (0.3)a	35.7 (0.2)b	42.7 (0.3)a	0.5 (0.1)b	30.6 (0.2)b
1.30 units	41.2 (0.2)a	1.4 (0.1)b	36.0 (0.2)b	nd	nd	nd
Control	40.6 (0.5)ab	0.3 (0.6)a	37.5 (0.9)ab	...	...	...
Control + XBS						
7.50 × 10 ⁻⁵ units	40.1 (0.3)a	0.9 (0.4)a	37.2 (0.7)ab	...	...	...
7.50 × 10 ⁻⁴ units	41.1 (0.6)b	0.7 (0.4)a	36.3 (0.5)bc	...	...	...
3.75 × 10 ⁻³ units	40.6 (0.4)ab	0.3 (0.4)a	36.9 (0.2)ab	...	...	...
1.50 × 10 ⁻² units	39.9 (0.4)a	0.7 (0.2)a	37.9 (0.1)a	...	...	...
4.00 × 10 ⁻² units	41.4 (0.4)bc	0.6 (0.1)a	36.7 (0.8)b	...	...	...
0.225 units	42.0 (0.9)c	0.8 (0.4)a	36.0 (0.7)c	...	...	...

^a Brown index (100 L*), red index (a*), and yellow index (b*). Values followed by the same letter are not significantly different ($P < 0.05$). Standard deviations are shown in parentheses.

^b Somogyi units/g of semolina.

^c Not determined.

TABLE II
Optimal Cooking Time (T)^a Determined for Pasta Produced from Two Commercial Semolinas (SemA or SemB) with Different Levels of *Bacillus subtilis* (XBS) and *Aspergillus niger* (XAN) Endoxylanases

Pasta	T (min)	Surface Condition ^b			Viscoelastic Index ^c		
		T + 6	T + 11	T + 1	T + 6	T + 11	
SemA							
Control	7.6 (0.4)a	5.5 (0.6)a	4.6 (0.8)a	5.8 (0.7)ab	4.7 (0.9)ab	2.8 (1.0)ab	
Control + XAN							
7.50 × 10 ⁻⁵ units ^d	7.3 (0.4)a	5.3 (0.2)a	4.3 (0.2)a	6.2 (0.8)a	5.2 (0.4)a	3.2 (1.0)a	
7.50 × 10 ⁻⁴ units	7.6 (0.4)a	5.1 (0.4)a	4.1 (0.1)a	5.5 (0.5)bc	4.5 (0.4)ab	2.1 (1.3)b	
3.75 × 10 ⁻³ units	7.3 (0.4)a	5.1 (0.2)a	4.1 (0.4)a	5.1 (0.6)cd	4.3 (1.1)bc	2.3 (1.1)ab	
1.50 × 10 ⁻² units	7.2 (0.1)ab	5.3 (0.1)a	4.3 (0.4)a	5.0 (0.7)cd	4.4 (0.7)abc	2.7 (1.2)ab	
4.00 × 10 ⁻² units	7.2 (0.1)ab	5.3 (0.4)a	4.1 (0.5)a	4.0 (0.7)e	3.7 (0.7)cd	2.0 (0.8)b	
0.225 units	6.9 (0.4)ab	6.0 (0.6)a	4.5 (0.7)a	4.5 (0.4)de	4.2 (0.8)bc	2.2 (1.0)ab	
1.30 units	6.3 (0.1)b	6.9 (0.6)b	6.6 (0.8)b	4.3 (0.9)e	3.0 (1.0)d	2.7 (1.5)ab	
Control	7.6 (0.4)a	5.5 (0.6)a	4.6 (0.8)a	5.8 (0.7)ab	4.7 (0.9)ab	2.8 (1.0)ab	
Control + XBS							
7.50 × 10 ⁻⁵ units	7.9 (0.5)a	5.0 (0.5)a	4.1 (0.3)a	5.3 (0.6)bc	4.6 (0.7)ab	2.8 (1.2)a	
7.50 × 10 ⁻⁴ units	7.5 (0.3)a	5.4 (0.5)a	4.5 (0.4)a	6.0 (0.9)a	5.1 (0.8)a	3.3 (1.2)a	
3.75 × 10 ⁻³ units	7.7 (0.3)a	5.3 (0.4)a	4.3 (0.5)a	5.7 (0.8)abc	4.8 (0.7)a	2.9 (1.1)a	
1.50 × 10 ⁻² units	7.7 (0.3)a	5.2 (0.4)a	4.5 (0.4)a	5.4 (0.7)abc	4.3 (0.8)ab	2.9 (1.0)a	
4.00 × 10 ⁻² units	7.1 (0.1)b	5.5 (0.3)a	4.6 (0.3)a	5.3 (0.7)bc	5.0 (0.5)b	3.2 (1.3)a	
0.225 units	7.0 (0.1)b	5.8 (0.3)a	4.5 (0.3)a	5.1 (0.6)c	4.5 (0.7)ab	2.4 (1.2)a	
SemB							
Control	7.3 (0.3)a	6.8 (0.1)a	4.3 (0.3)a	6.9 (0.8)a	5.9 (0.5)a	5.0 (0.7)a	
Control + XAN							
7.50 × 10 ⁻⁴ units	7.2 (0.2)a	5.8 (0.3)a	4.2 (0.3)a	6.1 (1.0)ab	5.6 (0.6)a	4.2 (0.4)b	
3.75 × 10 ⁻³ units	7.3 (0.3)a	6.0 (0.4)a	4.4 (0.4)a	5.6 (0.3)bc	5.4 (0.5)a	3.8 (0.5)b	
4.00 × 10 ⁻² units	7.3 (0.2)a	5.9 (0.4)a	4.3 (0.4)a	4.6 (0.6)c	4.4 (0.5)b	3.6 (0.3)b	
0.225 units	6.3 (0.3)b	6.5 (0.4)a	4.4 (0.4)a	5.2 (0.5)bc	5.2 (0.4)a	4.2 (0.3)b	

^a Surface condition and viscoelastic index measured at various cooking times (T, T + 1, +6, or +11 extra minutes). Values followed by the same letter are not significantly different ($P < 0.05$). Standard deviations are shown in parentheses.

^b Scores for general appearance, degree of swelling, and stickiness (1 = very bad, 9 = excellent) assigned by a trained panel using photographs for reference.

^c Viscoelastic index analyzed as in Abécassis et al (1999).

^d Somogyi units/g of semolina.

one-half (control dough 10.5 MPa, XAN 6.4 MPa, and XBS 6.7 MPa for semA doughs, respectively; and for semB, control dough 10.7 MPa and XAN 6.2 MPa) (Fig. 2). Further addition of endoxylanase did not result in a substantial reduction (Fig. 2B result not shown, 1.30 units using semA, 6.7 MPa). These observations are in line with earlier data showing that endoxylanases significantly decrease the maximal consistency of durum semolina doughs prepared in the farinograph, and that the simultaneous omission of a certain level of water and addition of a certain level of endoxylanase restores the maximal dough consistency (Ingelbrecht et al 2000). We mixed endoxylanase doughs for 20 min. The results in Fig. 1 demonstrate that, even for lower mixing times (such as industrial practice), endoxylanases have a drastic effect.

Color of Dried Pasta

The values of the three colorimetric indices (100-L*, a*, and b*) for the different dry pastas are given in Table I. With the highest

dosages of endoxylanases, small but significant influences on pasta color were seen. It seems that a less dense structure was obtained with endoxylanase-treated samples, probably as a result of lowered extrusion pressures (Fig. 2). If so, the more porous structure may have facilitated the occurrence of oxidation phenomena.

Cooked Quality Assessment

Surface condition and firmness of the cooked pasta. High dosages of endoxylanases caused a significant decrease in pasta cooking time (Table II). Surface condition of cooked pastas was generally not negatively influenced by an endoxylanase treatment during production. Although not understood at present, a significantly better product was obtained with the highest dosages of XAN for semA pastas produced with 0.225 units (cooked to T + 6 and T + 11) and 1.30 units (cooked to T + 11).

The VI of the cooked pastas at T + 1, treated with increasing dosages during production, was significantly lowered (Table II) for

TABLE III
Elastic Moduli (E), Maximal Forces Exerted (F), and Maximal Distances (D) Values Obtained Just Before Breakage of Pasta Strands Produced from Two Commercial Semolinas (SemA or SemB) with Different Levels of *Bacillus subtilis* (XBS) and *Aspergillus niger* (XAN) Endoxylanases Cooked to Optimal Cooking Time (T) or T + 11 min^a

	T			T + 11		
	E (g/mm)	F (g)	D (mm)	E (g/mm)	F (g)	D (mm)
SemA						
Control	1.1 (0.1)a	26.7 (1.0)a	42.5 (3.6)a	0.6 (0.1)a	19.0 (0.7)a	32.3 (2.8)a
Control + XAN						
7.50 × 10 ⁻⁴ units ^b	1.4 (0.1)b	25.8 (1.5)b	30.9 (1.5)b	0.7 (0.1)a	18.5 (0.6)ab	27.1 (2.2)bc
1.50 × 10 ⁻² units	1.1 (0.1)a	24.5 (1.2)b	45.1 (3.6)a	0.6 (0.1)a	18.3 (1.3)ab	31.3 (2.4)ab
0.225 units	1.1 (0.1)a	24.4 (1.6)b	42.5 (5.1)a	0.7 (0.1)a	17.4 (1.5)ab	25.9 (5.0)c
1.30 units	1.1 (0.1)a	23.8 (1.3)b	41.7 (4.0)a	0.6 (0.1)a	17.1 (0.9)b	26.3 (2.7)c
Control + XBS	1.1 (0.1)a	26.7 (1.0)a	42.5 (3.6)a	0.6 (0.1)a	19.0 (0.7)a	32.3 (2.8)a
Control + XBS						
7.50 × 10 ⁻⁴ units	1.4 (0.2)b	25.6 (1.0)ab	31.6 (3.0)b	0.7 (0.1)a	18.4 (1.4)a	27.9 (3.1)ab
1.50 × 10 ⁻² units	0.9 (0.1)c	22.5 (1.2)c	42.2 (3.6)a	0.7 (0.1)a	18.3 (1.1)a	26.2 (4.1)b
0.225 units	1.1 (0.1)a	24.2 (1.2)b	41.5 (5.0)a	0.7 (0.1)a	17.6 (1.1)a	28.0 (4.1)ab
SemB						
Control	1.2 (0.1)a	26.8 (1.7)a	40.6 (3.0)a	0.9 (0.1)a	24.2 (1.6)a	31.5 (2.3)a
Control + XAN						
0.225 units	1.2 (0.1)a	25.1 (0.9)b	45.8 (2.7)b	0.7 (0.1)b	17.9 (0.8)b	26.8 (2.4)b

^a Values followed by the same letter are not significantly different ($P < 0.05$). Standard deviations are shown in parentheses.

^b Somogyi units/g of semolina.

TABLE IV
Nonstarch Polysaccharide Composition^a of Total and Water-Extractable Hydrolysates of Pastas Produced from Two Commercial Semolinas (SemA or SemB) with Different Levels of *Bacillus subtilis* (XBS) and *Aspergillus niger* (XAN) Endoxylanases

	SemA			SemB		
	%AX	%AG	A/X	%AX	%AG	A/X
Total hydrolysate	1.94	0.29	0.83	2.08	0.34	0.80
Water-extractable hydrolysate						
Control	0.78	0.27	0.57	0.73	0.34	0.56
Control + XAN						
7.50 × 10 ⁻⁵ units ^b	0.83	0.29	0.58	nd ^c	nd	nd
7.50 × 10 ⁻⁴ units	0.91	0.28	0.58	0.82	0.34	0.55
3.75 × 10 ⁻³ units	1.16	0.30	0.58	nd	nd	nd
1.50 × 10 ⁻² units	1.33	0.31	0.58	0.94	0.35	0.55
4.00 × 10 ⁻² units	1.44	0.29	0.58	1.35	0.36	0.57
0.225 units	1.58	0.29	0.59	1.40	0.33	0.58
1.30 units	1.90	0.33	0.60	nd	nd	nd
Control + XBS						
7.50 × 10 ⁻⁵ units	0.87	0.29	0.60	...	...	...
7.50 × 10 ⁻⁴ units	0.88	0.29	0.58	...	...	...
3.75 × 10 ⁻³ units	0.89	0.25	0.58	...	...	...
1.50 × 10 ⁻² units	1.34	0.30	0.60	...	...	...
4.00 × 10 ⁻² units	1.55	0.26	0.58	...	...	...
0.225 units	1.68	0.33	0.59	...	...	...
Max. coefficient of variation (%)	6	5	6	3	3	1

^a Composition (dry basis) of arabinoxylans (%AX), arabinogalactans (%AG), and arabinose to xylose substitution degree (A/X).

^b Somogyi units/g of semolina.

^c Not determined.

both endoxylanases XAN and XBS and both semolinas (semA and semB). This negative relationship was also observed for cooking time T + 6 when using XAN and semA. For the samples produced with semB and cooked to T + 11, a significant difference was found between the VI of the control sample and those produced with XAN endoxylanase. In all other cases, there is almost no influence of the endoxylanase incorporation during pasta production (VI measured at T + 6 for semA and XBS and for semB and XAN, and VI measured at T + 11 for all semA samples, Table II).

Resistance to longitudinal deformations of the cooked pasta. For semA pastas, the E modulus of the pastas produced with endoxylanases was not negatively influenced when cooking them at T and T + 11. Only for one dosage (1.5 $\times 10^{-2}$ units of XBS), a small but significant decrease is seen (Table III). Small but significant changes in maximal force before breaking strands (F in g) were observed for semA pastas cooked to time T and containing endoxylanases (Table III), which was less obvious when cooking them at T + 11. The maximal distances (D in mm) before breakage remained relatively constant at T, except for 7.50 units of XAN and XBS. A slight but significant negative influence for this characteristic was noted at T + 11 from the endoxylanase incorporation.

For semB pastas, there was a significant decrease for measured parameters (E, F, and D) at overcooking (Table III). At optimal cooking time, only F was negatively influenced.

An important parameter during the pasta production process is extrusion pressure. It has to be sufficiently high to ensure a compact pasta structure, which better stands up to cooking (Pagani et al 1989). Recommended pressures for extrusion of long pasta goods are 9.0–2.5 MPa (Dalbon et al 1996). Forcing the dough through the die holes does not damage the protein network (Dalbon et al 1996). The small quality losses in pasta containing endoxylanases can probably be explained by the lower extrusion pressures during production (Fig. 2A and B). However, as noted earlier (Ingelbrecht et al 2000), lowering the water content of the dough may restore the extrusion pressure. Further investigation is needed.

It is probable that the lower cooking times for pasta samples containing endoxylanase can be explained by the less dense structure (caused by the lower extrusion pressures), which facilitates water penetration during cooking and therefore facilitates gelatinization of starch. Modification in the water distribution of the different constituents in the pasta doughs due to the endoxylanase action probably plays a key role in determining the viscosity of the dough and, consequently, extrusion pressures; therefore, it indirectly influences the quality characteristics of the resulting pastas. The possibility exists that the modification in water distribution also directly influences the quality characteristics.

NSP Composition of Enzyme-Treated Pastas

Percentages of AX solubilized ($[\%WE-AX \text{ in endoxylanase-treated samples} - \%WE-AX \text{ in control}]/\%TOT-AX$) (Table IV) for semA pastas produced with 0.225 units of XAN and XBS were 40.9 and 46.1%, respectively, compared with an initial 40.1% WE-AX for the untreated semA pasta. Almost complete solubilization of the WU-AX was obtained by adding 1.30 units of XAN. WE-AX was 35.3% in nontreated semB pasta. With 0.225 units of endoxylanase XAN, 32.0% AX was solubilized.

It should be noted that during pasta production, AX are solubilized even without addition of endoxylanases. This phenomenon was described earlier by Neukom et al (1962) and confirmed later by Lintas and D'Appolonia (1973) and Ingelbrecht et al (2001). Mechanical forces during mixing and extrusion stages (Rouau et al 1994), rather than the presence of endogenous endoxylanases, were thought to be responsible for the phenomenon (Ingelbrecht et al 2001).

The A/X ratios of the WE-AX population in control and endoxylanase treated pastas were quite comparable (Table IV).

MW Profiles of NSP

Purification yielded NSP material, which typically contained AGP and WE-AX in a 1.0/4.5 ratio. Again, no change in the A/X ratio was noted for WE-AX from pastas produced with endoxylan-

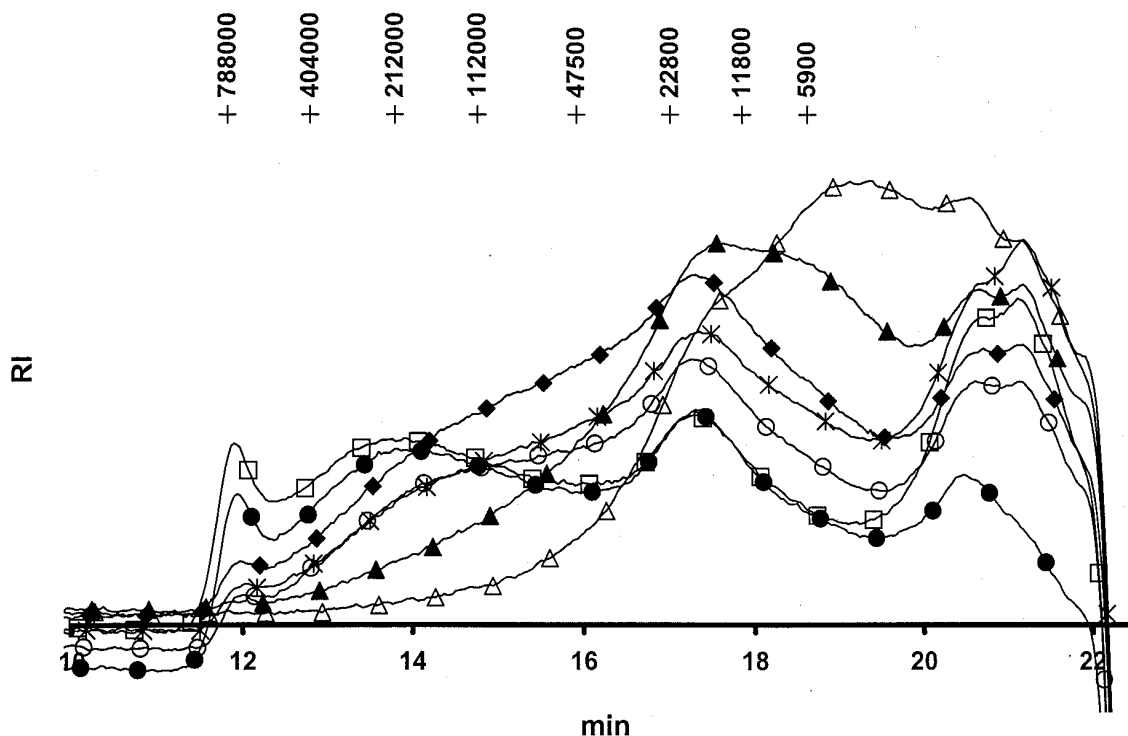


Fig. 3. Gel-permeation chromatography profiles of arabinoxylan–arabinogalactan–peptide material purified from pasta samples of commercial semolina A treated with *Bacillus subtilis* (XBS). Control (\square), 7.50×10^{-5} units (\bullet), 7.50×10^{-4} units (\blacklozenge), 3.75×10^{-3} units (\circ), 1.50×10^{-2} units (\star), 4.00×10^{-2} units (\blacktriangle), and 0.225 units (\triangle).

ases (results not shown). The MW of WE-AX of pasta samples from semA were reduced by the endoxylanase treatment with XBS (Fig. 3). With the highest dosages, MW of WE-AX were reduced to values lower than that of AGP, which is ≈22,000 (Ingelbrecht et al 2000). The AGP peak could be clearly recognized in the MW profiles of the control and the pastas produced with the lower dosages of XBS. Similar profiles were obtained using XBS and XAN (the latter with pasta produced from semB) (results not shown).

Cooking Losses

Because of the reduction in MW of the WE-AX by the endoxylanases used and the fact that, for the highest enzyme dosages, almost all AX were solubilized, it was expected that a lot of the soluble fiber would be released in the cooking water. Rather unexpectedly, AX were relatively well retained in the cooked pasta, even when large levels of endoxylanases were used (Tables V and VI). At optimal cooking time (Table V), a maximal 19.76% AX of TOT-AX and, with 11 min of overcooking (Table VI), a maximal

33.68% were leached out from the semA pasta which was produced with 1.30 units of XAN. Here, the MW profile of WE-AX, which under such conditions accounted for 97.6% of TOT-AX, was shifted below that of AGP (results not shown). In spite of this firm MW reduction, AGP material leached out more easily than AX material (for both cooking times T and T + 11). From these data, it could be hypothesized that AX were more firmly bound (by physical entrapment or chemical interactions) to the gluten network than AGP. In contrast, for a batter-based wheat gluten isolation process, Roels et al (1998) found high AGP/AX ratios in gluten fractions isolated from common wheat samples, indicating that AGP are relatively better retained by the gluten network than AX.

For pastas produced with different dosages of endoxylanases and control pasta, no great differences were noted for AGP, protein, and glucose losses. A small increase in dry matter loss was observed for the pasta produced with increasing dosages (Tables V and VI). This again may be related to the impact of enzyme treatment on extrusion pressure.

TABLE V
Materials Leached Out During Cooking (T)^a in Dried Pasta Produced from Two Commercial Semolinas (SemA or SemB) with Different Levels of *Bacillus subtilis* (XBS) and *Aspergillus niger* (XAN) Endoxylanases

Pasta	SemA					SemB				
	%dm	%AG	%AX	%prot	%gluc	%dm	%AG	%AX	%prot	%gluc
Control	6.3	32.3	2.2	3.7	4.8	6.3	25.5	1.5	3.9	4.5
Control + XAN										
7.50 × 10 ⁻⁵ units ^b	6.1	33.0	2.3	3.8	4.6	nd ^c	nd	nd	nd	nd
7.50 × 10 ⁻⁴ units	6.1	33.9	3.0	3.7	4.7	6.0	24.1	1.6	3.8	4.2
3.75 × 10 ⁻³ units	6.1	31.6	3.3	3.8	4.2	6.8	25.7	2.4	4.1	4.9
1.50 × 10 ⁻² units	6.3	27.4	3.8	3.7	4.4	nd	nd	nd	nd	nd
4.00 × 10 ⁻² units	6.3	30.9	6.1	3.7	4.2	6.9	27.4	5.1	4.2	5.4
0.225 units	6.7	31.0	10.8	4.0	4.5	8.5	32.0	10.9	5.3	6.4
1.30 units	7.8	32.5	19.8	4.9	4.7	nd	nd	nd	nd	nd
Control + XBS										
7.50 × 10 ⁻⁵ units	6.1	32.5	2.4	3.7	4.6	...	...	...	...	...
7.50 × 10 ⁻⁴ units	5.5	27.7	2.1	3.3	4.0	...	...	...	...	...
3.75 × 10 ⁻³ units	5.8	28.8	2.8	3.6	4.3	...	...	...	...	...
1.50 × 10 ⁻² units	6.5	33.7	4.7	3.9	4.7	...	...	...	...	...
4.00 × 10 ⁻² units	6.6	32.2	9.5	3.9	4.8	...	...	...	...	...
0.225 units	6.7	29.5	13.2	3.9	4.5	...	...	...	...	...
Max. coefficient of variation (%)	10	8	6	7	10	9	8	7	6	9

^a Materials: dry matter (%dm), arabinogalactan peptides (AG), arabinoxylans (%AX), proteins (%prot), glucose (%gluc), and ash (%ash).

^b Somogyi units/g of semolina.

^c Not determined.

TABLE VI
Materials Leached Out During Overcooking (T + 11 min)^a in Dried Pasta Produced from Two Commercial Semolinas (SemA or SemB) with Different Levels of *Bacillus subtilis* (XBS) and *Aspergillus niger* (XAN) Endoxylanases

Pasta	SemA					SemB				
	%dm	%AG	%AX	%prot	%gluc	%dm	%AG	%AX	%prot	%gluc
Control	7.9	38.0	4.0	4.6	6.2	8.2	36.2	3.2	5.1	7.0
Control + XAN										
7.50 × 10 ⁻⁵ units ^b	8.2	41.5	4.8	4.9	6.3	nd ^c	nd	nd	nd	nd
7.50 × 10 ⁻⁴ units	8.9	45.5	5.7	5.3	6.3	8.0	36.6	3.5	4.9	7.2
3.75 × 10 ⁻³ units	7.6	42.6	7.1	4.5	6.5	9.6	42.3	6.5	5.6	8.7
1.50 × 10 ⁻² units	8.1	39.3	7.6	4.9	6.0	nd	nd	nd	nd	nd
4.00 × 10 ⁻² units	8.3	40.7	12.0	4.7	6.3	7.4	30.4	7.7	4.5	6.1
0.225 units	9.2	41.4	19.4	5.4	6.8	9.2	38.5	15.8	5.7	7.8
1.30 units	10.6	45.8	33.7	6.7	7.5	nd	nd	nd	nd	nd
Control + XBS										
7.50 × 10 ⁻⁵ units	7.8	43.1	4.6	4.6	6.5	...	...	...	...	...
7.50 × 10 ⁻⁴ units	8.1	39.8	4.8	4.8	6.3	...	...	...	...	...
3.75 × 10 ⁻³ units	8.2	43.8	6.5	4.9	7.0	...	...	...	...	...
1.50 × 10 ⁻² units	8.6	43.8	8.5	4.9	6.5	...	...	...	...	...
4.00 × 10 ⁻² units	8.8	41.6	15.3	5.2	6.7	...	...	...	...	...
0.225 units	9.7	42.9	22.7	5.2	7.3	...	...	...	...	...
Max CV (%) ^b	10	9	5	10	10	11	9	7	...	8

^a Materials: dry matter (%dm), arabinogalactan peptides (AG), arabinoxylans (%AX), proteins (%prot), glucose (%gluc), and ash (%ash).

^b Somogyi units/g of semolina.

^c Not determined.

The use of endoxylanases during pasta production thus resulted in products with large levels of soluble dietary fiber (Table IV) which was not easily leached out during the pasta cooking process. It should be pointed out that endoxylanases, which preferably hydrolyze WE-AX and not WU-AX as used in the gluten-starch separation, would probably be less useful for this goal.

Further reduction of cooking losses and the concomitant (soluble) dietary fiber can be obtained by optimizing parameters that are known to have a great influence on cooking losses: cooking time (Binnington et al 1939); product shape and protein content (Holliger 1963); gliadin, globulin, albumin, and glutenin contents (Walsh and Gilles 1971); gluten strength (Grzybowski and Donnelly 1979); particle size of the flour used (Breen et al 1977; Alary et al 1979); hardness of the cooking water (Alary et al 1979; Dexter et al 1983; Seibel and Menger 1985); drying temperature (Dexter et al 1981); and dough temperature at the die (Abécassis et al 1994).

CONCLUSIONS

The most obvious effect of adding endoxylanases during pasta production was that the extrusion pressures are significantly lowered. Quality (in terms of color of the dried product and surface condition, viscoelastic index, and resistance to longitudinal deformations of the cooked product) of pastas containing endoxylanases remained fairly constant. Further improvements of the quality could be expected when using appropriate (lower) dough hydration levels, yielding normal extrusion pressure levels (9.0–12.5 MPa). These lower dough hydration levels could lead to shorter drying times of the extruded pasta. Further work will be undertaken to check this hypothesis.

The use of endoxylanases during pasta production resulted in a high turnover of WU-AX to WE-AX, while the MW of the WE-AX also were reduced. For the highest dosages used, the MW of the WE-AX was even lower than that of AGP. In contrast to expectations, WE-AX from pastas containing very high dosages of endoxylanases were not leached easily during cooking, even at excessive cooking times. AGP were consistently leached more easily, even when the WE-AX had attained a lower MW due to the endoxylanase treatment. A method is hereby provided to produce pasta with increased levels of soluble fiber (WE-AX).

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