Improving the Quality of Whole Wheat Bread by Using Various Plant Origin Materials

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Abstract

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The effects of various plant origin materials such as defatted *Cephalaria syriaca* flour (0.5%), rosehip (2.5%), vital gluten (2.5%), and malt flour (2%), and their combination on the quality of whole wheat bread were investigated. The plant origin materials used showed significant effects on the specific volume, acidity, colour, and textural properties of whole wheat bread. In general the acidity, specific volume, cohesiveness, and springiness values of whole wheat bread produced by treatments with plant origin materials were higher than those of the control bread. Treatment 13 (2% malt flour + 0.5% defatted *Cephalaria syriaca* flour + 2.5% vital gluten) resulted in the highest specific volume and the lowest 1st day crumb firmness. The results showed that the quality of whole wheat bread could be improved by adding various plant origin materials.

Keywords: bread; textural properties; cephalaria; vital gluten; malt flour

Most consumers prefer products of refined white flour to whole grain products, because they perceive the textural properties of whole grain products as less attractive. Bran characteristics of whole wheat flour have a great negative effect on the quality of whole wheat bread (Noort *et al*. 2010). To meet consumers' health requirements, breads with added nutritional compounds are now expanding (Poinot *et al*. 2009). However, the daily consumption of whole grain and high fibre products is desired to be significantly higher for the health reasons (Shenoy & Prakash 2002; Lasekan *et al*. 2011; Sullivan 2011). The consumption of whole grain products can be stimulated by improving their perceived attractiveness. Hence, the inclusion of some materials such as malt flour, rosehip, cephalaria, and vital gluten in the dough formulation can be considered to improve the quality of whole wheat bread.

How the addition of malt flour (MF) influences the rheological characteristics depends on its diastatic power and flour quality. The addition of MF increases the gas production in the dough, improves crust colour formation and flavour profile of the product. Malt α-amylase is necessary for optimal yeast growth and gas production (Hrušková *et al.* 2003). Vital gluten (G) is used to increase the protein content, water absorption of flour and dough tolerance, and to improve the final quality of the product in the bread production (Jood *et al.* 2001; Day *et al.* 2009; Ghorbel *et al*. 2010). The vitality of gluten is generally assessed by its ability of increasing the volume and improving the crumb structure of bread baked from standard flour fortified with gluten (Esteller *et al.* 2005). G is the insoluble protein portion of wheat flour that has been separated, washed and dried. Rosehip (*Rosa canina* – R) is a plant well known for its highest vitamin C content (300–4000 mg/100 g) among fruits and vegetables. Turkey has suitable growing conditions for cultivating high quality rosehip. Rosehips are used for medicinal purposes and some special traditional products (Ercisli 2007) and it can be used instead of synthetic ascorbic acid in order to improve rheological properties of the dough. Growing *Cephalaria syriaca* is generally encouraged in wheat fields in Turkey. The growth form of cephalaria is different from that of wheat. However, the fruit of cephalaria is similar to a wheat grain in terms of its size and shape. *Cephalaria syriaca* has been conventionally used as an additive which increasing the strength of the weak flour dough used in breadmaking by farmers living in some parts of Turkey. *Cephalaria syriaca* has a great positive effect on the extensograph characteristics of wheat flour (Karaoğlu 2006) and the quality of wheat bran bread (Karaoğlu 2011).

The aim of the present research is to determine the potential use of various materials (MF, R, cephalaria, and G) for increasing the final quality of whole wheat bread. The effects of these materials, used alone or in combination, on whole wheat bread were studied.

MATERIAL AND METHODS

Organic whole wheat flour. In order to produce whole wheat bread, we used two kinds of organic wheat (cvs Bezostaya and Kırik) purchased from organic wheat producers in Erzurum, Turkey. Cultivar Bezostaya is a hard red winter (HRW) wheat and has 12.5% protein content; cv. Kırik is a hard white spring (HWS) wheat and has 11.9% protein content. Organic wheats (cvs Bezostaya and Kırik) were mixed in the ratio of 1:1 (w/w) and were milled in a stone mill to produce organic whole wheat flour (WF).

Defatted Cephalaria syriaca flour. *Cephalaria syriaca* seeds were obtained from a seed merchant in Erzurum, Turkey. Grains were milled in a laboratory model vertical grinder (Brabender Type LST7170; Brabender® GmbH & Co. KG, Duisburg, Germany) with a sieve aperture of 1-mm diameter to produce whole cephalaria flour. Whole cephalaria flour was freeze dried using a freeze dryer (Hetosicc, CD 2.5; Heto Co., Allerod, Denmark) and extracted in a Soxhlet extractor with petroleum ether (60–80°C for 12 h) to produce defatted *Cephalaria syriaca* flour (DCSF). *Cephalaria syriaca* oil was extracted from *Cephalaria syriaca* groats in order to decrease the probability of the oxidative reactions in the final product. Chemical composition values of the defatted *Cephalaria syriaca* (on dry matter basis) were 6.21% moisture, 8.14% ash, 1.19% fat, and 14.29% protein.

Malt flour. MF was produced according to Odumodu (2008) with some modifications for this study. Organic wheat (Bezostaya/Kırik, 1:1, w/w) was soaked with tap water in the ratio of 1:4 (v/w). The grains were spread on moist trays in a basket covered with moist cloth and allowed to germinate for 72 h at 30 ± 3°C. The grains were watered in 12 h intervals. The germinated grains were dried at 50°C for 48 h and were subsequently milled in a laboratory model vertical grinder (Brabender Type LST7170) with a sieve aperture of 300 µm mesh screen to produce MF. MF was placed in a jar and stored in a deep freeze (–18°C) for the subsequent use. The effect of the malted wheat flour (with diastatic power 220 s) was evaluated by the addition of 2% per the whole wheat flour weight.

Vital gluten. Vital gluten was extracted from organic wheat flour. Organic wheat flour and water (2:1 w/v) were mixed for 2 min in a Stephan universal mixer (UM 5; Stephan, Erlangen, Germany). After resting for 20 min, the dough was washed gently in running tap water until the waste water appeared to be clear. The wet gluten obtained was cut into small pieces, spread on aluminum trays, and cooled down to –18°C in a deep freeze for 24 hours. Small gluten pieces were freeze dried in a freeze dryer and they were milled in a laboratory model vertical grinder (Brabender Type LST7170) to produce vital gluten. The vital gluten produced was stored in a deep freeze (–18°C) until subsequent use.

Rosehip. Rosehips were obtained from near fields in Erzurum, Turkey. After rosehip pips were taken away, rosehips were cooled down to –18°C in a deep freeze for 48 h and were then freeze dried. Then the dried rosehips were milled in a laboratory model vertical grinder (Brabender Type LST7170). The ascorbic acid content was 850 mg/100 g of milled rosehip. The amount of ascorbic acid in the rosehip was determined according to the methods of AOAC (1984).

The levels and combinations of different materials used in this investigation are given in Table 1.

Baking procedure. The whole wheat bread formula consisted of wheat flour (500 g), sourdough (30%), salt (1.5%, flour basis), and water (up to optimum absorption). DCSF (0.5%), malt flour (2.0%), rosehip (2.5%), and vital gluten (2.5%) were added to the whole wheat flour used in the whole wheat bread production. Sourdough used in the production of whole wheat bread was obtained from a commercial bakery in Erzurum, Turkey.

Table 1. List of treatment combinations

Treatment	Combinations in base of flour (%)
T0	100 WF
T1	97.5 WF + 2.5 G
T2	97.5 WF + 2.5 R
T3	99.5 WF + 0.5 DCSF
T4	98 WF + 2 MF
T5	95 WF + 2.5 R + 2.5 G
T6	97 WF + 0.5 DCSF + 2.5 G
T7	97 WF + 0.5 DCSF + 2.5 R
T8	95.5 WF + 2 MF + 2.5 G
T9	95.5 WF + 2 MF + 2.5 R
T10	97.5 WF + 2 MF + 0.5 DCSF
T11	94.5 WF + 0.5 DCSF + 2.5 R + 2.5 G
T12	93 WF + 2 MF + 2.5 R + 2.5 G
T13	95 WF + 2 MF + 0.5 DCSF + 2.5 G
T14	95 WF + 2 MF + 0.5 DCSF + 2.5 R
T15	92.5 WF + 2 MF + 0.5 DCSF + 2.5 R +2.5 G

WF – organic wheat flour; G – vital gluten; R – rosehip; DCSF – defatted Cephalaria flour; MF – malt flour

Sourdough was divided for all treatments and was stored in a deep freeze (–18°C) until subsequent use. All ingredients were put into a mixer (Stephan Um-5; Stephan, Erlangen, Germany) and mixed for 3 min at low speed (1500 rpm). The produced dough was left to rest for 15 min, divided (160 g), and kneaded. Then following a 30 min rest, the dough was degassed and aerated, and then left for resting for further 30 minutes. The pieces of dough were panned and proofed at 30°C and 70% RH for optimal dough development (190 min). The loaves were baked at 230°C for 25 minutes. The produced breads were wrapped up using polyethylene bags and stored at room temperature (20 ± 1°C) for 5 days.

Chemical and physical analyses. pH measurements of the whole wheat breads were taken according to Elgün *et al.* (2002) with some modifications. Breads (10 g) were suspended in 100 ml of distilled water and the suspension was homogenised using an Ultra-Turrax TP 18/10 (Janke & Kunkel, IKA Werk, Staufen, Germany) at 2000 rpm for minute. Then pH values were measured using a pH meter (INOLAB pH 720; WTW, Weilheim, Germany). The total titratable acidity (TTA) was determined according to Özkaya and Kahveci (1990). The breads were weighed within 1 h following the baking; bread volumes were measured using rape grains and specific volumes were calculated (Lee *et al.* 1982). Colour intensity of the bread crust was determined with the Minolta Colorimeter CR-200 (Minolta Camera Co., Osaka, Japan) (Elgün *et al.* 2002). All measurements were repeated three times.

Measurements of texture profile. The texture analysis of whole wheat bread crumb was performed according to method descibed by Carr and Tadini (2003) using the texture profile analyser (TPA) (SMS model TA-XT plus; Stable Micro System, Ltd., Godalming, UK) with a 35 mm probe. The application conditions of the TPA method were as follows: pre-test speed 2 mm/s, test speed 5 mm/s, post-test speed 5 mm/s, distance 20 mm, trigger type auto-20 g, and time 5 seconds. The calculation of the texture parameters was described as: firmness – the peak force during the first bite, (N); cohesiveness – area 2/area 1, (dimensionless); springiness – the ratio between the recovered height after the first compression and the original sample height; chewiness – firmness cohesiveness springiness (mJ).

Sensory evaluation of whole wheat bread. The finished whole wheat breads were allowed to cool for 1 h at room temperature and then were evaluated using a nine-point hedonic scale as recommended by Land and Shepherd (1984), where 9 = like extremely, 5 = neither like nor dislike, and 1 = dislike extremely. Before the sensory testing, the loaves were sliced into 1.4-cm thick slices. The end slices were discarded, 4 × 4 cm squared pieces were taken from each slice and immediately placed into plastic boxes. A three-digit code number was assigned to each box. The sensory evaluation was performed by 30 untrained panelists (15 males and 15 females) who were either graduate students or staff members of the Department of Food Engineering, Atatürk University (Turkey). The panelists were chosen using the following criteria: ages between 20 and 55, non-smokers, without reported cases of food allergies, whole wheat bread consumers. The panelists had some experience in sensory evaluation. The tests were performed in an isolated room with good illumination and natural ventilation. The panel members were asked to evaluate each loaf for grain, colour, and texture of the crumb, aroma, and general acceptability. They were also instructed to rinse their mouth with water after each whole wheat bread sample evaluation.

Statistical analysis. All the experiments were carried out in triplicate and in two different trials. Statistical evaluations were performed using the SPSS package (a completely randomised design procedure by SPSS) (SPSS for Windows Version 10.01; SPSS, Chicago, USA). The differences between the data were tested using the Duncan's range test ($P < 0.05$).

RESULTS AND DISCUSSION

Whole wheat flour containing bran gives whole wheat bread a very low specific volume (Seyer & Gélinas 2009). The specific volume significantly increased with the addition of the plant origin materials. Generally, lightness *L* values in whole wheat bread decreased with the addition of DCSF, R, and MF. That is, breads containing DCSF, R, and MF were darker than the control group (Table 2). This darkness could be due to the dark colour of the plant origin materials added. +*a* and +*b* colour values increased with DCSF, R, and G addition in whole wheat bread. The increase in +*b* value had no significant influence in whole wheat breads containing MF and DCSF. While the TTA values of whole wheat breads increased with the addition of MF, R, and G, they decreased with the addition of DCSF.

The results of the texture profile analysis (TPA) of whole wheat breads stored for 24 h at room temperature are shown in Table 3. The materials used in this study produced a significant effect on TPA parameters of whole wheat bread. The firmness of the breads decreased with the addition of MF, DCSF, R, and G, and the values obtained were smaller than those of their respective controls. The decrease in bread firmness was more pronounced with DCSF addition. The firmness is an important factor in bakery products since it is strongly correlated with consumers' perception of bread freshness (Onyango *et al.* 2010). The results also showed that springiness of whole wheat bread increased with the addition of DCSF and G, and it decreased with the addition of R. In general, high cohesiveness is desirable in bread because bread can form a bolus, rather than disintegrate, during mastication (Onyango *et al.* 2010). While the addition of MF and R significantly decreased the chewiness values of bread, the latter significantly increased with the addition of DCSF and G.

In general, no significant differences were observed with the sensory attributes between crumb grain, crumb colour, texture, and aroma of whole wheat bread (Table 3). However, the materials added to the whole wheat bread samples were shown to have positive effects on all of the sensory attributes. At least, the materials used in this study did not have a negative effect on the product quality and consumers' acceptance of whole wheat bread.

The lightness *L* values of bread with the added materials were lower than that of control bread (Table 4). The addition of rosehip and DCSF decreased crumb *L* colour value more than did vital gluten and malt flour. Therefore, crumb *L* colour value was lower in all treatments including rosehip and DCFS. However, the increase in darkness of bread crumb did not make a negative effect on consumers' acceptability (Table 5). This darkness

Table 2. The general effects of malt, *Cephalaria syriaca*, rosehip, and vital gluten on the specific volume, total titratable acidity (TTA), and crumb colour values of whole wheat bread (mean ± SE)

		Specific volume (cm^3/g)	TTA	Crumb colour		
				L	+*a*	+*b*
Malts flour (%)	0	2.55 ± 0.06^b	10.89 ± 0.07^a	53.75 ± 0.60^a	6.21 ± 0.41^a	21.32 ± 1.10^a
	2	2.65 ± 0.05^a	10.93 ± 0.06^a	53.33 ± 0.62^a	6.44 ± 0.36^a	22.29 ± 1.12^a
	P	**	ns	ns	ns	ns
DCSF (%)	0	2.42 ± 0.04^b	10.97 ± 0.05^a	54.53 ± 0.57^a	5.76 ± 0.30^b	21.38 ± 0.67^a
	0.5	2.76 ± 0.04^a	10.85 ± 0.08^b	52.54 ± 0.55^b	6.88 ± 0.41^a	22.23 ± 1.42^a
	P	**	**	**	**	ns
Rosehip (%)	0	2.55 ± 0.07^b	10.70 ± 0.06^b	55.54 ± 0.40^a	5.35 ± 0.33^b	19.76 ± 1.19^b
	2.5	2.63 ± 0.05^a	11.10 ± 0.04^a	51.53 ± 0.26^b	7.29 ± 0.24^a	23.84 ± 0.72^a
	P	**	**	**	**	**
Vital gluten (%)	0	2.49 ± 0.06^b	10.79 ± 0.06^b	53.26 ± 0.60^b	6.07 ± 0.29^b	20.58 ± 0.73^b
	2.5	2.69 ± 0.04^a	11.02 ± 0.07^a	53.81 ± 0.62^a	6.57 ± 0.45^a	23.01 ± 1.33^a
	P	**	**	*	*	**

TTA is reported as ml NaOH (0.1 N)/10 g bread; means with different letters in the same column are statistically significant; *$P < 0.05$; **$P < 0.01$; ns – not significant; $n = 16$

Table 3. The general effects of malt, *Cephalaria syriaca*, rosehip, and vital gluten on texture analysis values and sensory traits of whole wheat bread (mean ± SE)

		Firmness (N)	Cohesiveness	Springiness	Chewiness (mJ)
Texture analysis					
Malts flour (%)	0	18.49 ± 0.97^{b}	0.38 ± 0.01^{a}	0.62 ± 0.01^{a}	4.26 ± 0.14^{a}
	2	17.35 ± 0.89^{a}	0.37 ± 0.01^{b}	0.61 ± 0.01^{a}	3.94 ± 0.13^{b}
	P	**	*	ns	**
DCSF (%)	0	19.99 ± 0.95^{a}	0.35 ± 0.01^{a}	0.58 ± 0.01^{b}	3.96 ± 0.12^{b}
	0.5	15.84 ± 0.56^{b}	0.41 ± 0.01^{a}	0.66 ± 0.01^{a}	4.23 ± 0.14^{a}
	P	**	**	**	**
Rosehip (%)	0	18.83 ± 1.16^{a}	0.37 ± 0.01^{b}	0.62 ± 0.01^{a}	4.25 ± 0.14^{a}
	2.5	17.00 ± 0.57^{b}	0.38 ± 0.01^{a}	0.61 ± 0.01^{b}	3.95 ± 0.12^{b}
	P	**	**	**	**
Vital gluten (%)	0	19.58 ± 1.10^{a}	0.34 ± 0.01^{b}	0.59 ± 0.01^{b}	3.97 ± 0.13^{b}
	2.5	16.25 ± 0.45^{b}	0.40 ± 0.01^{a}	0.64 ± 0.01^{a}	4.23 ± 0.14^{a}
	P	**	**	**	**
Sensory traits					
Malts flour (%)	0	6.85 ± 0.21^{a}	6.67 ± 0.17^{a}	6.79 ± 0.14^{a}	6.64 ± 0.21a
	2	6.97 ± 0.22^{a}	6.81 ± 0.17^{a}	6.96 ± 0.15^{a}	6.93 ± 0.19^{a}
	P	ns	ns	ns	ns
DCSF (%)	0	6.52 ± 0.24^{b}	6.66 ± 0.21^{a}	6.68 ± 0.15^{a}	6.35 ± 0.20^{b}
	0.5	7.31 ± 0.24^{a}	6.81 ± 0.11^{a}	7.06 ± 0.13^{a}	7.23 ± 0.12^{a}
	P	**	ns	ns	**
Rosehip (%)	0	6.60 ± 0.23^{b}	6.52 ± 0.16^{b}	6.91 ± 0.16^{a}	6.52 ± 0.22^{b}
	2.5	7.22 ± 0.17^{a}	6.95 ± 0.15^{a}	6.83 ± 0.13^{a}	6.95 ± 0.15^{a}
	P	*	*	ns	*
Vital gluten (%)	0	6.83 ± 0.24^{a}	6.56 ± 0.19^{a}	6.75 ± 0.17^{a}	6.52 ± 0.22^{a}
	2.5	7.00 ± 0.19^{a}	6.92 ± 0.13^{a}	7.00 ± 0.10^{a}	7.06 ± 0.15^{a}
	P	ns	ns	ns	*

Means with different letters in the same column are statistically significant; *P < 0.05; **P < 0.01; ns – not significant; n = 16

resulting from the addition of rosehip could be due to the dark red colour of rosehip. Also, it was reported that the addition of DCSF to wheat flour significantly decreased the *L* colour value of flour (Karaoğlu 2006) and bran bread (Karaoğlu 2011). The lowest *L* value was obtained in T15 treatment containing all of the materials. +*a* and +*b* colour values of whole wheat bread with the added materials changed significantly from 4.48 to 9.01 and from 16.62 to 31.74, respectively.

In general, +*a* and +*b* colour values of whole wheat bread with the added materials were higher than those of the control group. The highest +*a* colour value was obtained in T11 (0.5% DCSF + 2.5% R + 2.5% G), while the highest +*b* colour value was obtained in T13 (2% MF + 0.5% DCSF + 2.5% G).

The results of all sensory attributes evaluated are shown in Table 6. No significant differences were observed between the sensory attributes to crumb colour, crumb grain, texture, aroma, and general acceptability. Crumb colour scores increased with the addition of the materials and the scores changed from 6.00 (T0) to 7.50 (T3, T10) in the treatments. The sensory evaluation scores of the treatments with the added materials were higher than those of the control (T0). While the highest crumb grain scores were determined in T14 and T15, it was the closest to the control in T4. The aroma scores were the lowest in T0, T4 and T14. The highest scores of general acceptability were obtained in T11, T15 and T7, respectively. However, T13 (2% MF + 0.5% DCSF + 2.5% G) had the highest hedonic mean scores in all of the sensory attributes tested.

Bread crumb firmness values with the addition of the materials changed from 12.50 N to 26.43 N after one day of the storage period (Figure 1a). The firmness values of whole wheat breads stored for one day were lower than those of control in all the treatments containing the plant origin materials.

Table 4. Effect of treatments (T) on acidity (TTA) and colour values of whole wheat bread (mean ± SE)

Treatment	TTA	Crumb colour		
		L	+*a*	+*b*
T0	10.55 ± 0.05^{g}	57.10 ± 0.08^{a}	4.73 ± 0.^{01e}	18.92 ± 0.02^{defgh}
T1	11.10 ± 0.10^{bcd}	56.35 ± 0.03^{abc}	4.53 ± 0.17 e	18.74 ± 0.31^{defgh}
T2	11.00 ± 0.00^{cde}	52.04 ± 0.09^{ef}	7.27 ± 0.05^{bc}	24.37 ± 0.10^{bc}
T3	10.60 ± 0.00^{g}	54.38 ± 0.53^{d}	5.22 ± 0.19^{de}	17.14 ± 0.12^{gh}
T4	10.80 ± 0.00^{f}	56.64 ± 0.29^{abc}	4.79 ± 0.30^{e}	19.10 ± 1.54^{defgh}
T5	11.25 ± 0.05^{ab}	52.76 ± 0.31^{e}	6.63 ± 0.07^{cd}	23.67 ± 0.55^{bcd}
T6	10.45 ± 0.05^{g}	55.57 ± 0.30^{bcd}	5.26 ± 0.07^{de}	17.31 ± 0.08^{fgh}
T7	10.95 ± 0.05^{def}	50.90 ± 0.82^{fg}	7.00 ± 0.16^{c}	22.28 ± 0.42^{cdefg}
T8	10.85 ± 0.05^{ef}	56.78 ± 0.44^{ab}	4.48 ± 0.17^{e}	18.51 ± 0.31^{efgh}
T9	11.15 ± 0.05^{bc}	51.86 ± 0.55^{ef}	6.97 ± 0.10^{c}	23.82 ± 0.01^{bcd}
T10	10.45 ± 0.05^{g}	52.21 ± 0.18^{ef}	5.12 ± 0.10^{e}	16.62 ± 0.04^{h}
T11	11.25 ± 0.05^{ab}	50.85 ± 0.80^{fg}	9.01 ± 1.72^{a}	28.12 ± 6.09^{ab}
T12	11.05 ± 0.05^{cd}	52.71 ± 0.25^{ef}	6.67 ± 0.13^{cd}	23.88 ± 0.20^{bcd}
T13	10.85 ± 0.05^{ef}	55.30 ± 0.58^{cd}	8.69 ± 0.27^{ab}	31.74 ± 0.44^{a}
T14	10.85 ± 0.05^{ef}	50.92 ± 0.31^{fg}	7.50 ± 0.10^{bc}	22.43 ± 0.26^{cdef}
T15	11.40 ± 0.00^{a}	50.18 ± 0.29^{g}	7.29 ± 0.17^{bc}	22.17 ± 0.11^{cdefg}
P	**	**	**	**

TTA is reported as ml NaOH (0.1 N)/10 g bread; means with different letters in the same column are statistically significant; $^{**}P < 0.01$; $n = 2$

This finding indicates that the addition of the materials improves the quality of whole wheat bread. As expected, the firmness values of whole wheat bread crumb increased, with increasing time storage. However, this increase was generally slower in the treatments containing the additional materials than in that without the materials (T0). While the lowest firmness values were obtained in T6 (0.5%

Table 5. Effect of treatments (T) on sensory traits of whole wheat bread (mean ± SE)

Treatment	Crumb grain	Texture	Crumb colour	Aroma	General acceptability
T0	5.50 ± 0.83	5.50 ± 0.50	6.00 ± 0.33	6.16 ± 0.16	5.00 ± 0.67
T1	6.17 ± 0.50	6.33 ± 0.33	7.00 ± 0.00	6.50 ± 0.50	6.50 ± 0.17
T2	7.33 ± 0.00	7.00 ± 0.33	6.50 ± 0.17	6.50 ± 0.17	6.50 ± 0.17
T3	7.50 ± 0.17	6.83 ± 0.16	7.50 ± 0.50	6.83 ± 0.16	6.83 ± 0.50
T4	5.33 ± 0.00	5.83 ± 0.50	6.16 ± 0.16	6.16 ± 0.16	5.83 ± 0.50
T5	6.83 ± 0.83	7.00 ± 0.67	6.83 ± 0.50	7.00 ± 0.00	6.50 ± 0.50
T6	7.16 ± 0.16	6.83 ± 0.16	7.00 ± 0.33	6.83 ± 0.16	7.00 ± 0.00
T7	7.16 ± 0.16	7.33 ± 0.33	6.50 ± 0.17	7.50 ± 0.17	7.17 ± 0.50
T8	6.66 ± 0.66	7.17 ± 0.50	7.17 ± 0.50	6.83 ± 0.50	7.16 ± 0.83
T9	7.16 ± 0.16	6.83 ± 0.50	6.83 ± 0.50	7.00 ± 0.67	6.50 ± 0.17
T10	7.16 ± 0.16	6.67 ± 0.00	7.50 ± 0.50	6.67 ± 0.00	7.00 ± 0.33
T11	7.17 ± 0.50	6.50 ± 0.17	7.00 ± 0.33	6.67 ± 0.00	7.67 ± 0.00
T12	7.16 ± 0.83	7.66 ± 0.33	7.00 ± 0.67	7.16 ± 0.16	6.83 ± 0.50
T13	7.33 ± 0.00	7.00 ± 0.00	7.00 ± 0.00	7.33 ± 0.00	7.16 ± 0.16
T14	7.50 ± 0.83	6.50 ± 0.83	7.00 ± 0.67	6.16 ± 0.83	7.33 ± 0.66
T15	7.50 ± 0.83	6.83 ± 0.16	7.00 ± 0.33	6.83 ± 0.50	7.66 ± 0.33
P	ns	ns	ns	ns	ns

Means with different letters in the same column are statistically significant; ns – not significant; $n = 2$

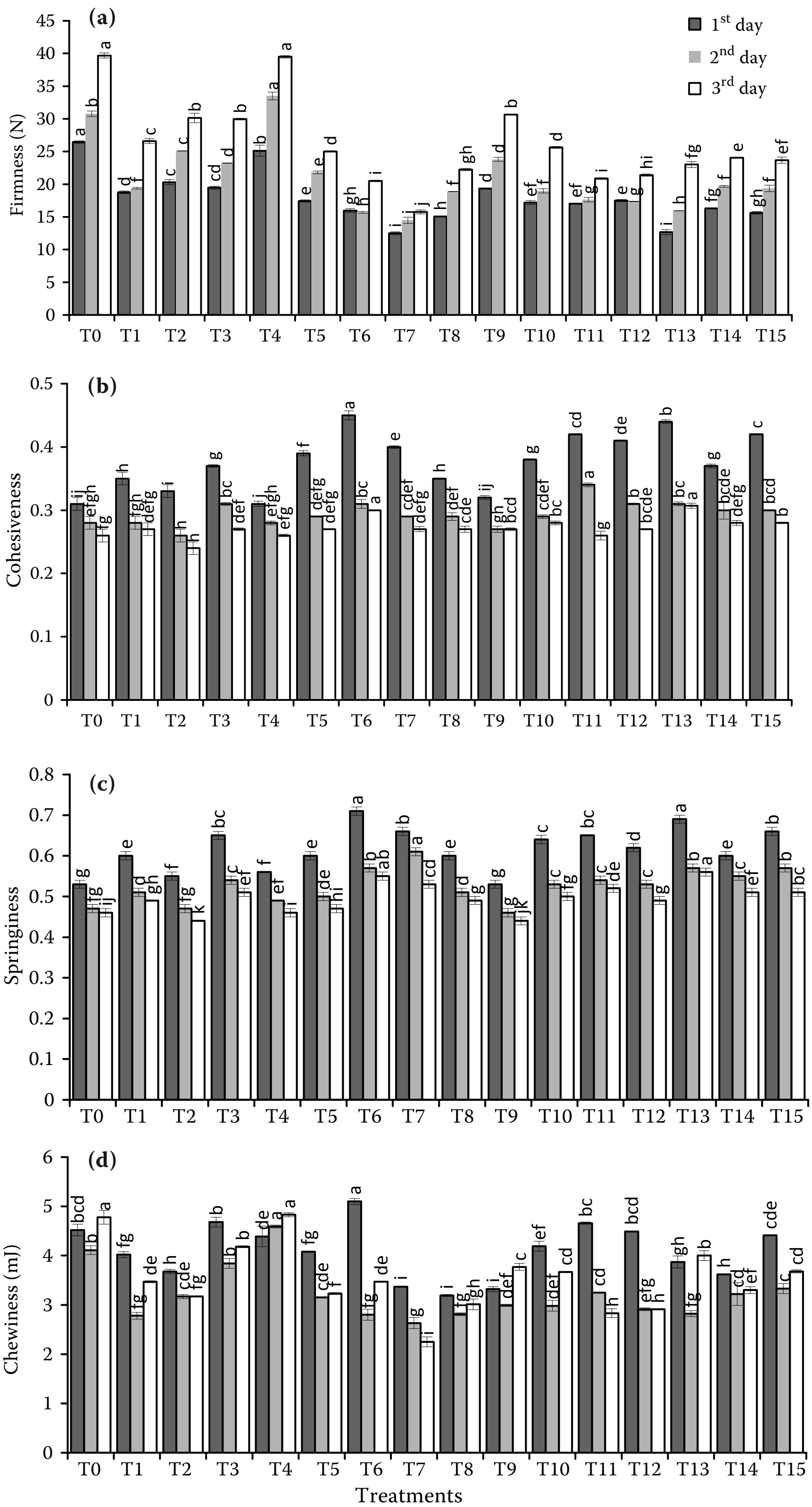

Figure 1. Effect of treatments on (**a**) firmness values, (**b**) cohesiveness values, (**c**) springiness values, and (**d**) chewiness values of whole wheat bread

DCSF + 2.5% G), T7 (0.5% DCSF + 2.5% R) and T13 (2% MF + 0.5% DCSF + 2.5% G), the highest values were obtained in T0 (control) and T4 (2% MF). On the other hand, while the highest specific volume was determined in T6, T7, T13, and T14, the lowest specific volume was determined in T0 and T4. Consequently, T6, T7, and T13 showed similar positive effects on both the crumb firmness and the loaf volume. The decrease in the crumb firmness can be explained by the increase in the loaf volume

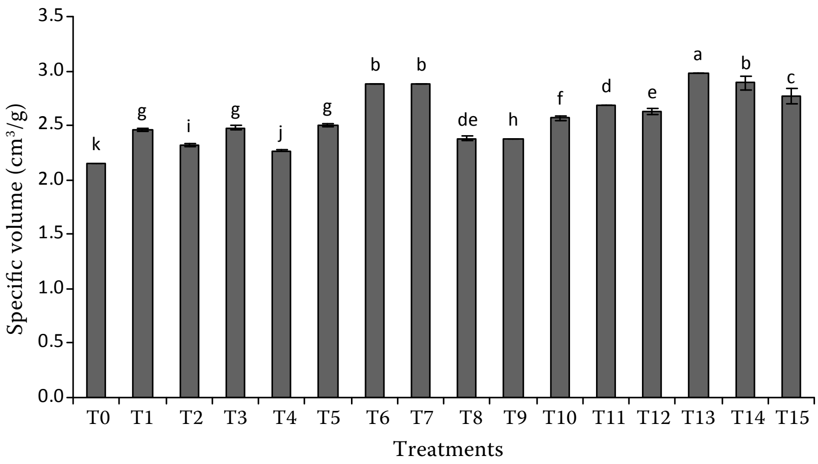

Figure 2. Effect of treatments on specific volume values of whole wheat bread

as well as the improvement in the crumb characteristics. It was been stated that the increased loaf volume is directly related to the decreased firmness values which is due to an increased probe-to-crust distance as the loaf volume increased (Wanga *et al.* 2002; Yamsaengsung *et al.* 2010). Looking at the materials in the treatments, it can be stated that DCSF and vital gluten have positive effects on both the crumb firmness and the loaf volume.

The internal resistance of bread crumb is evaluated by cohesiveness which is a characteristic of mastication. Cohesiveness is defined as how well the product withstands a second deformation relative to how it behaved under the first deformation (Wang *et al.* 2006). In general, cohesiveness in bread samples increased with the addition of the materials (Figure 1b). The cohesiveness values in all treatments containing additional materials were higher than those of the control within 1 day of storage time. The highest 1st day cohesiveness value was obtained in T6 and it was the lowest in T0. Cohesiveness in whole wheat bread samples decreased at different rates with the increasing storage time. This decrease in cohesiveness indicates increased susceptibility of the bread to fracture or crumble.

Springiness is a measurement of how much the bread crumb springs back after being compressed once and it can be defined as the elasticity of the bread crumb; it is also an important parameter to determine the staling degree of bread (Karaoğlu *et al.* 2008; Tian *et al.* 2009). Similar to the results of firmness and cohesiveness, T6 and T13 gave the highest 1st day springiness (Figure 1c). In general, springiness of bread decreased more significantly as the storage time increased from 1 to 3 days. However, when the storage time increased from 3 to 5 days, the decrease in springiness reached a lower extent.

Chewiness is related to the work needed to chew a solid sample such as bread to a steady state of swallowing. The crumb chewiness is a product of the crumb firmness, cohesiveness and springiness. In general, a decreasing tendency in chewiness for 3rd day of the storage time was followed by an increase in 5th day of the storage time (Figure 1d). While the highest chewiness value was determined in T6 (0.5% DCSF + 2.5% G) for 1 day storage, it was the lowest in T8 (0.5% DCSF + 2.5% R). The crumb chewiness of bread produced by different treatments changed in different ways with increasing storage time. Chewiness is one of the texture parameters easily correlated with sensory analyses through the panels (Esteller *et al.* 2004; Gomez *et al.* 2007). The chewiness values of bread crumb produced significant negative correlation with sensorial properties in this study (data not shown). Chewiness is a parameter dependent on firmness. Therefore, chewiness values of bread generally followed a similar trend as firmness.

Despite the benefits of consuming whole wheat bread, the consumers' acceptance of this product is limited due to its lower volume, coarser texture, and faster staling compared to refined wheat bread. The bread volume is related to the quantity and quality of gluten (Chloupek *et al.* 2008; Rosell *et al.* 2009). Bread volume is measured as one of the most important criteria in evaluating bread quality (Yamsaengsung *et al.* 2010). Our study showed that the specific volume values of whole wheat bread were increased by the additional materials (Figure 2). While the highest specific volume was determined in T13, it was the lowest in control (T0). The change in specific volume of whole wheat bread was similar to that of firmness. Karaoğlu (2011), who determined an increase effect in specific volume, made similar observations for DCSF. It is known that bread volume improves due to gas retention ability of vital gluten and the amylolytic activity of malt flour.

CONCLUSION

It could be concluded from the overall results that the addition of different plant origin materials created a positive influence on the product quality and consumers' acceptance. The firmness decreased with the addition of MF, DCSF, R, and G. After storage for 1 day at room temperature, treatment T6 (0.5% DCFS + 2.5% G) gave the highest cohesiveness, springiness, and chewiness values. The highest specific volume value was obtained in the treatment (T13) containing 0.5% DCSF, 2% MF, and 2.5% vital gluten. Whole wheat bread samples produced with the addition of the materials were also considered acceptable by the sensory panel. In addition, the addition of materials showed a positive effect on the general acceptability values of the bread samples. The quality of the final products revealed that the use of plant origin materials as improvement agents is well suited in whole wheat bread making**.**

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