# Rheological Properties of Dough Made from Grain Amaranth-Cereal Composite Flours Based on Wheat and Spelt

*Silva GROBELNIK MLAKAR, Martina BAVEC, Matjaž TURINEK and Franc BAVEC*

*Faculty of Agriculture and Life Science, University of Maribor, Hoče, Slovenia*

**Abstract**

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The purpose of this study was to investigate the effect of the addition of amaranth wholegrain flour on the rheological characteristics of wheat and spelt flour dough. Organically produced composite flours made from basic flours of wheat (refined) or spelt (refined, wholegrain) and amaranth flour in the propostions of 10%, 20%, and 30% (flour basis) were compared to cereal flours. Dough was analysed for its amylographic, farinographic and extensographic properties. The amaranth substitution altering of the examined measures relates to a certain extent to the properties of the basic flour used. By increasing the amaranth replacement ratio, the gelatinisation temperature, water absorption, development time, and stability increased whereas the dough softening was only slight. The amaranth addition strengthened the dough, mainly by decreasing its extensibility and, in spelt containing composite flours, also by increasing the resistance to extension. Considering the results obtained and the characteristics of the basic flour used, the amaranth substitution of 10–20% evidently improves some rheological properties and strengthens the dough. The present study provides the first report on the spelt-amaranth blends and dough extensograph behaviour of amaranth composite flours

**Keywords**: grain amaranth; composite flour; wheat; spelt; dough properties

The promotion of composite flours in the production of baked products started officially in 1964, when the Food and Agricultural Organisation of the United Nations launched its Composite Flour Program. The objective was to identify a new replacement for wheat in breadmaking, baked goods, and pasta products, and to find flour formulations with compositions combining optimal nutritive value with appropriate processing characteristics (De Ruiter 1978). Grain amaranth (*Amaranthus* spp.), owing to its agricultural advantages and nutritional benefits (Bavec & Bavec 2006a), has a potential as a non-wheat material in composite flours.

Amaranth is a pseudocereal native to South America, where the crop was a basic and sacred food in the pre-Columbus times. When the Spanish conquered the area, native religions were banned and the amaranth production and utilisation were prohibited. It was believed that besides the small size of its seeds, this was the main reason for the current lack of knowledge and scarce use of grain amaranth. However, the crop was rediscovered in the 1970s, and has recently attracted increased interest from

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the agronomic, nutritional, and processing points of view (Williams & Brenner 1995; Bavec & Bavec 2006a). Grain amaranth has nutritional properties that are superior to those of almost all common cereals. Among the notable nutritional attributes of amaranth grain is its high protein content (130–206 g/kg) with a better balance of amino acids and a particularly high lysine (49–61 g/kg protein) and sulphur containing amino acids (41 to 45 g/kg protein) contents. These characteristics, as well as its relatively high fat content (30–80 g/kg), unsaturation (76%), a significant squalene content in oil (22–69 g/kg), ash (25–44 g/kg) and iron (72–174 mg/kg) contents of high bioavailability, and water insoluble β-glucan content (26 g 100/g dry matter) make amaranth suitable as a component of composite flours for breadmaking (Becker *et al.* 1981; Singhal & Kulkarni 1988; Prakash & Pal 1992; Becker 1994; Bressani 1994; Williams & Brenner 1995; Bejosano & Corke 1998; Leon-Camacho *et al.* 2001; Písaříková *et al.* 2005; Bavec & Bavec 2006a; Hozová *et al.* 2007; Bodroža-Solarov 2008). The main problem with the use of amaranth in blends is the inferior baking quality due to its not containing gluten (Thompson 2001), and thus the addition to leavened products is limited. However, the reports on amaranth composite flours for breadmaking are all based on wheat flour, and virtually no research has been reported on spelt-amaranth composite flours. Spelt (*Triticum spelta* L.) is an old wheat species whose production greatly decreased in the 20$^{th}$ century, but the interest in this hulled, low-input wheat has recently increased again, and spelt is recognised as one of the most appropriate cereals for organic production (Bavec & Bavec 2006b). The most common spelt product is bread, and thus the information on the rheological properties of the dough and on the breadmaking properties has been reported in the literature (Ranhotra *et al.* 1995; Abdel-Aal *et al.* 1997; Jorgensen *et al.* 1997; Bonafaccia *et al.* 2000; Bojňanská & Frančáková 2002; Cubadda & Marconi 2002).

Among the studies on composite flours containing amaranth only a few deal with the rheological characteristics of the dough (Lorenz 1981; Breene 1991; Tosi *et al.* 2002; Silva-Sánches 2004; Sindhuja *et al.* 2005; Oszvald *et al.* 2009). However, these properties are important for the prediction of the dough behaviour during mechanical handling in breadmaking as they affect the quality of the resulting loaf.

The objectives of the present study, which was a part of a broader national research project on grain amaranth (project L4-6349-0482-06), were to investigate the effects of the effect by wholegrain amaranth flour substitution of organically produced cereals (wheat and spelt)on the rheological properties of the resulting dough and its suitability for breadmaking.

## MATERIALS AND METHODS

***Flour samples and composite flour formulations.*** Wheat and spelt were obtained from the Turinek biodynamic farming, a processing and baking unit in Slovenia. Grain amaranth (*A. cruenthus* L. G6) was obtained from the Bavec organic farm. Refined wheat and spelt flours were produced by roll milling and spelt wholegrain flour by stone milling in farm-scale mills. Amaranth wholegrain flour was produced in a smaller stone mill (Ost-tiroler Getreide Mühlen) with a narrower gap between the stones, as recommended by Becker *et al.* (1986), and was then sieved through a 0.4-mm mesh.

Composite flours were prepared by mixing amaranth flour in proportions (w/w on flour basis) of 10%, 20% and 30% (AFS) with the individual basic cereal flours (BF). Single basic flours were used as controls.

***Flour analyses and rheological tests***. The moisture content (according to SIST ISO 1985), total ash content (according to ICC standard No. 104/1, ICC 1993), and the falling number (according to SIST ISO 1982) were determined for all flour components. The falling number was determined using a laboratory mill (model 3100) and Falling number 1800 system (Perten, Sweden). The wet gluten content and gluten index of cereal flours were determined (Glutomatic 2200 Gluten System and Glutomatic Centrifuge 2015, Perten, Sweden) according to ICC standard No. 155 (ICC 1998).

The amylase activity of the individual flour components and blends was determined on an amylograph (model 800101, Brabender, Germany) according to the manufacturer's instructions. The test was performed without using silver nitrate. The initial gelatinisation temperature (Ti), gelatinisation peak temperature (Tg), time to reach maximum viscosity, and maximum viscosity (MV) were determined from the curves.

The rheological properties of doughs made from each cereal flour and different blends were determined using Brabander farinograph (300 g kneader, 63 rev. per min, 30°C) and extensograph (both with the data transmission to a PC, Brabender, Germany), and standard procedures ICC No. 115/1 and No. 114/1 for wheat flour, respectively (ICC 1998).

The following parameters were derived from the farinograms: water absorption (WA), development time (DT), stability (S), degree of softening (10 min after the start and 12 min after the maximum as DS 10´ and DS 12´, respectively) and farinograph quality number (FQN). The doughs were prepared to a farinogram consistency of 500 BU, and the extensogram properties such as the energy, resistance to extension, extensibility, and maximum resistance after resting periods of 45, 90, and 135 min were recorded. The ratio number and ratio number at maximum were calculated as the ratio of resistance and maximum resistance to extensibility, respectively.

The analyses were performed in triplicates and single basic flours were used for comparison.

***Statistical analysis***. Statistical analyses were performed using the Statgraphics Centurion XV statistical program (Statgraphics® 2005). Since significant differences were observed between the standard deviations for 12-level treatments (BF×AFS) with almost all of the characteristics investigated (Cochran's C and Bartlett's tests) and, therefore, the assumption of homogeneity of variance was not confirmed, the analysis of variance (ANOVA) was carried out for each basic flour separately. ANOVA was performed at a significance level of $P < 0.05$, and Duncan's multiple-range test was used to determine the significance of the differences between the means. The results are presented as the means ± SEM (standard error of the mean) or the means and PSE (pooled standard error) for triplicate analyses.

## RESULTS AND DISCUSSION

The moisture content of amaranth flour (112.3 g/kg) was lower than those of wheat and spelt flours (Table 1), as recommended for the storage of amaranth grain (Lehman 1996). The ash contents were 4.1, 5.5, and 14.4 g/kg for refined wheat, refined spelt, and wholegrain spelt flours, respectively. Amaranth flour had a significantly higher ash content (26.2 g/kg) which was in the range of 24.7–40.0 g/kg reported for different amaranth species (Singhal & Kulkarni 1988; Gamel *et al.* 2006).

The wet gluten content and gluten index are indicators closely related to the baking quality of flour. Wet gluten is a cohesive visco-elastic proteinaceous substance obtained after washing out starch granules from dough. Quality gluten, described by the degrees of strength and extensibility, allows a sufficient expansion, good distribution and retention of the gas cells within fermenting dough. Among the tests evaluating the gluten strength, the gluten index according to the glutamatic method (ICC 1998) is used and described by Miś (2000). The method is a fast and reliable tool for describing the gluten strength, and consists in subjecting to a centrifugal force a

Table 1. Characteristics of the flours components

| | Wheat refined | Spelt refined | Spelt whole grain | Amaranth whole grain |
|---|---|---|---|---|
| Moisture (g/kg) | 135.7 ± 0.33[a] | 126.7 ± 0.67[b] | 126.3 ± 0.33[b] | 112.3 ± 0.33[c] |
| Ash (g/kg) | 4.1 ± 0.03[d] | 5.5 ± 0.03[c] | 14.4 ± 0.04[b] | 26.2 ± 0.15[a] |
| Wet gluten (g/kg) | 178.3 ± 4.27[c] | 350 ± 3.0[a] | 292.8 ± 1.84[b] | – |
| Gluten index | 99 ± 0.0[a] | 67 ± 1.5[b] | 9 ± 0.7[c] | – |
| Falling number (s) | 327 ± 5.3[b] | 322 ± 3.4[b] | 346 ± 8.6[a] | 62 ± 0.0[c] |
| Amylase activity (AU) | 1248 ± 4.4[a] | 640 ± 2.9[c] | 650 ± 0.0[b] | 563 ± 1.7[d] |
| Granulometry (%) | | | | |
| < 200 µm | 100 ± 0.0 | 100 ± 0.0 | 76 ± 0.1 | 22.4 ± 0.12 |
| < 132 µm | 89.2 ± 0.1 | 91.3 ± 0.10 | 60.2 ± 0.09 | 15.8 ± 0.17 |

Values (± SEM) within a row followed by different letters are significantly different (Duncan, α = 0.05) sample of separated wet gluten placed on a special sieve. Wheat of good breadmaking quality is characterised by a minimum wet gluten content of 280 g/kg and a gluten index of 60–90. Flours with the gluten index below 60 are considered as too weak while those with values exceeding 95 are too strong for the bread production (Tašner & Čepon Trobec 2007). Wet gluten content of the organically produced wheat tested was much lower than the stated minimum and lower than that of spelt flours, while its gluten index was higher, especially compared to wholegrain spelt flour (Table 1). Low gluten content exhibited by the wheat flour tested (178.3 g/kg) could be, besides the individual cultivar properties, location, and environmental circumstances, also affected by agricultural factors connected to the organic production system (Torbica *et al.* 2007). Several researchers summarised by Cubadda and Marconi (2002) and Schober *et al.* (2006) have come to the conclusion that the content of gluten in spelt is higher, but it tends to be more extensible and less elastic than the gluten from modern wheat. Consequently, it has a lower gluten index which results in typical, weaker spelt dough. The wet gluten content of the refined spelt flour examined was 350 g/kg and that of the wholemeal spelt flour was 292.8 g/kg. The obtained values correspond to the range of wet gluten content (306.0–483.2 g/kg) in crushed grains of various cultivars published by Bojňanská and Frančáková (2002), and are similar to the wet gluten content and gluten index of spelt produced in Slovenia (Skrabanja *et al.* 2001). In the case of the last cited publication, the wet gluten content of refined spelt flour was 397.0 g/kg and that of the wholemeal flour was 415.0 g/kg. Gluten index of both flours was 10.

The amylase activity of cereal flours was to some extent in accordance with the falling number values (Table 1). Among the flours tested, refined wheat flour exhibited the highest maximum viscosity (1248 AU), thus giving the lowest amylase activity expressed as the falling number (327 s). With spelt flours, the relationship between the tests was not as clear. However, the enzyme activity of the organic cereal flours investigated was satisfactory, although a falling number > 300 s is considered as too high, and the addition is needed of another source of $\alpha$-amylase for optimising the levels of the reducing and fermentable sugars in flour (Nikolić 1996). Amaranth flour had the highest amylase activity among the flours tested (maximum viscosity 563 AU) and thus almost the lowest possible falling number that can be measured by the device used (62 s). In contrast, Gamel *et al.* (2005) reported considerably higher falling numbers of 193 and 195 s and maximum viscosity of 465 AU and 400 AU for flours of *A. cruentus* and *A. caudatus* L., respectively.

The stone milling and production of wholegrain flours of spelt and amaranth resulted in a coarser granulometry (Table 1).

The effects of amaranth flour substitution on the suspension pasting properties are shown in Table 2. The amylograms indicated that amaranth flour had the same initial gelatinisation temperature as wholegrain spelt flour, but this was significantly higher than the Ti for wheat and refined spelt flours. In comparison to wheat and spelt, amaranth flour had the lowest gelatinisation peak temperature and the shortest gelatinisation time.

When wheat was replaced by amaranth flour, the gelatinisation temperature increased by 1°C for substitution levels of 20% and 30%. The gelatinisation peak temperature and the time to peak viscosity gradually increased with the amaranth substitution. Maximum viscosity gradually decreased from 1248 AU to 1223 AU, 1127 AU and 1062 AU with the increasing amaranth substitution from 0% to 10%, 20%, and 30%, respectively (Table 2). This is likely because of the higher amylase activity (564 AU) of amaranth flour and the formation of amylose-lipid complexes in suspension, as proposed below. These results are in accordance with those of Lorenz (1981), who reported maximum viscosity of 1260 AU for a control sample that gradually decreased to 1190 AU for 3% and 1000 AU for 15% amaranth (*A. hypochondriacus* L.) substitution in wheat flour. Moreover, the initial gelatinisation temperature gradually increased from 58.5°C to 62.3°C for 15% amaranth substitution, which is more pronounced than the increase in Ti in the present study.

For refined spelt flour, the initial gelatinisation temperature was affected and decreased only for 30% substitution. Increasing proportion of amaranth in the composite flour increased the peak gelatinisation temperature and the time to peak viscosity. The maximum viscosity also increased on amaranth substitution (Table 2).

The substitution of amaranth for wholegrain spelt flour by more than 10% decreased Ti and increased the time to peak viscosity. The peak gelatinisation temperature gradually increased

Table 2. Effect of amaranth flour substitution (AFS) in composite flour of different cereals[1] on amylogram values

| Basic flour | AFS (%) | Ti (°C) | Tg (°C) | Time (min) | MV (AU) |
|---|---|---|---|---|---|
| Refined wheat | ANOVA[2] | ** | ** | ** | ** |
| | 0 | 63[b] | 90[d] | 43[d] | 1248[a] |
| | 10 | 63[b] | 91[c] | 44[c] | 1223[b] |
| | 20 | 64[a] | 93[b] | 45[b] | 1127[c] |
| | 30 | 64[a] | 95[a] | 47[a] | 1062[d] |
| | PSE | 0.0 | 0.17 | 0.17 | 4.2 |
| Refined spelt | ANOVA | ** | ** | ** | ** |
| | 0 | 61[a] | 92[d] | 43[d] | 640[c] |
| | 10 | 61[a] | 93[c] | 45[c] | 692[ab] |
| | 20 | 61[a] | 94[b] | 46[b] | 702[a] |
| | 30 | 58[b] | 95[a] | 47[a] | 682[b] |
| | PSE | 0.0 | 0.0 | 0.0 | 2.9 |
| Wholegrain spelt | ANOVA | * | ** | ** | NS |
| | 0 | 64[a] | 91[c] | 44[c] | 650 |
| | 10 | 63[ab] | 93[b] | 45[bc] | 713 |
| | 20 | 62[b] | 95[a] | 47[a] | 700 |
| | 30 | 62[b] | 95[a] | 46[b] | 640 |
| | PSE | 0.5 | 0.17 | 0.33 | 23.3 |
| Wholegrain amaranth (± SEM) | | 64 ± 0.0 | 87 ± 0.0 | 41 ± 0.0 | 563 ± 1.67 |

[1]Means followed by different letter are significantly different (Duncan, α = 0.05); $^{**}P = 0.01$, $^{*}P = 0.05$; NS – non-significant
Ti – initial gelatinisation temperature; Tg – gelatinisation peak temperature; Time – time to maximum viscosity; MV – maximum viscosity

with the amaranth addition from 91°C (control) to 93°C (10%) and 95°C (20% and 30%). The maximum viscosity was not affected by amaranth substitution (Table 2).

Amaranth substitution had the opposite effect on Ti for wheat and both spelt flours. Presumably, this was due to the spelt components that formed complexes other than those formed with wheat flour. However, the peak gelatinisation temperature for blends increased with the amaranth addition in all cases. As proposed by Peredes-López and Hernandez-López (1991) and by various authors as reviewed by D'appolonia and Rayas-Duarte (1994), this could be attributed to sucrose, which is present in much greater amounts in amaranth compared to other cereals, similar to the situation with other oligosaccharides and monosaccharides (Becker *et al.* 1981). Several explanations have been proposed for this effect, including the competition between sugars for the available water, a decrease in relative vapour pressure, sucrose inhibition of starch granule hydration, and specific sugar-starch interactions that stabilise the granular structure during heating (D'appolonia & Rayas-Duarte 1994). Moreover, the higher lipid content in grain amaranth as compared to other cereals (Becker *et al.* 1981) may also be a factor in the increase in Tg and time to maximum viscosity with increasing amaranth substitution. These parameters might be affected by the insoluble amylose-lipid complexes formed during heating of starch slurries, which reduce and delay the swelling of starch granules.

According to the farinogram and extensogram values (Tables 3 and 4), the refined wheat flour tested was of poor quality (Nikolić 1996). However, the Turinek unit produces suitable bread from this flour, which is very much in demand in the

Table 3. Effect of amaranth flour substitution (AFS) in composite flour of different cereals[1] on farinogram parameters

| Basic flour | AFS (%) | WA (%) | DT (min) | S (min) | DS 10´ | DS 12´ | FQN |
|---|---|---|---|---|---|---|---|
| Refined wheat | ANOVA[2] | ** | ** | ** | ** | * | ** |
| | 0 | 53.0[c] | 1.3[c] | 1.40[c] | 93.3[a] | 103.7[b] | 23[c] |
| | 10 | 55.2[b] | 1.9[c] | 3.90[b] | 64.3[b] | 89.3[b] | 57[b] |
| | 20 | 55.5[b] | 4.4[b] | 5.70[a] | 59.7[b] | 99.7[b] | 75[a] |
| | 30 | 55.9[a] | 5.3[a] | 3.46[b] | 69.7[b] | 124.3[a] | 74[a] |
| | PSE | 0.11 | 0.17 | 0.175 | 6.93 | 6.63 | 2.1 |
| Refined spelt | ANOVA | ** | ** | ** | $P$ = (0.057)* | NS | ** |
| | 0 | 60.0[d] | 2.4[c] | 1.93[c] | 100.0[a] | 123.0 | 36[d] |
| | 10 | 61.2[c] | 3.7[b] | 3.03[b] | 86.0[b] | 120.0 | 54[c] |
| | 20 | 61.8[b] | 4.0[b] | 3.40[a] | 85.0[b] | 126.0 | 62[b] |
| | 30 | 62.5[a] | 4.8[a] | 2.97[b] | 83.7[b] | 136.0 | 67[a] |
| | PSE | 0.11 | 0.10 | 0.126 | 4.32 | 5.24 | 1.8 |
| Wholegrain spelt | ANOVA | ** | ** | ** | ** | * | ** |
| | 0 | 60.0[b] | 2.0[b] | 1.37[c] | 115.3[b] | 122.0[c] | 28[d] |
| | 10 | 60.1[b] | 2.3[b] | 1.47[ab] | 115.3[b] | 127.3[c] | 33[c] |
| | 20 | 61.5[a] | 2.6[a] | 1.53[a] | 124.0[a] | 145.7[b] | 37[b] |
| | 30 | 61.7[a] | 2.7[a] | 1.40[bc] | 129.3[a] | 157.7[a] | 39[a] |
| | PSE | 0.08 | 0.08 | 0.041 | 2.22 | 2.56 | 0.5 |

[1]Means followed by different letters are significantly different (Duncan, α = 0.05); **$P$ = 0.01, *$P$ = 0.05; NS – non-significant WA – water absorption; DT – development time; S – dough stability; DS 10´ – degree of softening 10 min after the start; DS 12´– degree of softening 12 min after the maximum; FQN – farinograph quality number

local organic market. Jorgensen *et al.* (1997) used a Brabender farinograph to carry out experiments on refined flours of seven spelt varieties and compared them with bread wheat. The spelt samples tested absorbed water at rates of 48.7–52.7%, which is less than the rate in the present study (60.0%). The authors reported results similar to those of the present study (Table 3) for water absorption rapidity (development time 1.6–2.7 min) and dough stability (1.1–3.6 min). They also observed high values for the degree of softening 12 min after the maximum (88–185 FU).

The water absorption of composite flours increased with the amaranth substitution in all cases. WA increased from 53.0% to 55.9%, from 60.0% to 62.5%, and from 60.0% to 61.7% with amaranth substitution in wheat, refined spelt, and wholegrain spelt flours, respectively. The results are in accordance with those of Lorenz (1981), who reported that the water-binding capacity of *A. hypochondriacus* starch was 127.0%, whereas that of wheat starch was 71.8%. The farinogram data obtained in the same study revealed an increase in the water absorption of composite flours (from 64.0% to 66.5%) when the amaranth substitution increased from 0% to 15%. In contrast, Sindhuja *et al.* (2005) reported a small decrease in WA when amaranth flour (*A. gangeticus* L.) was substituted for wheat in proportions up to 35% in the composite flour for sugar snap cookie production.

An increase in the dough development time was observed on addition of amaranth flour. This was significant for all refined spelt samples and for > 10% amaranth addition to refined wheat and wholegrain spelt flours. The stability time of all composite doughs was higher than for the controls and was the highest for 20% AFS. For 30% substitution, the dough stability decreased in all cases. DS 10´ decreased on amaranth flour substitution for wheat and refined spelt flours, whereas a substitution ratio of > 10% increased softening for the wholegrain spelt-amaranth composite flour. The increase in DS 12´ was significantly pronounced with 30% amaranth substitution in wheat flour and with > 10% substitution in wholegrain spelt flour. Irrespective of the basic cereal flour used, a significant increase in the farinograph quality number was observed with increasing substitution (Table 3). The farinogram results are, to some extent, in agreement with the results of similar studies on wheat-amaranth composite flours. Sindhuja *et al.* (2005) observed a gradual increase in the dough development time (from 1.25 min to 4.0 min), but also a considerable decrease in the dough stability (from 4.0 min to 1.5 min) and pronounced weakening of the dough (increase in mixing tolerance from 30 BU to 120 BU) when amaranth was incorporated into the blend in the amount of up to 35%. Lorenz (1981) observed a slight decrease in the development time (from 4.0 min to 3.5 min), a very pronounced decrease in the dough stability (from 12.5 min to 2.5 min), and an increase in mixing tolerance (from 30 to 50 BU). Tosi *et al.* (2002) added hyperproteic whole amaranth flour and hyperproteic defatted amaranth flour to wheat flour in proportions of 4%, 8%, and 12%, and found that increasing amaranth substitution in the blend increased the water absorption and dough development time and decreased the farinographic stability. An increased development time and dough stability was reported by Silva-Sánches *et al.* (2004) in treatments where refined wheat flour was supplemented with 1% amaranth albumin isolate (concentration relative to wheat flour quantity). The rheological test based on farinograms showed that wheat flour substituted with 1% amaranth albumins improves the dough development time (8.3 min in comparison to control of 7.4 min) and mixing stability (11.1 min in comparison to control of 10.9 min), however, less water was required to get optimum dough development. The alveogram results provided by the authors suggested and baking test approved the improvement of the dough properties and bread crumb characteristics when albumin isolates were added. Similarly, Oszvald *et al.* (2009) reported the beneficial effects of amaranth albumin to wheat supplementation even in concentrations from 1% to 5% relative to the protein content of wheat (i.e. about one tenth of the protein used in the aforementioned study). Positive effects on the dough mixing properties as the development time, dough strength and stability were evident in both cases of the supplementation approaches investigated; simple amaranth albumin to flour addition, and amaranth albumin incorporation (albumin addition followed by dough chemical reduction/oxidation). The mixing time requirements, dough strength and stability increased proportionally to the increase in the amount of albumin supplementation. However, the impact of amaranth proteins on the dough characteristics was more pronounced when amaranth albumins were chemically incorporated through reduction/oxidation in comparison to the simple addition of proteins. The authors demonstrated that amaranth albumins are able to interact with the glutenin type subunits of the wheat storage proteins through free disulfide bonds, and thus the initial reduction of the amaranth albumins is not required for the incorporation.

To the best of our knowledge, the extensograph properties of amaranth-containing composite flours have not been investigated to date. In the present study, the extensogram parameters were determined after 45, 90, and 135 min of dough maturing and are listed in Table 4. For refined wheat flour, the dough energy decreased with increasing amaranth replacement. The resistance to extension and maximum resistance of dough with amaranth flour addition were lower than those of the control, except for the resistance to extension for 10% AFS flour after 45 minutes. According to the values obtained after 45 min, the extensibility of all doughs containing amaranth flour was significantly lower than that of the control dough. However, after 90 and 135 min the 10% AFS flour had the same dough extensibility as the control. The ratio number and ratio number at maximum decreased with increasing amaranth substitution, except for the ratio number after 45 min, which decreased only for 30% amaranth substitution (Table 4).

For refined spelt flour, the energy after 45 min was lower only for 30% substitution, and at prolonged dough maturing when 20% and more was replaced. The resistance to extension and dough maximum resistance were higher if amaranth was present in the composite flour, and the extensibility of the dough decreased depending on the increase in the substitution with amaranth flour. The ratio number and ratio number at maximum resistance consequently decreased (Table 4).

Because of the adhesiveness of wholegrain spelt dough, extensographs could not be measured for the composite flour containing the highest

Table 4. Effect of amaranth flour substitution (AFS) in composite flour of different cereals[1] on extensogram parameters

| Basic flour | AFS (%) | Energy (cm$^2$) | | | Resistance to extension (BU) | | | Extensibility (mm) | | | Maximum (BU) | | | Ratio number | | | Ratio number (Max.) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 45’ | 90’ | 135’ | 45’ | 90’ | 135’ | 45’ | 90’ | 135’ | 45’ | 90’ | 135’ | 45’ | 90’ | 135’ | 45’ | 90’ | 135’ |
| Refined wheat | ANOVA[2] | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | * | ** | ** | ** | ** | ** |
| | 0 | 89$^{a}$ | 113$^{a}$ | 104$^{a}$ | 345$^{a}$ | 507$^{a}$ | 565$^{a}$ | 147$^{a}$ | 137$^{a}$ | 123$^{a}$ | 460$^{a}$ | 655$^{a}$ | 686$^{a}$ | 2.3$^{a}$ | 3.7$^{a}$ | 4.6$^{a}$ | 3.1$^{a}$ | 4.8$^{a}$ | 5.6$^{a}$ |
| | 10 | 71$^{b}$ | 86$^{b}$ | 77$^{b}$ | 335$^{a}$ | 432$^{b}$ | 436$^{b}$ | 135$^{b}$ | 132$^{a}$ | 122$^{a}$ | 389$^{b}$ | 494$^{b}$ | 484$^{b}$ | 2.5$^{a}$ | 3.3$^{b}$ | 3.6$^{b}$ | 2.9$^{b}$ | 3.7$^{b}$ | 4.0$^{b}$ |
| | 20 | 49$^{c}$ | 57$^{c}$ | 55$^{c}$ | 285$^{b}$ | 370$^{c}$ | 376$^{c}$ | 119$^{b}$ | 111$^{b}$ | 109$^{b}$ | 297$^{c}$ | 379$^{c}$ | 382$^{c}$ | 2.4$^{a}$ | 3.3$^{b}$ | 3.5$^{b}$ | 2.5$^{c}$ | 3.4$^{c}$ | 3.5$^{c}$ |
| | 30 | 38$^{d}$ | 40$^{d}$ | 40$^{d}$ | 230$^{c}$ | 273$^{d}$ | 278$^{d}$ | 112$^{c}$ | 105$^{b}$ | 103$^{b}$ | 232$^{d}$ | 274$^{d}$ | 278$^{d}$ | 2.1$^{b}$ | 2.6$^{c}$ | 2.7$^{c}$ | 2.1$^{d}$ | 2.6$^{d}$ | 2.7$^{d}$ |
| | PSE | 2.0 | 1.2 | 1.9 | 4.2 | 6.0 | 6.7 | 2.1 | 2.0 | 2.2 | 7.6 | 4.4 | 8.3 | 0.05 | 0.08 | 0.09 | 0.09 | 0.06 | 0.09 |
| Refined spelt | ANOVA | * | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** | ** |
| | 0 | 34$^{a}$ | 36$^{ab}$ | 35$^{a}$ | 113$^{c}$ | 128$^{b}$ | 128$^{c}$ | 178$^{a}$ | 171$^{a}$ | 170$^{a}$ | 123$^{b}$ | 137$^{b}$ | 137$^{c}$ | 0.6$^{d}$ | 0.7$^{d}$ | 0.7$^{d}$ | 0.7$^{d}$ | 0.8$^{d}$ | 0.8$^{d}$ |
| | 10 | 36$^{a}$ | 38$^{a}$ | 37$^{a}$ | 158$^{b}$ | 167$^{a}$ | 163$^{b}$ | 144$^{b}$ | 149$^{b}$ | 147$^{b}$ | 164$^{a}$ | 174$^{a}$ | 169$^{b}$ | 1.1$^{c}$ | 1.1$^{c}$ | 1.1$^{c}$ | 1.2$^{c}$ | 1.2$^{c}$ | 1.1$^{c}$ |
| | 20 | 31$^{ab}$ | 31$^{b}$ | 31$^{b}$ | 168$^{ab}$ | 177$^{a}$ | 168$^{b}$ | 122$^{c}$ | 122$^{c}$ | 124$^{c}$ | 170$^{a}$ | 179$^{a}$ | 169$^{b}$ | 1.4$^{b}$ | 1.5$^{b}$ | 1.4$^{b}$ | 1.4$^{b}$ | 1.4$^{b}$ | 1.4$^{b}$ |
| | 30 | 27$^{b}$ | 26$^{c}$ | 27$^{c}$ | 181$^{a}$ | 182$^{a}$ | 184$^{a}$ | 103$^{d}$ | 101$^{d}$ | 102$^{d}$ | 123$^{a}$ | 182$^{a}$ | 184$^{a}$ | 1.8$^{a}$ | 0.7$^{a}$ | 1.8$^{a}$ | 1.8$^{a}$ | 1.8$^{a}$ | 1.8$^{a}$ |
| | PSE | 1.5 | 1.2 | 1.0 | 4.5 | 4.5 | 3.4 | 1.5 | 1.8 | 1.4 | 5.5 | 4.9 | 3.5 | 0.03 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| Wholegrain spelt | ANOVA | * | ** | NS | ** | ** | ** | NS | * | * | ** | ** | ** | ** | ** | ** | ** | ** | ** |
| | 0 | 14$^{b}$ | 18$^{b}$ | 20 | 79$^{c}$ | 104$^{c}$ | 119$^{b}$ | 114 | 117$^{a}$ | 122$^{a}$ | 92$^{c}$ | 116$^{c}$ | 131$^{c}$ | 0.7$^{c}$ | 0.9$^{c}$ | 1.0$^{c}$ | 0.8$^{c}$ | 1.0$^{c}$ | 1.1$^{c}$ |
| | 10 | 19$^{a}$ | 22$^{a}$ | 25 | 113$^{b}$ | 133$^{b}$ | 148$^{b}$ | 113 | 113$^{a}$ | 118$^{a}$ | 134$^{b}$ | 151$^{b}$ | 163$^{b}$ | 1.0$^{b}$ | 1.2$^{b}$ | 1.3$^{b}$ | 1.2$^{b}$ | 1.3$^{b}$ | 1.4$^{b}$ |
| | 20 | 19$^{a}$ | 25$^{a}$ | 27 | 141$^{a}$ | 180$^{a}$ | 200$^{a}$ | 91 | 95$^{b}$ | 94$^{b}$ | 166$^{a}$ | 202$^{a}$ | 221$^{a}$ | 1.6$^{a}$ | 1.9$^{a}$ | 2.1$^{a}$ | 1.8$^{a}$ | 2.2$^{a}$ | 2.3$^{a}$ |
| | 30 | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| | PSE | 0.9 | 1.0 | 1.5 | 3.7 | 4.3 | 9.0 | 4.8 | 4.8 | 3.9 | 3.7 | 1.5 | 6.8 | 0.04 | 0.06 | 0.05 | 0.05 | 0.09 | 0.05 |

[1]Means followed by different letters are significantly different (Duncan, $\alpha = 0.05$); **$P = 0.01$, *$P = 0.05$; NS – non-significant

amaranth substitution. However, the energy of the dough increased with the amaranth addition, mainly due to an increase in the dough resistance to extension and maximum resistance, whereas the extensibility slightly decreased. The ratio number and ratio number at maximum increased with the amaranth substitution (Table 4).

A general observation from the extensograms is that the amaranth addition strengthened the dough, mainly by decreasing its extensibility and, in the case of spelt flours, by increasing the dough resistance to extension. The phenomenon is presumably due to the gluten dilution in composite flours and to those constituents in amaranth flour that might be involved in the dough strengthening. However, dough is a complex system with a large number of constituents that may undergo changes during mixing, dough formation, and maturing, as well as during baking and product storage.

## CONCLUSIONS

According to the results obtained, wholegrain amaranth flour has a considerably higher ash content than the cereal flours tested, and thus amaranth substitution has the potential to improve the nutritive value of leavened products, besides other favourable nutritional claims. The pasting characteristics of amaranth-containing composite flour and the rheological properties of the dough depended mostly on the basic cereal flour used. In general, it can be concluded that the increasing amaranth addition delays the maximum viscosity and, consequently, flour gelatinisation occurs at higher temperatures. Moreover, water absorption by composite flours increased, and the increase in the development time led to a significantly slower blend hydration. The dough stability was generally higher for the composite than for basic flours, and it increased with the amaranth substitution of up to 20%. The amaranth addition to blends strengthened the dough, mainly by decreasing its extensibility, and by increasing the dough resistance to extension with spelt flours. Considering the results obtained and the characteristics of the basic flour used, the amaranth substitution of 10–20% is evident to improve some rheological properties and strengthen the dough; in consequence, some baking and sensory properties of the breads, which are not the subject of this publication, improve.

Owing to the scarcity of information on amaranth-containing composite flours and their rheological properties, the present study provides useful information for the formulation of novel fortified baking products. Moreover, the paper provides the first report on spelt-amaranth blends and dough extensograph behaviour of amaranth composite flours.

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*Corresponding author:*

Prof. Franc Bavec, University of Maribor, Faculty of Agriculture and Life Sciences, Pivola 10. Hoče, 2311 Slovenia
tel.: + 386 232 090 30, e-mail: franci.bavec@uni-mb.si