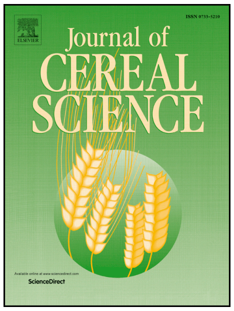

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A study on the quality of einkorn (*Triticum monococcum* L. ssp. *monococcum*) pasta

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ABSTRACT

The continuous increase of pasta consumption is favoured by the availability of new products, manufactured from non-traditional cereals. Einkorn is a diploid relative of durum and bread wheats, appreciated for its high protein, carotenoid and tocol contents, and for its excellent organoleptic characteristics. Aim of this research was to assess its suitability for pasta production and the quality of its products.

The dry einkorn pasta differed from durum wheat pasta for most of the traits, including dimensions, carotenoids content, colour and image analysis parameters. During cooking the pasta from einkorn flours was significantly less firm but had lower cooking losses, probably for a better structure of the gluten matrix. Compression-extrusion tests evidenced, at equal cooking times, significant differences between pasta samples. Among einkorns, ID331 and SAL98-32 showed firmness values similar to durum wheat pasta. Pasta manufacturing led to a significant decrease in lutein and a limited increase in heat damage, but cooking did not induce any further changes. Overall, einkorn pasta had similar technological characteristics but better nutritional value than the control durum wheat pasta.

1. Introduction

Nutritional value and palatability foster the ever-increasing worldwide consumption of pasta. Product quality and consumers acceptance are influenced by colour, cooking properties, texture and taste: dry pasta must have an appealing look, while cooked pasta must retain good yellow colour, pleasant flavour, minimal cooking losses, good firmness and low stickiness (Sisson et al., 2005).

Pasta cooking quality depends on raw of material characteristics and conditions adopted during processing (De Noni and Pagani, 2010). Quantity and quality of semolina proteins strongly influence cooked pasta properties (Pagani et al., 2007); a high protein polymerization during extrusion, in fact, promotes the formation of a viscoelastic network around the starch granules (Resmini and Pagani, 1983). Upon cooking, a well-developed gluten network promptly coagulates and limits starch swelling, thus improving pasta firmness and reducing surface stickiness and material losses into the cooking water (De Noni and Pagani, 2010). With regards to processing, the cooking quality of pasta dried at high temperatures (HT) or very high temperatures (VHT) is usually superior to that of pasta dried at low temperatures (LT) (De Stefanis and Sgrulletta, 1990), leading most manufacturers to select HT and VHT drying for industrial production. Nevertheless, increasing drying temperatures modify nutritional properties, primarily because of Maillard reactions (Manthey and Twombly, 2006), while low drying temperatures (≤65°C) limit heat damage and better preserve the nutritional and sensory properties of the product.

In the Mediterranean region, durum wheat is preferentially used for pasta manufacturing because of its taste, good protein content, rheological properties, and yellow pigment content. Other wheats (spelt, emmer, khorasan, etc.) are sometimes used (Marconi et al., 1999; Fares et al., 2008): for example, emmer pasta is manufactured and marketed as a premium product in Italy (D'Antuono and Bravi, 1996), while spelt, Kamut® and, recently, einkorn pastas are available in some countries (e.g. Italy, France, Germany and USA).

Einkorn (*Triticum monococcum* L. subsp. *monococcum*), a diploid hulled wheat closely related to durum and bread wheat, is an environment-friendly cereal because its frugal nature and disease resistance favour low-input or organic management. The renewed nutritional interest for this cereal is mainly due to its high protein, carotenoid and tocol contents (Hidalgo and Brandolini, 2014; Lachman et al., 2013; Lachman et al., 2017). The light-yellow hue of its flour intensifies during processing, leading to foods with an appealing deep yellow colour. Furthermore, its limited lipoxygenase activity (Hidalgo and Brandolini, 2012) contributes to better preserve nutritional quality during processing in comparison to other wheats (Hidalgo and Brandolini, 2011; Hidalgo et al., 2010).The diffusion of einkorn cultivation and consumption relies on manufacturing food products that combine excellent nutritional and organoleptic properties with good technological characteristics. However, to date only few articles deal with the characteristics of einkorn products, and in particular of pasta before and after cooking (Pasini et al., 2015; La Gatta et al., 2017).Therefore, aim of this research was to assess the quality of *T. monococcum* uncooked and cooked pasta prepared from several einkorn accessions, adopting different processing conditions but following a traditional low-temperature (LT) drying.

2. Materials and methods

2.1. Materials

Kernels of *T. monococcum* Monlis, ID331, ID1395, SAL98-32 and of *T. aestivum* Blasco (BWF) were harvested from three replicated 10 m^2 plots and stored at 5 °C until utilization. Kernels of Monlis for larger-scale pasta production, instead, came from a 100 m^2 non-replicated plot, and were stored at room temperature until processing. All the accessions were cropped in 2013-14 at Sant’Angelo Lodigiano (Po plain, Italy), following standard cultural practices, including limited nitrogen fertilisation (80 kg/ha). Additionally, a durum wheat semolina (DWS; Molino Grassi, Parma, Italy) was utilized as control.

Before milling, the seeds of Monlis, ID331 and ID1395 were de-hulled with an Otake FC4S thresher (Satake, Hiroshima, Japan); dehulling was not necessary for the free-threshing einkorn SAL98-32 and the bread wheat Blasco. After overnight tempering at 15% moisture, the samples were milled with a Bona 4RB (Bona, Monza, Italy) experimental mill which separates the flour fraction from bran and germ.

2.2. Flour characterization

Moisture content was determined according to Method 44-15A (AACC, 1995); protein content (g/100 g DM) was measured by NIR analysis, using a NIRSystem spectrophotometer (FOSS NIRSystems Inc., Hillerød, Denmark) with dedicated reference curves; ash content was assessed following Method 08-03 (AACC, 1995). Lutein, the most abundant carotenoid in *Triticum* spp., was quantified by normal phase HPLC (Hidalgo et al., 2010). Furosine, glucosylisomaltol (GLI) and hydroxymethylfurfural (HMF) contents, which measure heat damage, were determined by HPLC (Hidalgo and Brandolini, 2011). All chemical analyses were performed at least in duplicate.

2.3. Pasta preparation

For the lab-plant trials, about 2 kg of DWS or flour (Monlis, ID331, ID1395, SAL98-32 or BWF) were processed into short-cut pasta (macaroni), mixing with water to make a dough with 30% moisture (32.5% for DWS), and extruding at 8 MPa, 45 °C, under no-vacuum, with a MAC30 lab-scale pasta maker (Italpast, Fidenza, Italy). For the industrial plant trials, about 15 kg DWS or Monlis flour were processed into short-cut pasta (macaroni) and spaghetti, mixing with water to prepare a dough with 30% moisture (32.5% for DWS), and extruding at 10 MPa (11 for DWS), 40 °C, under vacuum, with a Zambra industrial-scale pasta maker (Braibanti, Padova, Italy). Dough mixing lasted, in both lab- and industrial-plant trials, 7 min, while extrusion took ca 5 min in the lab-plant and ca 10 min in the industrial-plant. For all the samples, pasta drying was carried out at low/medium temperature (pre-heating: 50 °C; peak temperature: 65 °C) over 17 hours at constant 75% relative humidity in a pilot-scale drier (Braibanti, Padova, Italy).

For ease of comprehension, henceforward the pasta samples from the Zambra plant will be coded as Z.

2.4. Uncooked pasta characterization

All pasta samples were tested in double for moisture (Method 44-15A; AACC, 1995). The colour was measured with a Minolta Chroma Meter CR-210 (Minolta, Osaka, Japan, in triple), and three random readings were recorded on the levelled surface of 10 macaroni or of 50–60 spaghetti strands aligned in a specific box. The results were expressed in the CIE LAB space as L^* (lightness; 0 = black, 100 = white), a^* ($+a$ = redness, $-a$ = greenness) and b^* ($+b$ = yellowness, $-b$ = blueness) values.

The geometrical features of dry pasta were determined by Image Analysis (IA) on ten random macaroni or spaghetti. The samples were placed on a flatbed scanner (Epson Perfection 3170 Photo, Seiko Epson Corp., Japan) and covered with a black box to amplify the contrast between objects and background. The images were captured at 600 dpi resolution, saved in TIFF format and processed with a dedicated software (Image Pro-Plus v. 4.5.1.29, Media Cybernetics Inc, Rockville, MD, USA). The following parameters were computed: density red (R), density green (G), density blue (B) and density mean for colour evaluation; heterogeneity (HTG), *i.e.* pixels fraction that vary more than 10% from the average intensity, for the evaluation of surface texture. Furthermore, average diameter (mm), crown area (mm^2), hole area (mm^2) and hole ratio (crown/(hole+crown)) were determined on the macaroni transversal section, while average diameter (mm) was measured on the spaghetti transversal section section (Riva et al., 2006).

The fracture properties of dried spaghetti were evaluated by the Three-Point Bending Test, carried out at room temperature. For this purpose, a TA.HDplus Texture Analyser (Stable Micro Systems, Godalming, UK), controlled by the specific software Texture Exponent TEE32 version 3.0.4.0. (Stable Micro Systems, Godalming, UK), was employed. The sample – one spaghetti strand, 10 cm long – was set on the appropriate device (HDP/3PB – Three Point Bend), having a 64 mm span length, and broken by a blade moving at 10 mm/s; a 10 N load-cell was used (Mariotti et al., 2011). Measurements were replicated at least 8 times. The following parameters were considered: breaking force (N), fracturability (mm, distance covered by the blade before the sample rupture) and stress (σ, N/mm). The following equation (Bruns and Bourne, 1975) was used: $\sigma = \sigma = (F * L) / (\pi * r^3)$ where: F, breaking force (N); L, span length (61 mm); r, radius of the sample (mm). Energy (J), i.e the work required to break the sample, was calculated as the area under the force-distance curve (Mariotti et al., 2011).

Lutein and furosine were determined in double on dry pasta, as previously outlined for flour.

2.5. Cooked pasta quality

To assess cooked pasta quality, macaroni or spaghetti (50 g) were cooked in 0.5 L boiling spring water (Levissima®, Sanpellegrino S.p.A, Italy) without salt addition. The optimum cooking time (OCT; min) for each sample was determined following Method 16-50 (AACC, 1995). The pasta was considered cooked when the observed white, opaque core had disappeared after pressing it between two glass plates; to better assess the correct moment of white core disappearance, the test was supported by Image Analysis (Riva et al., 2006).

Afterwards, the different samples were cooked at their OCT (10 min), and overcooked (13 and 16 min), strained and evaluated for weight increase (%); dimensions increase (%) and colour (carried out by Image Analysis, as already described); cooking loss, determined by evaporating the cooking water to dryness overnight at 100 °C in an air oven (Method 16-50; AACC, 1995). The results are reported as g solids/kg of dry pasta. All cooking tests were performed twice.

To evaluate the textural characteristics of cooked pasta, the creep test and the compression-extrusion test (Kramer test) were performed on spaghetti and macaroni samples, respectively, adopting a double-column dinamometer Texture Analyser TA.HD plus (Stable Micro Systems, Godalming, UK) connected to a registration system Texture Exponent 32, version 4.0.8.0 (Stable Micro Systems, Godalming, UK).

The creep test was performed on spaghetti cooked for 10 and 13 min; in a creep test, samples are subjected to a sudden and constant stress, and the corresponding strain is measured as a function of time. The samples were compressed for 120 s (longer periods determined samples dehydration), at a constant 50 N load, and strain variations were recorded over time (Lucisano et al., 2012). For each cooking time, five repetitions were performed. The rheological property of interest was the ratio of strain (γ) to stress (σ) as a function of time, referred to as the creep compliance, J(t) (1/Pa) (Steffe, 1996). After building the strain *vs.* time curve, the parameter compliance ($J_{(t)}=\gamma/\sigma$) was calculated as a function of time. Considering only the linear end-tract of the curve (80-120 s), a regression line was computed, from which the viscosity parameters at the Newtonian plateau (μ_0; Pa*s), computed as the inverse of the angular coefficient t(1/μ), and the instantaneous compliance ($J_{0;}$ 1/Pa), i.e. the intercept on the ordinate of the tangent to the final part of the curve that describes the elastic component during the viscous flux, were calculated. From $J_{(t)}$ and μ_0, the function $J_{(C)}=J_{(t)}-(t/\mu_0)$ was computed, thus obtaining a curve that describes the viscoelastic behaviour of the samples as a function of time (Steffe, 1996).

For the Kramer test, pasta (20 g) was cooked for 10, 13 and 16 min, then compressed and extruded through the grid at 0.67 mm/s with a load-cell of 2.5 kN. For each cooking time, five repetitions were performed. From the resulting curves, the following parameters were determined: maximum force to compress the sample (N), compression energy (N*mm), and total energy (area of the curve related to compression-shear-extrusion, N*mm)

Lutein and furosine were determined in double on cooked pasta as previously outlined for the flour.

2.6. Statistical analysis

Multifactor analyses of variance (ANOVA), considering different samples and cooking times as factors, followed by Fisher's least significant difference (LSD) test at $p \leq 0.05$, were performed using the software StatGraphics Plus 5.1 (StatPoint Technologies, Inc., Warrenton, VA, USA). Means and standard errors were computed with Office Excel 2003 (Microsoft, Redmond, WA, USA).

3. Results and discussion

3.1. Flour characteristics

The ANOVA (*not shown*) evidenced significant differences among samples for all traits. The einkorn flours (Supplementary Table 1) presented significantly higher protein and lutein content (17.6-19.7 g/kg and 6.0-10.0 mg/kg DM, respectively) than DWS and BWF, as previously reported (Hidalgo and Brandolini, 2014). The lowest (0.55±0.013 g/kg DM) and highest (0.84±0.07 g/kg DM) ash levels were found in BWF and DWS, respectively, while in einkorn ranged between 0.66 and 0.77 g/kg.

3.2. Dry pasta characteristics

3.2.1. Macaroni

The ANOVA (*not presented*) highlighted significant differences among samples as well as among production plants. Macaroni made from different einkorn accessions had moistures ranging from 9.7% to 10.9%. In general, all the accessions had similar values, with the exception of Monlis that exhibited the highest ones (10.5±0.08 and 10.9%±0.11 for MAC30 and Zambra samples, respectively). The macaroni from the Zambra plant had a significantly higher moisture content (10.8% *vs.* 10.1%; $p \leq 0.05$) than those from the MAC30 plant, because of the higher optimal humidity of the Zambra doughs (32.5% *vs.* 30.0%). Therefore the drying step, identical for all the samples, did not lead to similar moisture levels.

Among the MAC30-made samples, weight, diameter and crown area (Table 1) were smallest for ID1395 and Monlis macaroni, while BWF and DWS products showed the smallest and the biggest central hole area, respectively. The smaller geometrical features of the Zambra macaroni were only a consequence of the extruder die used.

The control macaroni (DWS and BWF) had the highest *L** values, while ID1395 gave the darkest pasta (Table 1); Zambra-made macaroni presented lower *L** than the corresponding MAC30 pasta. The *a** index was highest for einkorn macaroni, while the *b** index was very variable: einkorn SAL98-32 pasta had the highest *b** values, followed by DWS and the other einkorn samples, while BWF pasta, from flour with minimal lutein content, showed the lowest *b** value. Nevertheless, *b** was higher for the Zambra samples, indicating better stability of lutein when the pasta is manufactured under vacuum, as already reported Hidalgo et al. (2010). Einkorn flour has a higher lutein content than other wheats (Hidalgo and Brandolini, 2014), but apparently this did not lead to a deeper yellow colour, which is regulated also by other factors, such as refining degree and flour size (Hidalgo et al., 2014), as well as extent of the Maillard reactions which take place during pasta drying. In addition, when water and oxygen are available, the carotenoids are degraded by enzymes: this could explain why pasta manufactured under vacuum (i.e. without oxygen) in the Zambra plant had higher *b** values than those of similar products from the MAC30 plant, where kneading was carried out under atmospheric pressure.

Image Analysis (Table 1) showed that einkorn pasta presented, compared to the control samples, lower B (blue) and, often, G (green) intensity indices, while R (red) was more variable; overall, the mean density of einkorn pastas was also inferior. The control BWF macaroni had the highest heterogeneity, which is associated to the surface structure of the product and gives information on its roughness (Sun, 2004): thus, high HTG values denote a coarse surface. The vacuum pasta-making process led to significantly lower

HTG values than the atmospheric pressure process, indicating that vacuum has an effect on pasta compactness, which is reflected at the surface level.

3.2.2. Spaghetti

The ANOVA *(not shown)*, evidenced significant differences among samples for most traits. The spaghetti, produced under vacuum with the Zambra plant, had moistures of 10.3% DM for DWS and 10.7% DM for Monlis. Significant differences ($p \leq 0.05$) for the parameters $L*$ and $a*$ (but not for $b*$) were observed: the einkorn spaghetti were less bright (50.9±1.79) and with a higher red index (8.5±0.16) than the DWS ones (63.4±0.92 and 4.09±0.27, respectively). The Image Analysis confirmed these results, as the einkorn samples presented significantly lower values ($p \leq 0.05$) than the DWS samples for all the indices. The Image Analysis, performed on the spaghetti sections, highlighted that the DWS sample had an average diameter of 1.70±0.07 mm, while the Monlis one had a value of 1.64±0.07 mm, significantly thinner ($p \leq 0.05$) than the control. Similarly, their HTG was 0.21±0.10 and 0.17±0.10, respectively, indicating again that einkorn flour led to smoother spaghetti.

A fracture test was carried out to evaluate the mechanical characteristics of the pasta samples. In order to remove size influence on breakage resistance, the "strength" parameters were normalized with respect to the diameter of the sample (Bruns and Bourne, 1975). The Monlis spaghetti broke down under a significantly lower force than the DWS samples (0.54±0.07 *vs.* 1.12±0.06 N; $p \leq 0.05$), and had lower fracturability (2.51±0.22 *vs.* 4.42±0.28 mm), strain (0.007±0.001 *vs.* 0.012±0.001) and stress (17.82±2.31 *vs.* 32.37±1.63 N/mm^2) values, indicating an inflexible and weak structure.

3.3. Cooking behaviour

3.3.1. Macaroni

The ANOVA (*not shown*) highlighted significant differences among samples, and among cooking times; the interactions, always significant, were anyway of minor importance.

The doughs had different viscous properties, that influenced the output speed and thus the dimensions of the macaroni. The longest pastas were obtained from DWS (about 4 cm), while all the other samples showed variable length, with einkorn ID1395 and Monlis being the shortest (2.3 and 2.7 cm, respectively). Therefore, cooking tests were performed on 20 randomly-chosen macaroni per test, and for statistical analyses the results were scaled to a common macaroni average weight. All the samples recorded a sharp weight increase (from 94% to 116%) after 10 min of cooking (Fig. 1A), indicating intense water uptake in the early stages of cooking. The phenomenon continued with additional cooking time, showing fairly similar trends between samples. The ID1395 macaroni exhibited the highest weight increases, with the maximum (156%) at 16 min, indicating a progressive deterioration of the structure, probably because of the weak bonding strength of the storage proteins. The extent of water absorbed was not influenced by the pasta-making plant employed (Supplementary Fig. 1). Monlis pasta had a behaviour similar to the DWS control pasta at 10 min, but afterward it absorbed more water; on the other hand, the two pastas from ID331 and SAL98-32 showed results similar to the DWS control (Fig. 1A).

Interestingly, the einkorn samples (in particular SAL98-32) displayed lower cooking losses (Fig. 1B) than both control pastas, probably because of their high protein content, that led to the formation of a well-structured and compact protein network, able to better contain the swelling and breaking starch granules. The production technology had some influence on cooking losses, as the macaroni from the Zambra plant showed lower values than those manufactured with the MAC30 plant, probably due to the formation of a more compact structure.

The dimensional changes of macaroni during cooking were monitored by Image Analysis. All the parameters showed significant increases over time (Fig. 1C-E), due to water absorption and progressive relaxation of the structure. The ID1395 sample displayed not only the highest weight gain during cooking, as previously mentioned, but also the largest raise in diameter and crown area at all cooking times (47.5% and 206.3% after 16 min, respectively). The ID331 macaroni, on the contrary, generally exhibited the minimum change of the initial values (33.0% and 105.8% after 16 min, respectively). The BWF pasta presented the highest hole area increase (up to 79.1%); the limited variation of its crown area, however, indicates stretching of the structure rather than increase in thickness. The einkorn samples showed rather variable hole increases, but always similar or inferior to the two controls (DWS and BWF).

The density mean parameter indicated that the cooked pastas (Fig. 1F) were brighter than the dry products (Table 1), as the changes taking place during cooking (mainly involving starch gelatinization) led to a less compact, more plastic and clearer structure. In general, the longer the cooking time, the brightest the pastas: cooking, in fact, determines a distension of pasta structure as a consequence of water penetration, leading to a smoother surface. However, the texture of the product may be also influenced by the material released during cooking and still adhering to it. The BWF and Monlis macaroni, characterised by high HTG values of the dry products (Table 1), exhibited (Fig. 1G) significant reductions, but only after 16 min cooking; the other pastas did not show significant changes although a minimal increase was spotted for the ID1395 and

SAL 98-32, suggesting that their surface became, to a small extent, more heterogeneous after cooking.

The macaroni from the Zambra plant had low HTG values when dry (Table 1), indicating a smooth surface structure; after cooking, however, their HTG increased rapidly, before reaching a plateau (Supplementary Fig.1). The Monlis sample presented a higher increase than DWS: its lower release of material in the cooking water may hint that probably the leaked material remained adherent to the surface of the product, making it rougher.

The texture characteristics of cooked pasta (Table 2), evaluated by the compression-extrusion tests, showed that the macaroni from the DWS control and the two einkorn accessions ID331 and SAL 98-32 presented the highest peak load and compression energy at all cooking times, while the ID1395 sample offered the least resistance to compression, highlighting a change in structural properties already during the early cooking stages. A decrease of the values of both parameters during cooking was also evident, as a result of water absorption and starch gelatinisation.

The cutting-extrusion tests indicated that Blasco had the highest consistency after 10 min cooking, while after 16 min Blasco, DWS and Monlis pastas had the best values. Only Monlis and DWS pastas maintained largely stable cutting-extrusion energies throughout all the cooking times, suggesting that these macaroni had the best texture at longer cooking times.

3.3.2.Spaghetti

Both DWS and Monlis spaghetti more than doubled their initial weight after 10 min cooking (Supplementary Fig. 2A). Over longer cooking times, water absorption continued, but the spaghetti from Monlis always showed a lower absorption capacity than the DWS ones, because their higher protein content allowed the formation of a more compact matrix, better resistant to water penetration.

Area and diameter of the spaghetti section showed similar evolutions for both samples during cooking (Supplementary Fig. 2). A substantial increase was present within the first 10 min, demonstrating major structural changes in the early stages, but afterwards no significant variations were scored for the control sample (DWS), while a further increase was observed for the Monlis spaghetti after 16 min cooking. Overall, however, after overcooking diameter and area of the two samples were comparable.

Colour (density) and texture (heterogeneity) of the surface increased from dry to cooked product, reaching similar values after 10 min (Supplementary Fig. 2). Einkorn pasta showed a significant, although minimal, reduction of mean density after further cooking. The heterogeneity of spaghetti surface further increased after 10 min (more in the Monlis than in the control spaghetti) because the greater distension of the structure made it smoother.

The texture characteristics were assessed by a creep test at optimal (10 min) and excessive (13 min) cooking time. The constant stress, applied for 120 s, caused a deformation of the samples following a viscoelastic behaviour (Fig. 2A and 2B). The curves showed a sudden and pronounced deformation of the spaghetti within the first 20-30 s, indicating the prevalence of the elastic component, while more limited deformations appeared in the subsequent period, suggesting the prevalence of the viscous component. Moreover, the structure of the Monlis sample endured greater deformation than the control after 10 min cooking. After 13 min the Monlis sample did not exhibit further variations, probably because most of the changes took place within the first 10 min cooking; on the contrary, DWS-Z deformations went on even after 13 min, reaching Monlis levels after 120 s.

Further elaboration of the creep curves allowed to obtain the viscosity of Newtonian plateau (μ_0), a parameter that describes the behaviour of the materials in the final linear portion of the J(t) curve. The μ_0 value was higher for Monlis spaghetti than for DWS spaghetti at both cooking times (125 *vs.* 95 Pa·s at 10 min; 143 *vs.* 39 Pa·s at 13 min, respectively), indicating major structural changes in the viscoelastic characteristics. Subtracting from the creep curve (strain-time curve) the viscous component, *via* the function $J_{(C)}=J_{(t)}-(t/\mu_0)$, the curves that describe the viscoelastic behaviour of the samples were obtained (Fig. 2C and 2D). The curves of the products cooked for 13 min were shifted towards higher Jc values with respect to the corresponding 10 min curves, probably for an increased hydration of the product. Moreover, for Monlis the two cooking times did not lead to great differences, unlike the control, indicating that its viscoelastic properties did not undergo large changes with overcooking, probably because its structure did not suffer major modifications after 10 min.

3.4. Lutein

The ANOVA for lutein content (*not shown*), carried out individually on each sample, showed highly significant differences ($p \leq 0.001$) only between flour and dried pasta of Monlis, while the scarce lutein found in BWF did not exhibit significant variations during pasta making and cooking. The lutein in Monlis flour (7.0±0.15 mg/kg DM *vs.* 0.3±0.01 mg/kg DM for BWF), as a result of the pasta making process, was reduced by about 44%, a value comparable to that reported by Hidalgo et al. (2010), who observed that kneading degraded the carotenoids, while drying did not cause significant modifications. Greater degradation (77%) was observed among 13 accessions of emmer examined from flour to dough (Fares et al., 2008). The difference is mainly attributable to the manufacturing conditions (temperature and time of kneading/extrusion and drying) and to the genotypes tested, which present different lipoxygenase activity. Additionally, lower carotenoid losses operating under vacuum are reported, because limited oxygen exposure reduces enzymatic activity and ensures better stability of the antioxidants (Hidalgo et al., 2010).

The level of lutein remained virtually unchanged during the cooking of pasta, irrespective of the time, as also observed in durum wheat pasta (Fares et al., 2008).

3.5. Heat damage

Heat damage was analyzed in two samples of macaroni obtained with the MAC30 lab pasta maker (Monlis and BWF). The furosine level in the flour was low (7.5±0.1 and 9.8±0.4 mg/100 g protein, respectively), but in dry pasta reached a higher value in BWF than in Monlis (160.8±3.8 *vs.* 131.2±6.0 mg/100 g protein, respectively). The presence of furosine in dried pasta is well known (García-Baños et al., 2004) and the levels encountered in this study were within the range of values reported (*i.e.* 107.3 to 553.3 mg/100 g protein, Giannetti et al., 2013; 44 to 462 mg/100 g protein, García-Baños et al., 2004). The variation in furosine content is related to the drying conditions, and the values increase under drastic treatments (Anese et al., 1999; Acquistucci, 2000). Furosine content in cooked pasta was not significantly different from uncooked pasta, confirming that cooking in boiling water does not lead to the formation of furosine (Pagani et al., 1996), because water absorption slows down the Maillard reaction (suboptimal A_w) and induces loss of components (starch and free reducing sugars).

Neither manufacturing nor cooking led to the formation of HMF and GLI, indicating that kneading and low-temperature drying did not favour the advanced stages of the Maillard reaction. No presence or traces of HMF are found in commercial pasta (Degen et al., 2012; Resmini et al., 1993), and GLI is present only in high-temperature dried pasta (Resmini et al., 1993).

4.1 Conclusions

Pastas from einkorn flours were significantly different from the controls in terms of lower amount of solid losses into cooking water at all cooking times, a characteristic probably linked to a better organization of the gluten-starch matrix. Compression-extrusion tests detected, at equal cooking times, significant differences between the various samples of pasta, but ID331 and SAL98-32 showed firmness values similar to those of durum wheat pasta. A significant decrease of lutein was recorded during pasta manufacturing; however, cooking did not cause any further loss. In addition, lutein was still present in good quantities in einkorn pastas even after storage or cooking. Moreover, during cooking no further significant change in the content of furosine or other indices of thermal damage was recorded. All these results indicate that the production of einkorn pasta with high technological and nutritional quality is a feasible process.

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Figures captions

Figure 1. Changes during cooking in weight, cooking loss, dimensions, density and heterogeneity, in macaroni produced with a MAC30 lab pasta maker. The bars represent the standard errors. For each trait, different letters indicate significant differences ($p \leq 0.05$) among samples at the same cooking time, following the LSD test.

Figure 2. Creep curves for the spaghetti samples produced with a Zambra (Z) industrial pasta maker, at two different cooking times (10 and 13 min): A-B, strain (%) *vs.* time (s) curves; C-D, creep compliance curves (J_c, Pa^{-1}).

Supplementary Figure 1. Changes during cooking in weight, dimension, density and heterogeneity in macaroni produced with a MAC30 lab pasta maker and a Zambra (Z) industrial pasta maker. The bars represent the standard errors.

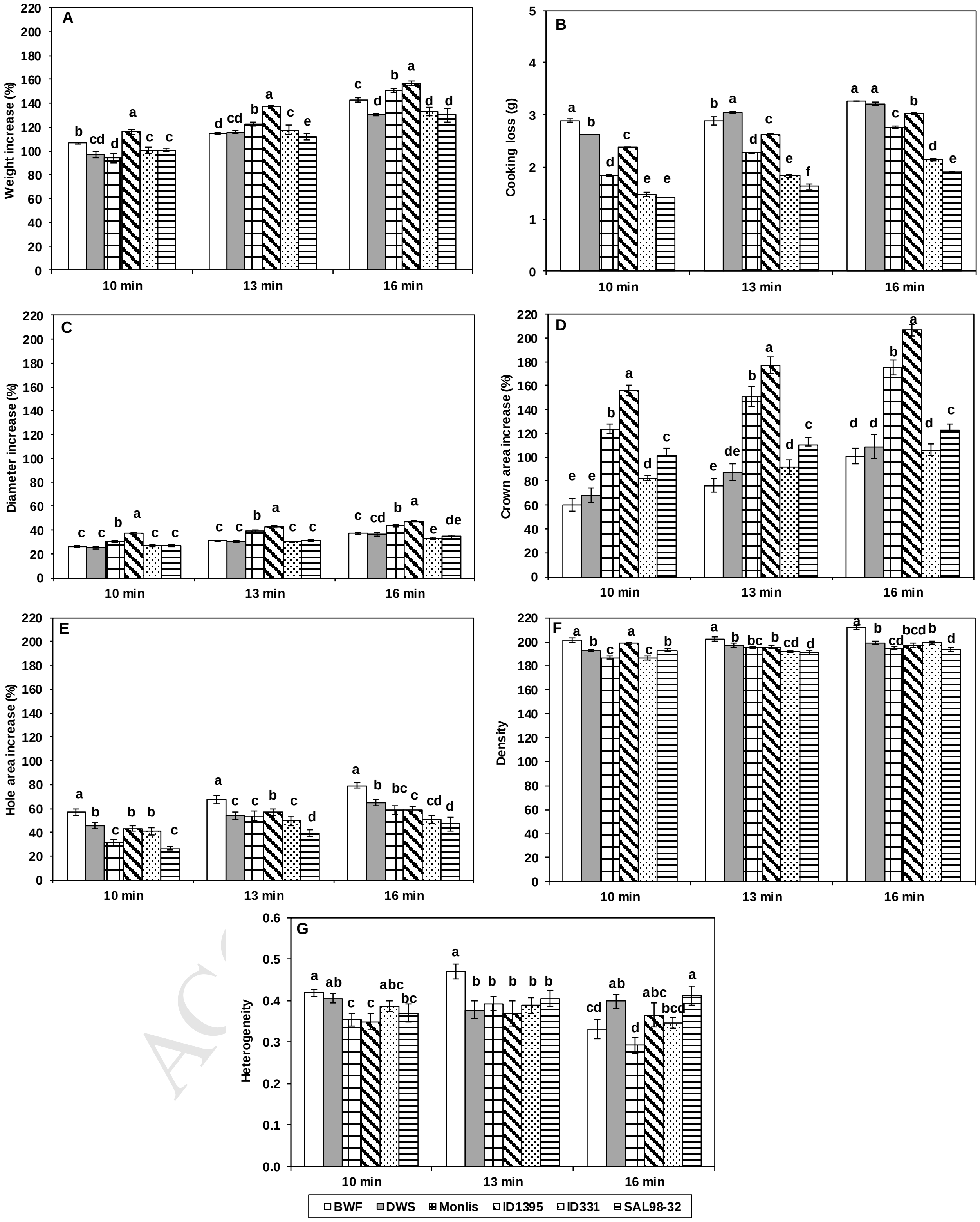
Supplementary Figure 2. Changes during cooking in weight, dimension, density and heterogeneity in spaghetti produced with a Zambra (Z) industrial pasta maker. The bars represent the standard errors.

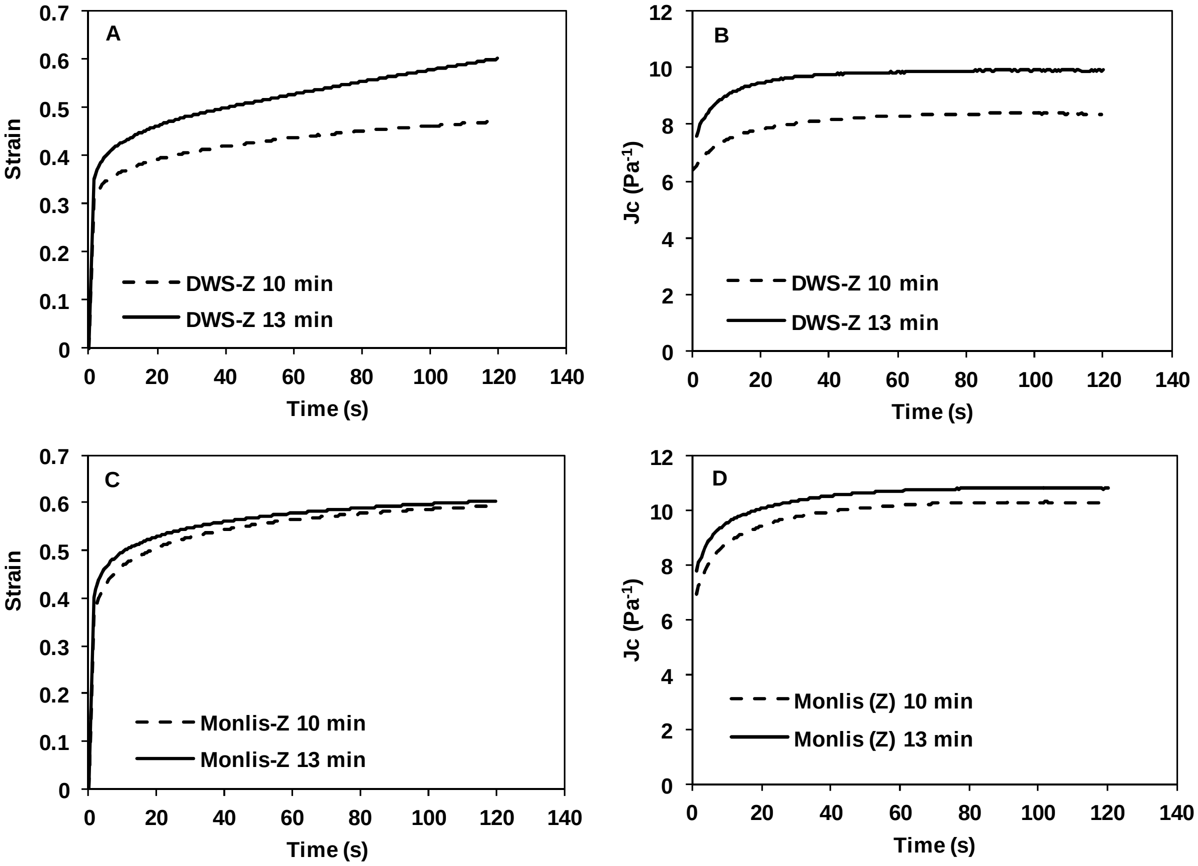
Table 1. Mean dimensions, colour parameters (L*, a*, b*), density and heterogeneity of macaroni prepared from flour of bread wheat cv. Blasco (BWF), einkorn cv. Monlis, einkorn lines ID1395, ID331 and SAL98-32, and durum wheat semolina (DWS). For each trait, different letters in the row indicate significant differences ($p \leq 0.05$) among samples from the same production plant, following the LSD test. Small letters: macaroni from MAC30 lab machine; capital letters: macaroni from Zambra (Z) industrial machine.

	BWF	DWS	Monlis	ID1395	ID331	SAL98-32	DWS-Z	Monlis-Z
Weight (g)	27.9^{d}	36.3^{a}	22.0^{e}	18.6^{f}	29.7^{c}	30.2^{b}	26.5^{A}	22.2^{B}
Diameter (mm)	10.0^{ab}	10.0^{ab}	9.4^{c}	9.2^{d}	9.9^{b}	10.0^{ab}	7.8^{A}	7.8^{A}
Crown area (mm^2)	40.1^{a}	40.8^{a}	28.6^{c}	26.7^{d}	37.4^{b}	36.9^{b}	26.0^{A}	24.9^{B}
Hole area (mm^2)	39.2^{c}	39.0^{c}	41.8^{a}	40.9^{b}	40.8^{b}	42.1^{a}	22.0^{B}	23.1^{A}
L*	62.0^{b}	62.9^{a}	51.8^{d}	47.0^{e}	52.3^{cd}	52.5^{c}	56.7^{A}	47.2^{B}
a*	3.4^{d}	3.0^{e}	5.2^{b}	4.7^{c}	5.3^{b}	5.6^{a}	4.7^{B}	6.6^{A}
b*	16.5^{e}	29.8^{b}	23.3^{d}	22.5^{d}	26.8^{c}	31.8^{a}	38.4^{A}	28.6^{B}
R	197.0^{c}	208.6^{a}	202.0^{b}	197.1^{c}	210.8^{a}	206.7^{a}	211.3^{A}	186.9^{B}
G	185.6^{b}	195.6^{a}	179.3^{c}	172.4^{d}	185.2^{b}	179.7^{c}	197.5^{A}	163.0^{B}
B	147.9^{a}	121.0^{b}	110.6^{c}	92.6^{e}	102.8^{d}	86.7^{f}	99.5^{A}	72.2^{B}
Density	176.8^{a}	174.4^{a}	164.0^{b}	154.0^{d}	166.3^{b}	157.7^{c}	145.7^{A}	140.7^{B}
Heterogeneity	0.46^{a}	0.35^{c}	0.39^{b}	0.31^{d}	0.34^{c}	0.32^{cd}	0.19^{A}	0.15^{B}

Table 2. Peak load, compression energy and cutting/extrusion energy (mean) of macaroni prepared from flour of bread wheat cv. Blasco (BWF), durum wheat semolina (DWS), einkorn cv. Monlis, and einkorn lines ID1395, ID331 and SAL98-32 with the MAC 30 lab pasta maker (top) and with the Zambra (Z) industrial pasta maker (bottom). For each trait and cooking time, different letters in the column indicate significant differences among samples from the same production plant at $p \leq 0.05$ following the LSD test. Small letters: macaroni from MAC 30 lab machine; capital letters: macaroni from Zambra (Z) industrial machine.

	Cooking time (min)	Peak force (N)	Compression energy (N^2 mm)	Cutting/extrusion energy (N^2 mm)
BWF	10	237.7^{c}	529.9^{b}	1357.0^{a}
DWS	10	281.5^{ab}	634.3^{a}	1065.2^{cd}
Monlis	10	205.9^{d}	475.3^{c}	1052.3^{d}
ID1395	10	179.7^{e}	402.6^{d}	1132.6^{bc}
ID331	10	292.3^{a}	649.7^{a}	1186.5^{b}
SAL 98-32	10	273.8^{b}	621.8^{a}	1134.3^{bcd}
BWF	13	199.6^{c}	457.2^{b}	1319.4^{a}
DWS	13	239.5^{b}	561.8^{a}	1079.0^{c}
Monlis	13	171.7^{d}	392.0^{c}	1214.6^{b}
ID1395	13	152.1^{e}	345.3^{d}	1134.5^{c}
ID331	13	241.0^{ab}	536.7^{a}	1022.4^{d}
SAL 98-32	13	245.6^{a}	553.5^{a}	1008.0^{d}
BWF	16	175.1^{b}	418.5^{b}	1193.2^{a}
DWS	16	216.5^{a}	519.0^{a}	1116.0^{a}
Monlis	16	155.7^{c}	301.1^{c}	1139.5^{a}
ID1395	16	136.4^{d}	290.9^{c}	911.1^{b}
ID331	16	212.9^{a}	492.6^{a}	968.7^{b}
SAL 98-32	16	210.6^{a}	514.0^{a}	991.1^{b}
DWS-Z	10	286.4	611.9^{A}	1449.7
Monlis-Z	10	241.7	544.3^{B}	1298.2
DWS-Z	13	234.4^{A}	521.9^{A}	1547.9
Monlis-Z	13	174.2^{B}	416.0^{B}	1438.0
DWS-Z	16	203.7^{A}	463.4	1253.4^{B}
Monlis-Z	16	163.4^{B}	406.3	1391.9^{A}


A
Weight increase (%)
0
20
40
60
80
100
120
140
160
180
200
220
b cd d a c c
d cd b a c e
c d b a d d
10 min
13 min
16 min
B
Cooking loss (g)
0
1
2
3
4
5
a b d c e e
b a d c e f
a a c b d e
10 min
13 min
16 min
C
Diameter increase (%)
c c b a c c
c c b a c c
c cd b a e de
10 min
13 min
16 min
D
Crown area increase (%)
e e b a d c
e de b a d c
d d b a d c
10 min
13 min
16 min
E
Hole area increase (%)
a b c b b c
a c c b c d
a b bc c cd d
10 min
13 min
16 min
F
Density
a b c a c b
a b bc b cd d
a b cd bcd b d
10 min
13 min
16 min
G
Heterogeneity
0.0
0.1
0.2
0.3
0.4
0.5
0.6
a ab c c abc bc
a b b b b b
cd ab d abc bcd a
10 min
13 min
16 min
BWF
DWS
Monlis
ID1395
ID331
SAL98-32


A
Strain
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Time (s)
0
20
40
60
80
100
120
140
DWS-Z 10 min
DWS-Z 13 min
B
Jc (Pa^{-1})
0
2
4
6
8
10
12
Time (s)
DWS-Z 10 min
DWS-Z 13 min
C
Strain
Time (s)
Monlis-Z 10 min
Monlis-Z 13 min
D
Jc (Pa^{-1})
Time (s)
Monlis (Z) 10 min
Monlis (Z) 13 min

- Macaroni and spaghetti were prepared from einkorn, durum and bread wheats
- Dry einkorn pasta differed from the controls for most traits analysed
- Einkorn pasta was less firm but had lower cooking losses than durum wheat pasta
- After cooking lutein was more abundant in einkorn than in durum wheat pasta
- Einkorn pasta has better nutritional value than durum wheat pasta