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Influence of steaming treatment on chemical and technological characteristics of einkorn (*Triticum monococcum* L. ssp. *monococcum*) wholemeal flour

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ABSTRACT

Einkorn (*Triticum monococcum* ssp. *monococcum*) is an underutilised wheat with high protein, lutein and tocols content, particularly suited for baby and specialty foods. To study the influence of kernel steaming treatments on chemical and technological properties, seeds of five einkorn accessions and one bread wheat control (cv. Blasco) underwent different steaming conditions, and their wholemeal flours were compared for ash, protein, lutein, tocols and α-amylase content, SDS sedimentation volume and gelatinisation parameters. Furosine, a heat damage marker, was measured as well. The treatments significantly influenced most of the parameters. In particular, lutein, tocols and α-amylase diminished after steaming; SDS sedimentation volumes and most gelatinisation parameters also decreased, whereas gelatinisation temperatures and furosine contents increased. The changes were stronger under more drastic steaming conditions, although treatment × genotype influence was sometimes detected. Steaming induced migration of lutein and tocopherols from the bran and germ fractions to the kernel endosperm.

1. Introduction

Einkorn (*Triticum monococcum* L. subsp. *monococcum*) is a diploid wheat ($2n = 2x = 14$) that for millenia had a relevant role in prehistoric agriculture; since the Bronze age, however, its distribution is restricted to limited areas and marginal soils (Nesbitt & Samuel, 1996). After centuries of near oblivion, the interest in this cereal has been rekindled by the discovery of its peculiar nutritional characteristics that, in an era of health-conscious customers, recommend it as a nutritionally superior wheat. For example, its content in protein and antioxidant compounds lutein, tocopherols and tocotrienols is largely superior to that of both bread and durum wheat (Abdel Aal, Young, Rabalski, Hucl, & Fregeau-Reid, 2007; Abdel-Aal et al., 2002; Hidalgo, Brandolini, Pompei, & Piscozzi, 2006). Furthermore, a reduced toxicity, if any, of einkorn flour for celiac patients is reported (De Vincenzi, Luchetti, Dal Belin Peruffo, Curioni, Pogna, & Gasbarrini, 1996; Mølberg et al., 2005; Vincentini et al., 2007). While most einkorn accessions show poor dough and baking properties (D'Egidio, Nardi, & Vallega, 1993), genotypes with outstanding breadmaking attitude exist (Borghi, Castagna, Corbellini, Heun, & Salamini, 1996; Corbellini et al, 1999); limited information on the gelatinisation properties of its starch is also available (Brandolini, Hidalgo, & Moscaritolo, 2007; Løje, Moller, Lausten, & Hansen, 2003).

Current trends towards low-impact and sustainable agriculture, coupled with an increase in the intake of functional foods, suggest that this cereal may still play a role in human consumption. In France, Germany, Italy and some other countries, specialty shops already sell einkorn grains, flour, bread, pasta, beer, biscuits and other products. A further diversification and diffusion of einkorn-based products, however, will require a comprehensive understanding of the behaviour of nutrients as well as of flour technological parameters during processing.

Steaming treatments are broadly employed in cereals, for example in the parboilisation of rice (Bhattacharya, 2004; Luh & Mickus, 1980) or in the production of bulgur from wheat (Bayram, Oner, & Eren, 2004), barley (Köksel, Edney, & Özkaya, 1999), triticale (Singh & Dodda, 1979), sorghum (Young, Haidara, Rooney, & Waniska, 1990), etc. Reported advantages are: (a) diffusion of vitamins and minerals throughout the grain, altering their concentration among its fractions; (b) inactivation of enzymes; (c) prevention of the proliferation of fungi and insects; (d) gelatinisation of the starch granule, that improves texture and reduces broken grains; and (e) higher milling yields (Luh & Mickus, 1980). Besides the traditional method, that includes water saturation of the kernels, low-moisture parboiling procedures are utilised (Iengar, Gangadharan, & Rajendran, 1974; Unnikrishnan & Bhattacharya, 1987a).

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The aim of this research was to evaluate the influence of steaming treatments on: (i) stability and distribution of lutein and tocols in seed fractions; (ii) inactivation of α-amylase; (iii) heat damage, as measured by furosine content; and (iv) breadmaking and gelatinisation properties of einkorn wholemeal flour.

2. Materials and methods

2.1. Samples

Five einkorn accessions (cv. Monlis, populations ID331, ID1395, and free-threshing breeding lines SAL 98-38 and SAL 98-32) and, as control, the bread wheat cv. Blasco were cropped in 2006–2007 at Rome (Italy) in 10 m^2 plots with three replications, following standard cultural practices (Castagna, Borghi, Di Fonzo, Heun, & Salamini, 1995). Treatments and analyses were performed on mature kernels from the three replications combined.

2.2. Steaming treatments

In the first trial, hulled kernels of Monlis (150 g) were moistened to 15–16% humidity and then heated by steaming in the cylindrical container of a bench autoclave (Smart clave; TKA, Milan, Italy) at four different combinations of time and temperature: 115 ± 2 °C, 1.8 bar, 5 min (T1); 120 ± 1 °C, 2.1 bar, 5 min (T2); 120 ± 1 °C, 2.1 bar, 10 min (T3); 120 ± 1 °C, 2.1 bar, 15 min (T4). The steamed kernels were dried to 11% humidity on trays at room temperature. Monlis, a recently released einkorn variety from Italy, is characterised by high lutein and tocols content as well as outstanding breadmaking attitude (Hidalgo & Brandolini, 2008).

To assess the effect of steaming on different genetic backgrounds, in a second experiment all five einkorn accessions and the bread wheat cultivar Blasco were treated at the time/temperature combinations T1 and T3.

2.3. Sample preparation and analytical methods

Immediately before the analyses, both untreated and steamed seeds were de-hulled in a M3B micro-thresher (Co.Mi.L, Rome, Italy), and ground to wholemeal flours by a Cyclotec 1093 lab mill (FOSS Tecator, Denmark). Dry matter, protein ($N \times 5.7$) and ash contents were determined following methods 44-15, 46-10 and 08-03 (AACC – American Association of Cereal Chemists., 1995), respectively. Lutein content was determined by reverse phase HPLC, as reported in Hidalgo et al. (2006), while tocopherols and tocotrienols quantification was performed by normal phase HPLC, following Panfili, Fratianni, and Irano (2003). Lutein and tocols distribution in the germ, bran and endosperm fractions of Monlis kernels steamed at T3 were determined as described in Hidalgo and Brandolini (2008). Furosine was determined following the method reported by Resmini and Pellegrino (1991). The α-amylase activity was assessed following method 22-02 (AACC, 1995), using the Ceralpha assay kit (Megazyme International Ireland Ltd., Bray, Ireland).

Sedimentation volume (ml) with a solution of 3% sodium dodecyl sulfate (SDS) was performed following the procedure described by Preston, March, and Tipples (1982) with minor modifications. The pasting behaviour of starches during gelatinisation was assessed with a Rapid Visco Analyzer (RVA, Newport Scientific Pty. Ltd., Warriewood, NSW, Australia). Wholemeal flour (4.0 g, based on 14% moisture) was dispersed in an aluminium canister containing 25 ml of distilled water. With constant stirring, the flour–water suspension was held at 50 °C for 1 min, heated to 95 °C over 3 min 45 s, maintained at 95 °C for 2 min 30 s and progressively cooled to 50 °C over 3 min 45 s. The starch viscosity parameters measured were peak viscosity, through, breakdown, final viscosity, setback, peak time and pasting temperature.

All chemical and pasting measurements were performed twice; the results are presented as means of the measurements on a dry matter base (DM).

2.4. Statistical analysis

Analysis of variance (ANOVA) was performed on all the traits considering steaming treatment and genotype as main factors. When significant differences ($p \leqslant 0.05$) were detected, Fisher's least significant difference (LSD) test (at $p \leqslant 0.05$) was applied. ANOVA and LSD were performed using the Statgraphics Plus software (version 4.0, StatPoint Inc., Herndon, VA, USA). Pearson's correlations of the means were calculated using the SYSTAT for Windows (version 5) software.

3. Results and discussion

3.1. Steaming treatments effects

This experiment, focused on determining the most discriminant time/pressure/temperature combination, showed a significant influence of all the steaming conditions on antioxidants concentration (with the exception of β-tocopherol) and technological properties, but not on ash and protein content.

Table 1 reports the chemical and technological data of the steaming treatments. In general, more drastic steaming leads to a progressive loss in antioxidants. Lutein was the least stable antioxidant, recording a loss of up to 25%. Although β-tocopherol, as already mentioned, was stable, the other three tocols detected (α-tocopherol, α-tocotrienol and β-tocotrienol) showed a decrease of 10.8%, 14.1% and 14.7%, respectively, between the control and the T4 treatment. Tocols protect lipids from oxidation, and the antioxidant activities of the different homologues are related to their degradation speed (Hoffmann, 1989) and concentration (Yoshida, Kajimoto, & Emura, 1993). During storage, several authors (e.g. Peterson, 1995; Piironen, Varo, & Koivistoinen, 1988) observed a better stability of β- versus α-tocopherol, as well as a higher loss in tocotrienols with comparison to tocopherols (Håkansson & Jägerstad, 1990; Rossi, Alamprese, & Ratti, 2007; Serbinova, Tsuchiya, Goth, Kagan, & Packer, 1993). In cereals, steaming treatment exerted a negative influence on the content of vitamin E, thiamine and riboflavin of bulgur (Köksel et al., 1999; Singh & Dodda, 1979); similarly, Padua and Juliano (1974) observed increasing thiamine losses in rice parboiled at 100 and at 121 °C. The harm induced by the steaming treatments is confirmed also by the steady increase of furosine, a chemical marker of heat damage, across the different treatments: the T4 treatment shows levels three times higher than the control (29.2 versus 9.2 mg/100 g proteins).

A strong effect of steaming was observed on the content of the enzyme α-amylase, which was inactivated even by the mildest treatment. Under similar treatment conditions, an activity decrease of the enzymes involved in carotenoids degradation (lipoxygenase and peroxidase: Leenhardt et al., 2006; McDonald, 1979) was observed in wheat (Håkansson & Jägerstad, 1990; McDonald, 1979) and in parboiled rice (Barber, Benedito de Barber, & Novo, 1983).

The technological parameters were also influenced by the steaming treatments. The breadmaking attitude (measured by SDS sedimentation test) of the wholemeal flour of Monlis, for example, was completely lost under the most drastic treatment conditions, as evidenced by the fall of the SDS volume from 70.5 (control) to 19.0 ml (T4); however, the treatment T1 induced very limited loss of sedimentation volume. A similar trend was reported

Table 1
Mean values ± standard error of several characteristics measured in whole flour samples of the einkorn cultivar Monlis, untreated and steamed at four different conditions

Characteristic	Steaming treatment					Significance level
	Raw	T1	T2	T3	T4	
Ash (g/100 g DM)	2.4 ± 0.01	2.4 ± 0.01	2.4 ± 0.01	2.4 ± 0.00	2.4 ± 0.01	n.s.
Protein (g/100 g DM)	18.8 ± 0.00	19.1 ± 0.00	18.8 ± 0.00	18.8 ± 0.00	19.0 ± 0.00	n.s.
Lutein (mg/kg DM)	6.1^{a} ± 0.08	5.6^{b} ± 0.05	5.2^{b} ± 0.12	4.8^{bc} ± 0.32	4.6^{c} ± 0.01	*
α-Tocopherol (mg/kg DM)	13.0^{a} ± 0.15	11.5^{bc} ± 0.19	11.7^{b} ± 0.11	11.8^{b} ± 0.06	11.6^{b} ± 0.43	**
α-Tocotrienol (mg/kg DM)	19.8^{a} ± 0.21	18.4^{b} ± 0.00	18.0^{bc} ± 0.09	17.9^{bc} ± 0.05	17.0^{c} ± 0.17	***
β-Tocopherol (mg/kg DM)	4.2 ± 0.07	4.0 ± 0.24	4.0 ± 0.16	4.1 ± 0.44	4.3 ± 0.01	n.s.
β-Tocotrienol (mg/kg DM)	43.0^{a} ± 1.01	41.3^{ab} ± 0.88	39.9^{bc} ± 0.61	37.4^{cd} ± 0.12	36.7^{d} ± 1.66	**
Total tocols (mg/kg DM)	79.9^{a} ± 1.00	75.2^{b} ± 1.31	73.5^{bc} ± 0.43	71.1^{cd} ± 0.19	69.7^{d} ± 2.26	**
Furosine (mg/100 g proteins)	9.2^{d} ± 1.28	10.9^{cd} ± 0.84	12.4^{c} ± 1.11	18.9^{b} ± 0.89	29.2^{a} ± 1.41	***
α-Amylase (CU/g)	0.15^{a} ± 0.007	0.03^{b} ± 0.002	0.03^{b} ± 0.003	0.03^{b} ± 0.002	0.03^{b} ± 0.001	***
SDS sedimentation volume (ml)	70.5^{a} ± 0.71	66.0^{b} ± 1.41	46.5^{c} ± 2.12	20.0^{d} ± 0.00	19.0^{d} ± 0.00	***
Peak viscosity (cP)	2154.0^{a} ± 28.28	1742.0^{b} ± 14.14	1589.0^{c} ± 14.14	1449.0^{c} ± 33.94	1052.5^{d} ± 21.92	***
Trough (cP)	1797.0^{a} ± 42.43	1537.0^{b} ± 28.28	1465.0^{bc} ± 21.21	1367.5^{c} ± 24.75	995.5^{d} ± 43.13	***
Break down (cP)	357.0^{a} ± 14.14	205.0^{b} ± 14.14	124.0^{c} ± 7.07	81.5^{d} ± 9.19	57.0^{d} ± 21.21	***
Final viscosity (cP)	2747.0^{a} ± 22.63	2557.0^{b} ± 24.04	2496.0^{bc} ± 14.14	2425.5^{c} ± 12.02	1966.5^{d} ± 62.93	***
Setback (cP)	950.0 ± 65.05	1020.0 ± 52.33	1031.0 ± 7.07	1058.0 ± 12.73	971.0 ± 19.80	n.s.
Peak time (min)	6.60^{b} ± 0.04	6.40^{c} ± 0.03	6.31^{d} ± 0.02	6.27^{d} ± 0.00	6.90^{a} ± 0.14	**
Pasting temperature (°C)	64.5^{d} ± 0.28	72.7^{c} ± 0.28	76.6^{b} ± 0.28	82.6^{a} ± 0.60	82.7^{a} ± 0.67	***

T1 = 115 ± 2 °C, 1.8 bar, 5 min; T2 = 120 ± 1 °C, 2.1 bar, 5 min; T3 = 120 ± 1 °C, 2.1 bar, 10 min; T4 = 120 °C, 2.1 bar, 15 min; n.s.: non significant; $^{*}p \leqslant 0.05$; $^{**}p \leqslant 0.01$; $^{***}p \leqslant 0.001$; different letters after the mean values indicate significant differences at $p \leqslant 0.05$ following LSD test.

by Prakash, Haridas Rao, Susheelamma, and Prabhakar (1998) in wheat steamed for increasing times at constant temperature.

Steaming also influenced gelatinisation parameters: peak, through and final viscosity significantly decreased, while breakdown (the difference between peak and through viscosity) was reduced; setback (the difference between final and through viscosity), on the other hand, did not change significantly. Peak time showed differences between treatments, but no clear trends, while peak temperature clearly indicated a progressive increase passing from control to T4. In rice similar observations, linking a decrease of gelatinisation parameters to the drasticity of parboilisation treatments, were reported by several authors (e.g. Biswas & Juliano, 1988; Priestley, 1976). The gelatinisation temperature significantly increased from 65 to 83 °C, as also evidenced in rice by Biswas and Juliano (1988), Lai (2001), Priestley (1976) and Raghavendra Rao and Juliano (1970). In the present research the decreased peak viscosity might be related to the formation of starch–lipid inclusion complexes: the amylose helix can link fatty acid chains into complexes which are insoluble and stable at relatively high temperatures, as suggested by Priestley (1976). Their formation restricts swelling and solubilisation of starch, leading also to a shifting of the gelatinization temperature (Thomas & Atwell, 1997). In the present research a limited starch gelatinization, because of the relatively short steaming times (5, 10 and 15 min) coupled to low seed humidity, can be hypothesized (Unnikrishnan & Bhattacharya, 1987a).

3.2. Genotypes and steaming treatments

The results of the preliminary test suggested the adoption of treatments T1 and T3 for further analyses, carried out on five einkorn accessions as well as on bread wheat Blasco as control. T1 was chosen because it hardly modified chemical composition and technological characteristics of the flours, while T3 because it strongly influenced all the main characteristics. The analysis of variance (not presented) showed that differences exist between einkorn and bread wheat, as well as among einkorn accessions, for all traits; steaming treatments and the treatment × genotype interaction (this last especially for the technological traits) significantly influenced most of the parameters.

Table 2 depicts the mean values of the wholemeal flours chemical characteristics. Ash, protein and β-tocopherol contents were not influenced by the steaming treatment or by the treatment × genotype interaction, and are therefore reported only as means of the three treatments; on the other hand, both α-tocols showed a significant interaction effect and are thus presented in detail. As a general rule, the results on the five einkorns and the control were similar to those observed from Monlis alone; however, accession-specific behaviours were often observed. For example, α-tocopherol and α-tocotrienol decreased after steaming treatments, but the decrease was mainly limited to samples with high concentrations (ID1395, SAL98-32 and Monlis). The most abundant tocol, β-tocotrienol, decreased with steaming, but the loss ratio between the control and T3 varied from 1.3% (ID1395) to 13.0% (Monlis); a similar behaviour was observed for total tocols, whose loss was however very limited (average: 6.6%). Lutein was again the antioxidant most degraded by the steaming treatment, with an average decrease of 23.9% (range: 13.2–36.6%). Furosine increase was mostly limited to the effect of the steaming treatments, with little genotype contribution. The α-amylase activity collapsed already with T1, and T3 did not further reduce it.

The technological parameters of the wholemeal flours are presented in Table 3. For all these traits (excluding peak time) a strong effect of the treatment × genotype was always present, indicating a somewhat different response of the various accessions to the treatments. In some cases, the behaviour was related to the initial properties of the flour. The SDS volume of most samples was poor, and only Monlis and ID331 had volumes of 70 ml or more: the steaming-related decrease in sedimentation volume was therefore maximum for these two einkorns and almost non-existent for ID1395 and SAL98-38 (interestingly, and unexpectedly, the SDS volume of these last two einkorn almost doubled after the mild T1 treatment).

The influence of the treatment × genotype interaction was particularly evident on the gelatinisation parameters: although treatment and genotype were still the most important factors, each accession reacted in its specific way to the different treatments. This is readily appreciable in Fig. 1, which shows the gelatinisation profiles of the wholemeal flours (untreated, T1 and T3) of the six different accessions. Monlis demonstrates a clear and direct influence of the treatments: the harsher the treatment, the lower the gelatinisation viscosities. ID331, SAL98-32, and SAL98-38 still present a strong treatment influence on the gelatinisation, but the difference between T1 and T3 disappears during the late stages of the RVA run. ID1395 and Blasco show a third profile, where the most drastic treatment (T3) yields flours with the lowest peak

Table 2
Mean values ± standard error of chemical characteristics measured in whole flour samples of five einkorn and one bread wheat accessions, untreated and steamed at two different conditions

Characteristic		ID331 (n = 2)	ID1395 (n = 2)	SAL 98-38 (n = 2)	SAL 98-32 (n = 2)	Monlis (n = 2)	Blasco (n = 2)
Ash (g/100 g DM)		2.4 ± 0.01	2.2 ± 0.00	2.6 ± 0.03	2.4 ± 0.00	2.4 ± 0.00	1.7 ± 0.00
Protein (g/100 g DM)		21.2 ± 0.00	19.1 ± 0.00	19.6 ± 0.00	20.5 ± 0.00	18.8 ± 0.16	12.8 ± 0.02
Lutein (mg/kg DM)	Raw	4.1 ± 0.06	5.7 ± 0.03	6.0 ± 0.03	5.0 ± 0.02	6.1 ± 0.03	0.9 ± 0.01
	T1	3.4 ± 0.22	5.3 ± 0.24	5.0 ± 0.15	4.5 ± 0.01	5.5 ± 0.16	0.8 ± 0.02
	T3	2.6 ± 0.28	4.3 ± 0.10	4.4 ± 0.00	4.3 ± 0.03	4.8 ± 0.23	0.7 ± 0.01
α-Tocopherol (mg/kg DM)	Raw	7.6 ± 0.01	12.5 ± 0.04	10.8 ± 0.09	13.3 ± 0.03	13.0 ± 0.10	11.9 ± 0.16
	T1	7.3 ± 0.10	11.8 ± 0.15	11.2 ± 0.16	13.1 ± 0.02	11.5 ± 0.14	12.1 ± 0.16
	T3	7.5 ± 0.11	11.4 ± 0.18	11.0 ± 0.05	13.2 ± 0.02	11.8 ± 0.04	11.8 ± 0.22
α-Tocotrienol (mg/kg DM)	Raw	10.2 ± 0.09	12.6 ± 0.07	10.0 ± 0.00	18.5 ± 0.15	19.8 ± 0.15	3.7 ± 0.12
	T1	10.3 ± 0.14	13.7 ± 0.04	10.8 ± 0.10	18.0 ± 0.18	18.4 ± 0.00	3.6 ± 0.15
	T3	10.4 ± 0.04	13.2 ± 0.10	10.3 ± 0.15	17.8 ± 0.05	17.9 ± 0.04	3.7 ± 0.00
β-Tocopherol (mg/kg DM)		2.4 ± 0.02	4.5 ± 0.12	4.2 ± 0.22	3.0 ± 0.10	4.1 ± 0.04	6.5 ± 0.08
β-Tocotrienol (mg/kg DM)	Raw	44.9 ± 0.21	36.8 ± 0.18	38.6 ± 0.23	45.7 ± 0.20	43.0 ± 0.71	25.7 ± 0.97
	T1	42.2 ± 0.85	36.7 ± 0.10	36.5 ± 0.00	44.0 ± 0.11	41.3 ± 0.62	23.6 ± 0.47
	T3	40.7 ± 0.33	36.3 ± 0.28	37.1 ± 0.11	41.9 ± 0.04	37.4 ± 0.09	23.2 ± 0.32
Total tocols (mg/kg DM)	Raw	65.2 ± 0.44	66.7 ± 0.11	63.7 ± 0.10	80.3 ± 0.17	80.0 ± 0.71	47.8 ± 1.15
	T1	62.1 ± 1.40	66.6 ± 0.15	63.1 ± 0.00	78.3 ± 0.30	75.2 ± 0.93	45.9 ± 0.17
	T3	61.0 ± 0.21	65.2 ± 0.13	62.1 ± 0.12	76.0 ± 0.02	71.1 ± 0.15	45.0 ± 0.64
Furosine (mg/100 g proteins)	Raw	4.4 ± 0.93	6.6 ± 0.78	11.4 ± 0.37	8.1 ± 0.76	9.2 ± 0.91	9.8 ± 0.80
	T1	9.6 ± 0.08	10.5 ± 0.63	18.0 ± 0.89	13.4 ± 2.52	12.4 ± 0.79	9.9 ± 0.11
	T3	16.2 ± 0.01	20.2 ± 1.93	25.1 ± 1.09	18.2 ± 0.86	18.9 ± 0.64	27.0 ± 0.71
α-Amylase (CU/g)	Raw	0.14 ± 0.010	0.19 ± 0.007	0.21 ± 0.004	0.18 ± 0.015	0.15 ± 0.007	0.14 ± 0.007
	T1	0.03 ± 0.002	0.03 ± 0.001	0.05 ± 0.001	0.03 ± 0.001	0.03 ± 0.002	0.04 ± 0.000
	T3	0.03 ± 0.001	0.03 ± 0.002	0.04 ± 0.001	0.04 ± 0.004	0.03 ± 0.002	0.04 ± 0.007

T1 = 115 ± 2 °C, 1.8 bar, 5 min; T3 = 120 ± 1 °C, 2.1 bar, 10 min.

Table 3
Mean values ± standard error of technological characteristics measured in whole flour samples of five einkorn and one bread wheat accessions, untreated and steamed at two different conditions

Characteristic		ID331 (n = 2)	ID1395 (n = 2)	SAL 98-38 (n = 2)	SAL 98-32 (n = 2)	Monlis (n = 2)	Blasco (n = 2)
SDS (ml)	Raw	70 ± 1.5	20 ± 0.0	20 ± 0.5	50 ± 1.5	71 ± 0.5	53 ± 2.0
	T1	66 ± 0.5	36 ± 2.0	39 ± 0.0	51 ± 1.0	56 ± 0.0	49 ± 1.0
	T3	28 ± 0.5	26 ± 0.0	26 ± 0.5	26 ± 1.0	20 ± 0.0	22 ± 2.0
Peak viscosity (cP)	Raw	2323 ± 10.0	2105 ± 9.0	1906 ± 8.0	2315 ± 16.0	2154 ± 20.0	2099 ± 14.0
	T1	2096 ± 30.0	1929 ± 6.0	1871 ± 9.5	2067 ± 21.0	1646 ± 3.5	2076 ± 7.0
	T3	1901 ± 12.0	1822 ± 11.0	1476 ± 7.0	1847 ± 5.0	1449 ± 24.0	1724 ± 20.0
Trough (cP)	Raw	1866 ± 12.0	1709 ± 4.0	1234 ± 1.0	1760 ± 0.0	1797 ± 30.0	1338 ± 28.0
	T1	1607 ± 6.0	1632 ± 10.0	1415 ± 18.0	1564 ± 9.0	1501 ± 6.0	1498 ± 3.0
	T3	1495 ± 4.0	1615 ± 13.0	1365 ± 14.0	1449 ± 11.0	1368 ± 17.5	1636 ± 29.0
Break down (cP)	Raw	457 ± 2.0	396 ± 13.0	672 ± 9.0	555 ± 16.0	357 ± 10.0	761 ± 14.0
	T1	489 ± 24.0	297 ± 4.0	456 ± 8.5	503 ± 12.0	145 ± 2.5	578 ± 4.0
	T3	406 ± 8.0	207 ± 2.0	111 ± 7.0	398 ± 16.0	82 ± 6.5	88 ± 9.0
Final viscosity (cP)	Raw	2745 ± 4.0	2814 ± 2.0	2230 ± 11.0	2679 ± 9.0	2747 ± 16.0	2550 ± 11.0
	T1	2591 ± 10.0	2702 ± 2.0	2467 ± 9.0	2503 ± 3.0	2527 ± 30.5	2995 ± 4.0
	T3	2560 ± 6.0	2999 ± 6.0	2569 ± 3.0	2466 ± 9.0	2426 ± 8.5	3226 ± 12.0
Setback (cP)	Raw	879 ± 8.0	1105 ± 6.0	996 ± 10.0	919 ± 9.0	950 ± 46.0	1212 ± 17.0
	T1	984 ± 4.0	1070 ± 8.0	1052 ± 9.0	939 ± 12.0	1026 ± 36.5	1497 ± 1.0
	T3	1065 ± 10.0	1384 ± 19.0	1204 ± 17.0	1017 ± 2.0	1058 ± 9.0	1590 ± 17.0
Peak time (min)	Raw	6.67 ± 0.025	6.40 ± 0.020	6.20 ± 0.015	6.53 ± 0.010	6.60 ± 0.030	5.87 ± 0.070
	T1	6.40 ± 0.005	6.60 ± 0.020	6.13 ± 0.010	6.39 ± 0.020	6.38 ± 0.025	5.60 ± 0.030
	T3	6.13 ± 0.000	6.27 ± 0.025	6.13 ± 0.000	6.27 ± 0.020	6.27 ± 0.000	5.80 ± 0.030
Pasting temperature (°C)	Raw	63.9 ± 0.20	62.8 ± 0.00	63.0 ± 0.15	65.5 ± 0.00	64.5 ± 0.20	61.2 ± 0.10
	T1	66.8 ± 0.10	65.4 ± 0.00	83.2 ± 0.15	67.2 ± 0.10	74.7 ± 0.95	62.0 ± 0.20
	T3	81.6 ± 0.20	82.2 ± 0.00	82.2 ± 0.20	81.7 ± 0.05	82.6 ± 0.40	66.2 ± 0.10

T1 = 115 ± 2 °C, 1.8 bar, 5 min; T3 = 120 ± 1 °C, 2.1 bar, 10 min.

viscosity but the highest final viscosity. Finally, while peak temperature is only genotype-dependent, the pasting temperatures vary according to the treatment, the genotype and, in small measure, the interaction T × G (e.g. Blasco). A similar genotype-specific behaviour has been reported by several authors (Biswas & Juliano, 1988; Raghavendra Rao & Juliano, 1970; Unnikrishnan & Bhattacharya, 1987b) during parboiling of different rice varieties.

3.3. Lutein and tocols distribution in steamed kernels

The lutein and tocols concentration in the whole flour and in the three different fractions obtained from the steamed seeds of Monlis are reported in Table 4. The germ was rich in lutein and contained almost all the α- and β-tocopherol fractions, while α- and β-tocotrienols, most abundant in the bran, were nonetheless well represented in the three fractions.

To evaluate the effect of steaming treatment on tocols and lutein distribution in different kernel fractions of cv. Monlis, the data were compared with those reported by Hidalgo and Brandolini (2008) for an untreated sample of the same cultivar (but representative also of other accessions; see Hidalgo & Brandolini, 2008). The results are presented as percent endosperm, bran and germ contribution to the total kernel composition (Fig. 2).

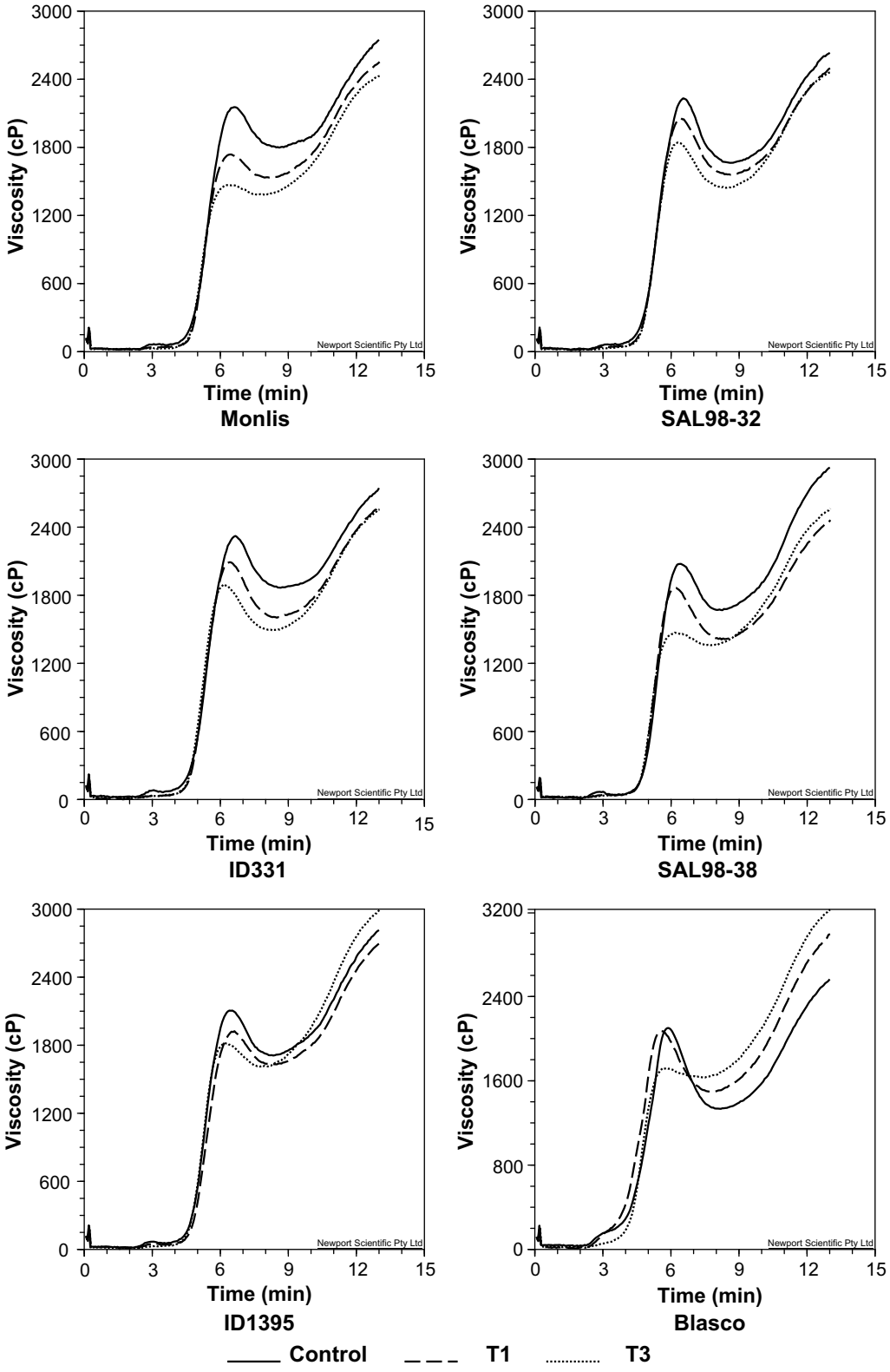

Fig. 1. Gelatinisation profiles of the whole meal flours of five einkorn and one bread wheat accessions: seeds untreated and steamed at two different conditions (T1=115 ± 2 °C, 5 min; T3=120 ± 1°C, 10 min).

Both in the untreated and in the T3-steamed wholemeal flours, the tocopherols were almost all in the germ fraction; no significant variation in distribution was observed between the two treatments. The tocotrienols, instead, were scarce in the germ, while abundant in the flour and (particularly) in the bran. However, the steaming treatment showed a strong influence on their distribution, favouring their migration from the bran into the flour: in the endosperm, the α-tocotrienol content almost doubled, while the β-tocotrienol content increased ca. 50%. This change in distribution was mirrored in the total tocols, as tocotrienols are their

Table 4
Mean values ± standard error of lutein, α-tocopherol, α-tocotrienol, β-tocopherol, β-tocotrienol, and total tocols (mg/kg DM) in whole flour, endosperm, bran and germ fractions of steamed seeds of the einkorn Monlis

	Lutein	α-Tocopherol	α-Tocotrienol	β-Tocopherol	β-Tocotrienol	Total tocols
Whole flour	5.5 ± 0.06	11.8 ± 0.14	17.6 ± 0.28	4.1 ± 0.18	37.8 ± 0.55	71.3 ± 1.16
Endosperm	5.9 ± 0.03	0.9 ± 0.03	9.6 ± 0.27	0.3 ± 0.00	27.6 ± 0.12	38.7 ± 0.37
Bran	2.2 ± 0.15	1.80 ± 0.50	45.6 ± 1.57	0.3 ± 0.00	73.7 ± 1.78	121.4 ± 3.91
Germ	17.7 ± 1.58	366.7 ± 1.29	17.4 ± 8.84	127.2 ± 5.86	35.0 ± 2.26	546.3 ± 0.58

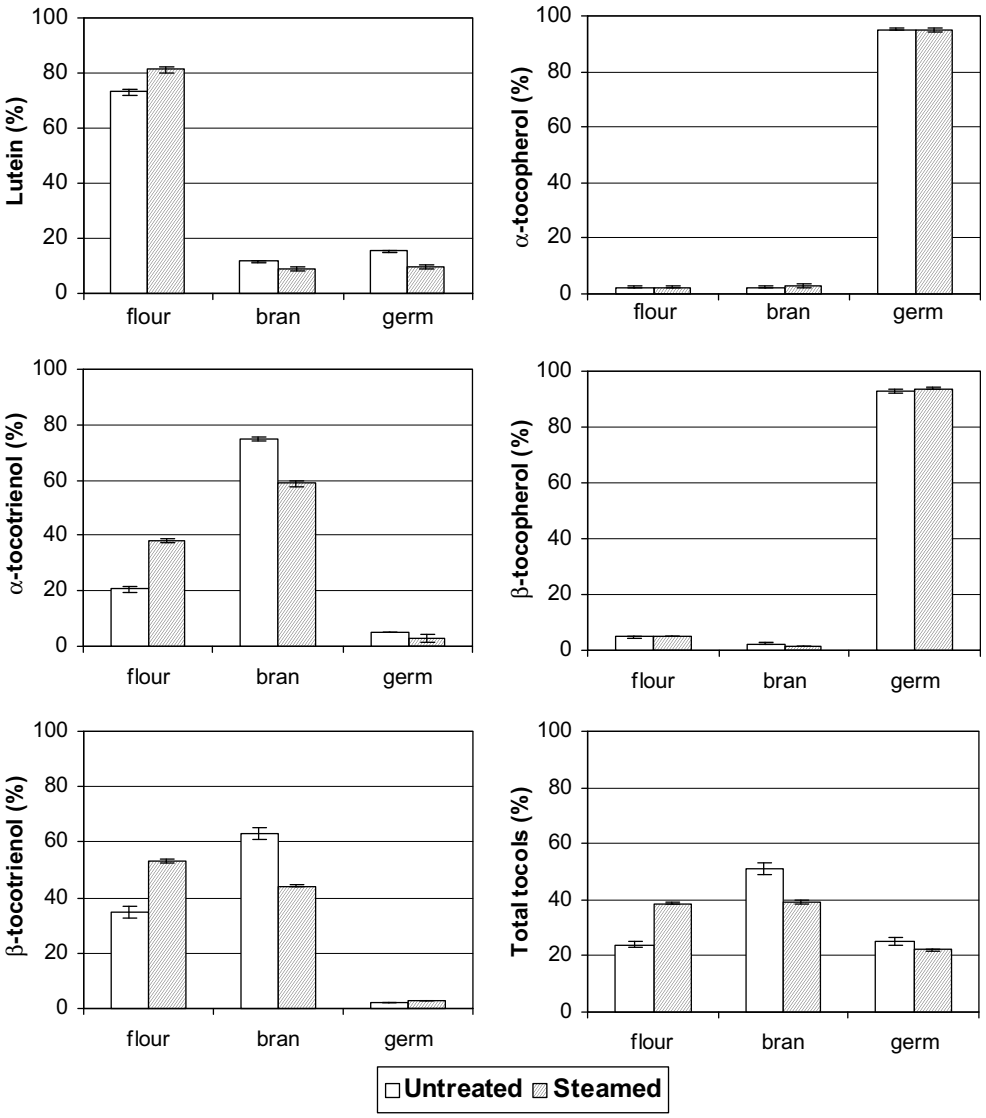

Fig. 2. Endosperm, bran and germ contribution (%) to the total kernel composition of lutein, α-tocopherol, α-tocotrienol, β-tocopherol, β-tocotrienol and total tocols of untreated (Hidalgo & Brandolini, 2008) and steamed seeds of einkorn cv. Monlis. Error bars indicate the standard error of the mean ($n = 2$).

most abundant component. A similar trend was observed for lutein content: after the steaming treatment, this xanthophyll increased in the flour, while diminishing in the germ and bran fractions.

Steaming as a method to improve the composition of flours or kernels has been studied and acknowledged by several authors (Bhattacharya & Ali, 1985; Padua & Juliano, 1974; Subba Rao & Bhattacharya, 1966) and is particularly useful in rice (the parbolisation process). Thiamine and other hydrosoluble B vitamins, for example, are much more in milled parboiled rice than in milled raw rice. The analogous behaviour observed for lutein and tocols, which are liposoluble antioxidants, might be linked to changes in fat distribution, due to the loss of lipids globular structure during steaming reported in rice by Bhattacharya and Ali (1985).

4. Conclusions

All the steaming treatments showed a sharp influence on most chemical and technological characteristics of the wholemeal flours, while only the mild T1 did not compromise the breadmaking attitude of Monlis and ID331. Although the presence of significant treatment × genotype interaction highlighted the relevance of genotype-specific behaviour on some traits, such as gelatinisation

parameters, steaming the hulled kernels reduced antioxidants and α-amylase contents, SDS sedimentation values and RVA values, while provoking moderate (but significant) heat damage to the whole meal flours. However, the steaming treatment favoured the migration of lutein and tocols from bran and germ to endosperm, confirming its usefulness in improving the nutritional value of refined flours.

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