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EFFICIENT VALORIZATION OF DEFATTED WHEAT GERMS IN BREAD MAKING BASED ON DOUGH PROPERTIES AND BREAD QUALITY

Iuliana BANU, Nicoleta MATEI, Iuliana APRODU

"Dunarea de Jos" University of Galati, Faculty of Food Science and Engineering, 111 Domneasca St, 800201, Galati, Romania

Corresponding author email: iuliana.aprodu@ugal.ro

Abstract

Wheat germs rich sources of biologically active compounds and are therefore among the most valuable by-products of the milling industry. Effect of defatted wheat germ powder addition on dough rheological properties and bread quality prepared with white wheat flours with different gluten index was investigated in this study. Different percentages of defatted wheat germ powder (5 and 10 g/100 g flour) were added to the white wheat flour samples, and dough rheological properties were tested using various Mixolab protocols. Defatted wheat germ powder addition increased the water absorption, dough development time, stability and weakening. Significant positive correlation between dough weakening or stability and Wixo parameters were registered. The Chopin+ torque values associated to starch gelatinization and retrogradation decreased from 2.03 to 1.90 Nm and from 3.21 to 2.68 Nm, respectively. Finally, the baking test indicated that bread samples with 10% defatted wheat germ powder had significantly lower specific volume and higher crumb firmness compared to the controls. Overall the results indicated that the addition of 5% defatted wheat germ powder to the wheat flour allows preparing bread with acceptable quality.

Key words: *bread quality, defatted wheat germ, rheological properties, white wheat flour.*

INTRODUCTION

There is an increasing worldwide concern for the sustainable development of healthy and nutritionally balanced foods. In this respect, the use of by-products rich in nutrients and biologically active compounds for developing value-added food products is of high interest. In particular the fortification of the bakery products while valorizing these kinds of by-products might be an efficient way to overcome some nutrition security issues. A common food habit consists on the consumption of white wheat flour bread, which is poor in vitamins, minerals and fibers and has low nutritional value. Bran is the main by-product obtained by cereals milling, but germs can be considered the most valuable by-product, even if are obtained in much smaller quantities than bran. Considering that the wheat germs represent 2-3% of the kernel, it appears that, at least theoretically, about 25 million tons of wheat germs should be separated annually worldwide (Boukid et al., 2018; Sun et al., 2015). Beyond these important quantitative resources, wheat germs are the most valuable anatomical part of the grain from a nutritional point of view. Thus, wheat germs contain appreciable amounts of proteins with a balanced essential amino acids ratio (Sun et al., 2015), unsaturated fatty acids (Boukid et al., 2018), dietary fiber (Marti et al., 2014), minerals, vitamins (E, thiamine, riboflavin, niacin), and compounds with antioxidant properties, mainly phenolic (Sun et al., 2015), flavonoids, phytosterols and polycosanols (Boukid et al., 2018).

The valorization of the nutritional potential of this anatomical component of the wheat grain depends on their isolation, storage and stabilization in order to prevent lipid oxidation (Boukid et al., 2018). The main strategies tested for getting wheat germs stabilization consist on: physical – thermal, radiation, thermal/mechanical treatments (Gomez et al., 2012; Marti et al., 2014; Sun et al., 2015), chemical treatment – alkalis, acids, supercritical carbon dioxide (Boukid et al., 1918; Ma et al., 2014) and biological treatment – fermentation (Marti et al., 2014). Each type of strategy approached has advantages and disadvantages, which finally influence the quality of the end product in which the wheat germs are added (Boukid et al., 2018).

The aim of this study was to investigate of the effect of wheat germ powder addition on the technological behavior of dough prepared with wheat white flours by using different protocols specific to the Mixolab device, namely Chopin+, Simulator and Wixo, and on bread quality. The three Mixolab protocols were selected to highlight the effect of wheat germs addition on the behavior of the dough during the dual mixing and temperature constraints (Chopin+ protocol), during mixing at constant speed (80 rpm) and temperature (30°C) (Simulator protocol), and during mixing at increasing speed from 80 to 240 rpm and constant temperature (30°C) (Wixo protocol).

MATERIALS AND METHODS

Flour samples selection and preparation of the mixtures

Four samples of superior white wheat flours (WF) produced by three major Romanian producers - Boromir, Pambac and Dobrogea, were purchased from the Galati market. Preliminary analyzes performed on these flours indicated that all samples had quality indices that respect the admissibility conditions of the SR 877:1996 – ash content max 0.48%, protein content min 11%, gluten content min 28%, gluten deformation 5-12 mm, granularity rest on 180 mesh min 8% and sifted through 125 mesh max 70%. We selected four flour samples with various gluten quality, which were considered representative for this study. The gluten quality was assessed on the basis of the gluten deformation index and the gluten index.

Each of the four white wheat flour samples was supplemented with defatted wheat germ powder (G), purchased from Pronat (Romania). Two different supplementation levels were considered in the study, namely 5% (samples coded WF1 … WF4+5G) and 10% (samples coded WF1 … WF4+10G).

Proximate composition of wheat white flours and wheat germ powder

The proximate composition of the white wheat flours and wheat germ powder was determined as follows: moisture content by SR ISO 712:2005 (ASRO, 2008), protein content by using a nitrogen-to-protein conversion factor of 6.25 (semimicro-Kjeldahl method, Raypa Trade, R Espinar, SL, Barcelona, Spain), fat content through Soxhlet extraction method with ether (SER-148; VELP Scientifica, Usmate Velate (MB), Italy), crude fiber content using the Fibretherm Analyser (C. Gerhardt GmbH & Co. KG, Germany) and ash content by SR ISO 2171:2002 (ASRO, 2008).

Gluten quantity and quality of wheat white flours

Gluten quantity and quality of white wheat flours were estimated based on the wet gluten content and gluten index (SR ISO 21415-2:2007, ASRO, 2008) (Glutomatic 2200, Perten Instruments AB), and on gluten deformation (Bordei et al., 2007).

Rheological properties of the dough samples

Rheological properties of the dough samples prepared with white wheat flours alone or in admixture with 5 and 10% wheat germ powder were evaluated using the Simulator, Wixo and Chopin+ protocols of the Mixolab device (Chopin Technology, Villeneuve La Garenne, France).

The Simulator protocol was used for determining the mechanical properties of dough subjected for 30 minute at 80 rpm mixing at constant temperature of 30°C (Dubat and Boinot, 2012). The main parameters registered from the Simulator curves are water absorption (WA), development time (DT), stability (S) and weakening (W).

The Wixo protocol was used for determining the mechanical properties of the dough samples upon subjecting them to mixing at constant temperature (30°C) at speed of 80 rpm for 4 min, followed by 240 rpm for 4 min, (Dubat and Lebrun, 2019).

The Chopin + protocol was used for determining the thermo-mechanical properties of the dough during the dual mixing (80 rpm) and temperature constraints. The torque values were measured while running a thermal diagram consisting of: a 8 min plateau at 30°C, followed by temperature increase by 4°C/min up to 90°C; the second plateau of 7 min at 90°C was followed temperature decrease by 4°C/min to 50°C; the third plateau of 5 min at 50°C (Dubat and Boinot, 2012).

The main parameters selected from the Mixolab curves registered while running the Chopin+

protocol are: consistency after 8 min of mixing at constant temperature (30°C), C2 torque reflecting the protein weakening while increasing the temperature, C3 torque reflecting starch gelatinization, C4 associate to the hot gel stability and C5 torque estimating the extent of starch retrogradation upon cooling down to 50ºC (Dubat & Boinot, 2012). Other Mixolab curve parameters measured were: α – associated to the speed of heat related protein weakening was determined as the slope of curve delimited by the end of the 30°C plateau and C2; β - associated to starch gelatinization speed under the effect of heat and measured as the slope of curve delimited by C2 and C3 torque values; and (C5-C4) that defines starch retrogradation degree.

The bread-making procedure

The following recipe was used to prepare the bread: 100 g of white wheat flour alone or in admixture with wheat germ powder was supplemented with 1.5% salt, 3% compressed baker's yeast (Pakmaya, Rompak SRL, Pascani, Romania) and water. The amount of water used for preparing the dough was decided based on the water absorption capacity determined for each flour mixture by means of the Mixolab tests. The one stage method was selected to prepare the dough samples. Further on, the bread-making procedure proposed by Banu et al. (2010) was followed.

Bread analysis

After cooling to room temperature for two hours, the bread samples were characterized in terms of specific volume, crumb firmness and color.

The specific volume of the breads was determined using the rapeseed displacement method (SR 91:2007; ASRO, 2008).

The firmness of the crumb was measure with the MLFTA apparatus (Guss, Strand, South Africa) by using a probe with diameter of 7.9 mm. Measurements were performed on two different bread slices taken from the center of each bread sample. The parameters proposed by Banu et al. (2017) were selected for performing the test: penetration speed of 5 mm/s, trigger threshold force of 1.96 N, and penetration depth of 25 mm.

The lightness (L*), a* (green - red) and b* (blue - yellow) chromatic components of the crumb were measured using the Chroma Meter CR-410 (Konica Minolta Sensing Americas Inc., Ramsey, NJ, USA). Three measurements were taken on different areas for each sample and the overall color change (DE) induced by wheat germs powder addition in respected to the corresponding white wheat flour sample was determined as follows:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

Statistical analysis

The experimental measurements were done in triplicate, and the results are reported as average together with standard deviation values. The differences between samples with different levels of white wheat flour substitution with wheat germ powder were determined through one-way ANOVA with a 95% confidence interval.

RESULTS AND DISCUSSIONS

Proximate composition of wheat white flours and wheat germ powder

The proximate composition of wheat germ powder and of the four white wheat flours selected after preliminary tests are shown in Table 1. The wheat germ powder used in this study contains higher contents of proteins (30.42%) and minerals (ash of 3.17%) compared to the wheat flour samples. No important differences were found among the white wheat flour samples considered in the study; the coefficient of variations was low for all quantified chemical components (Table 1). In particular, the protein and ash contents of the white wheat flours varied between 11.20-11.55% and 0.46-0.48%, respectively.

All white wheat flour samples had high gluten content, which varied between 30.3 and 31.8%, but gluten deformation and gluten index presented high coefficients of variation, of 33.10% and 11.78%, respectively. The values of gluten deformation and gluten index varied from 5.00 to 11.80 mm, and from 67 to 88%, respectively (Table 2). These variations, indicating the existence of important differences on the gluten qualities, were in fact the main criteria for selecting the flour sample used in the experiment.

Table 1. Proximate composition of wheat germ powder and white wheat flours (WF)

Sample		Moisture, %	Protein,%	Fat, %	Fiber, %	Ash, %	Starch, %
Wheat germ powder		13.87	30.43	0.89	1.59	3.17	53.29
Wheat flour	WF1	11.71	11.25	0.88	0.36	0.48	87.03
	WF2	11.64	11.20	0.90	0.34	0.47	87.09
	WF3	11.29	11.35	0.89	0.36	0.48	86.92
	WF4	11.35	11.55	0.94	0.35	0.46	86.70
	Average±SD	11.50 ±0.21	11.34 ±0.15	0.90 ±0.03	0.35 ±0.01	0.47 ±0.01	86.49 ±0.17
	CV, %	1.81	1.37	2.91	2.72	2.03	0.20

SD - standard deviation; CV – coefficient of variation

Gluten deformation provides information on the gluten quality, being useful mainly for assessing the elasticity and viscosity of the gluten. The high deformation ability of the gluten when is left to rest is an indication of the low quality (Mironeasa et al., 2016). Gluten index is a parameter related to the protein network. The gluten samples with large amounts of high molecular weight proteins have high value of the gluten index. It is therefore expected to identify relationships between this parameter and those related to greater protein quality (Collar et al., 2007).

Table 2. Gluten quantity and quality of white wheat flours (WF)

Wheat flour	Wet gluten, %	Gluten deformation, mm	Gluten index, %
WF1	31.80	11.80	88.00
WF2	30.30	5.00	67.00
WF3	30.40	10.50	83.00
WF4	31.10	8.50	75.00
Average ±SD	30.90±0.70	8.95±2.96	78.25±9.22
CV, %	2.26	33.10	11.78

SD - standard deviation; CV – coefficient of variation

Dough rheology

Simulator protocol

The effect of wheat germ powder addition on the rheological properties of white wheat flour was first measured using the Simulator protocol. The main parameters registered in the Simulator curves for all flour samples considered in the study are presented in Table 3. Simulator curves presenting the average torque values determined for each supplementation level of the white wheat flour with wheat germ powder are displayed in Figure 1.

As can be seen in Figure 1 and Table 3, the incorporation of wheat germ powder into white wheat flour caused significant changes in the rheological behaviour of the dough during kneading at temperature of 30°C.

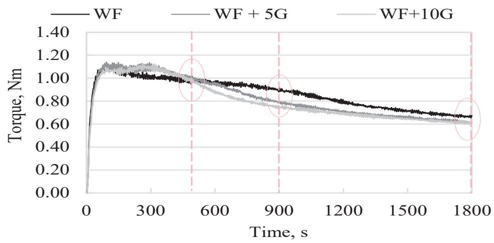

Figure 1. Simulator curves of white wheat flour with 0% (WF) 5% (WF+5G) and 10% (WF+10G) wheat germ powder. The average torque values are presented for each supplementation level. The red ellipsoids indicate the zones of the Simulator curves with major differences among samples with different amounts of wheat germ powder.

The wheat germ powder addition affected the rheological properties of the white wheat flour, through diluting the gluten and altering the water behavior because of the charges occurring in the ratio between the main components of the mixture, particularly between proteins and fiber (Gomez et al. 2012). Thus, WA and DT increased, while S and W decreased with increasing the addition level of wheat germ powder to the white wheat flour.

The increase of WA from 60.4 to 61.3% (Table 3) with increasing the level of wheat germ powder addition could be explained by the cumulative effect of the higher fiber and protein contents (Marti et al., 2014; Sun et al., 2015). Replacement of the white wheat flour with wheat germ powder resulted in the increase of the fiber and protein contents, mainly globulins (Zhu et al., 2006). Our observations regarding the increase of WA through incorporation of wheat germ powder into wheat white flour are in agreement with the literature. Marti et al. (2014) reported an increase of WA from 63.5 to 65.8%, Sun et al. (2015) noted an increase from 64.5 to 65.3%, while Gomez et al. (2012) reported an increase of WA from 58.2 to 59.6%, upon supplementing the control sample with 10% wheat germs.

On the other hand, our results regarding the DT increase from 2.5 min, for wheat white flour, to 3.70 and 4.80 min when adding 5 and 10% wheat germ powder, respectively (Table 3), contradicts other studies. For example, Sun et al. (2015) did not registered significant changes of DT, while Marti et al. (2014) reported significant decreases of DT, from 18 min, for the control sample, to 5.9, 6.3 and 7.2 min through the addition of 3, 10 and 20% wheat germ. The explanation for this behaviour could rely on the higher fiber content in the wheat germ powder used in this study, compared to those reported in other studies. Basically, the dough needs a longer time to develop due to the increase of the fiber content, which requires a longer time for water absorption (Torbica et al, 2010), compared to the wheat dough that have a lower dough development time because of the fast hydration and direct interaction between available thiol groups while kneading, leading to inter- and intramolecular sulphur bridges (Patrascu et al., 2017).

Table 3. The effect of wheat germ powder (G) addition on the rheological properties of white wheat flour (WF) measured using Simulator protocol

Sample		WA, %	DT, min	S, min	W, Nm
WF	WF1	61.0	2.40	10.80	0.15
	WF2	60.4	2.60	8.58	0.17
	WF3	61.0	3.20	9.30	0.15
	WF4	59.2	1.80	10.30	0.14
	Average ±SD	60.4±0.85	2.50±0.58	9.75±1.00	0.15±0.01
	CV, %	1.40	23.09	10.22	8.25
WF+5G	WF1+5G	61.5	4.80	8.01	0.29
	WF2+5G	61.2	4.50	7.40	0.32
	WF3+5G	61.2	3.30	8.50	0.19
	WF4+5G	59.6	2.70	8.70	0.21
	Average ±SD	60.9±0.86	3.70±1.10	8.15±0.58	0.25±0.06
	CV, %	1.42	29.85	7.11	24.71
WF+10G	WF1+10G	61.9	4.80	7.00	0.31
	WF2+10G	61.7	5.40	6.90	0.33
	WF3+10G	61.5	5.40	8.10	0.29
	WF4+10G	60.1	3.40	7.80	0.32
	Average ±SD	61.3±0.82	4.80±0.94	7.45±0.59	0.31±0.02
	CV, %	1.33	19.86	7.94	5.47

WA – water absorption; DT – development time; S – stability; W – weakening; SD - standard deviation; CV – coefficient of variation

However, the addition of wheat germ powder decreased the dough stability from 9.75 to 7.45 min, and increases the weakening from 0.15 to 0.31 Nm (Table 3). Interesting are the trends of the simulator curves registered for the samples with different levels of wheat germ powder (Figure 1). After 7 minutes (420 s) of kneading, the dough consistencies of all samples have extremely close values, but in the next 8 minutes (480 s) the consistency values decrease with different speeds: by 10% in the case of wheat flour, up to near 0.91 Nm, and by 25% and 27% in the case of the samples with 5% and 10% wheat germ powder added, up to near 0.76 and 0.73 Nm, respectively. In the next 15 minutes, practically until the end of the test, the decrease of the dough consistency attenuation was notices in the case of all samples; the wheat flour finally registering a torque of 0.67 N, while the flour supplemented with wheat germ powder had torque values of 0.61 and 0.62 Nm, respectively. The effect of wheat germ powder on the dough stability can be attributed to the deterioration of the protein matrix quality, in respect to the control sample consisting on white wheat flour. Even if the wheat germs have large quantities of proteins, they mainly consist of globulins. Therefore, their incorporation into the wheat flour produce the so-called gluten dilution effect. In addition the globulins from the wheat germs compete with gluten proteins for dough water (Sun et al., 2015). Based on microscopy studies, Zhan et al. (2019) noted that the addition of more than 4% wheat germ accelerates the loss of gluten network properties and separates the starch granules from the protein matrix. The incorporation of wheat germ causes a redistribution of water in the dough and the breaking of -S-S- bonds in the dough, the final effect consisting on the reduction of the dough stability (Sun et al., 2015; Marti et al., 2014). The main responsible for breaking the -S-S- bonds from the gluten network is glutathione, a chemical component found in the wheat germ, and the most affected protein fraction is the high molecular weight glutenin, which undergoes a depolymerization process (Zhan et al., 2019).

Analyzing the behaviour of the dough for each of the four flour samples, can be seen how the addition of the wheat germ powder differently influences the dough stability (Table 3, Figure 1), depending on the gluten network quality, assessed based on gluten deformation and gluten index (Table 2). For example, even if the doughs prepared with WF1 and WF2 have different stabilities, upon the addition of 10% wheat germ powder, they rich rather close stability values (Table 3). Regarding the weakening, it can be seen that samples prepared with WF1 and WF2 flours and 5% of wheat germ powder have significantly higher values compared to WF3 and WF4, but the weakening values are very close for all flours supplemented with 10% wheat germ powder (Table 3).

Wixo protocol

The most important parameters of Wixo curves registered for the samples prepared with white wheat four flour samples with various gluten amounts and quality are presented in Table 4. Additionally, the Wixo curves represented using the average torque values calculated for each supplementation level of the white wheat flour with wheat germ powder are presented in Figure 2.

The dough is formed while mixing at 80 rpm in the first 4 minutes of the test; the dough consistency measured at the end of this stage is named C_{end} FI.

The dough is formed while mixing at 80 rpm in the first 4 minutes of the test; the dough consistency measured at the end of this stage is named C_{end} FI. When the speed increases to 240 rpm, the dough consistency suddenly increases at a value of C_{start} FII.

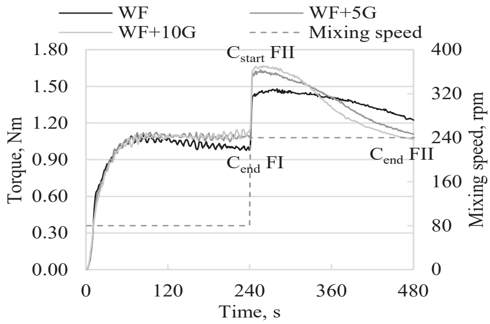

Figure 2. Wixo curves of the white wheat flour with 0% (WF) 5% (WF+5G) and 10% (WF+10G) wheat germ powder. The average torque values are presented for each supplementation level.

The higher difference between C_{start} FII and C_{end} F I define a dough resistant (Dubat and Lebrun, 2019). According to the results from Table 4, the wheat germ powder addition to the white wheat flour results in the increase of the difference between C_{start} FII and C_{end} F I consistency values, most probably because of the contribution of the fibers residing from wheat germ powder. A significant positive correlation of 0.82 ($p<0.01$) between DT (Table 3) and (C_{start} FII - C_{end} FI) (Table 4) was observed.

The final dough consistency measured at the end of the Wixo protocol is named C_{end} FII. During the 4 minutes of kneading at 240 rpm, the consistency of the dough decreases with a much higher speed in the case of samples with the wheat germ powder addition compared to the corresponding wheat white flours. Thus, if in the case of white wheat flour the decrease was about 8%, from 1.30 to 1.25 Nm, in the case of samples with wheat germ powder addition the extents of the decrease were about 25 and 31%, from 1.51 to 1.13 Nm, and from 1.56 to 1.07 Nm, respectively. These results suggest the weakening of the gluten network by the addition of wheat germ powder. A positive correlation of 0.93 ($p<0.01$) was obtained between weakening (W) measured with Simulator protocol and (C_{start} FII - C_{end} FII). At the same time, the low values of C_{end} F II indicate a low dough stability. In fact S measured with the Simulator protocol was positively correlated (0.88, $p<0.01$) with C_{end} FII.

Table 4. The effect of wheat germ powder (G) addition on the rheological properties of white wheat flour (WF) measured using the Wixo protocol

Sample		C_{start} FII – C_{end} FI, Nm	C_{end} FII, Nm	C_{start} FII - C_{end} FII, Nm
WF	WF1	0.41	1.23	0.21
	WF2	0.35	1.18	0.17
	WF3	0.38	1.31	0.07
	WF4	0.30	1.26	0.00
	Average ±SD	0.36±0.05	1.25±0.05	0.11±0.10
	CV, %	13.03	4.37	84.76
WF+5G	WF1+5G	0.44	1.14	0.44
	WF2+5G	0.42	1.07	0.44
	WF3+5G	0.46	1.17	0.36
	WF4+5G	0.35	1.13	0.28
	Average ±SD	0.42±0.05	1.13±0.04	0.38±0.08
	CV, %	11.47	3.72	20.16
WF+10G	WF1+10G	0.47	1.08	0.52
	WF2+10G	0.47	1.01	0.54
	WF3+10G	0.47	1.08	0.49
	WF4+10G	0.38	1.09	0.41
	Average ±SD	0.45±0.05	1.07±0.04	0.49±0.06
	CV, %	10.06	3.47	11.66

SD - standard deviation; CV – coefficient of variation

Chopin+ protocol

The thermo-mechanical properties of the wheat white flour supplemented with the wheat germ powder measured using Chopin+ protocol are shown in Table 5 and, as average, in Figure 3.

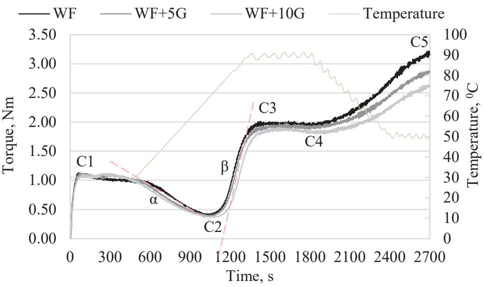

Figure 3. Mixolab curves of white wheat flour with 0% (WF) 5% (WF+5G) and 10% (WF+10G) wheat germ powder. The average torque values are presented for each supplementation level.

When the dough was subjected to mixing and temperature constraints, by increasing the temperature from 30 to 56±2°C, the consistency decreased to C2 value due to protein weakening. The C2 values decreased with the wheat germ powder addition to the wheat white flour (Table 5). Moreover, the addition of wheat germ powder to the white wheat flour samples determined the increase of the protein weakening speed during heating (α) (Table 5). These results suggest a higher weakening of the samples supplemented with wheat germs powder during heating, most likely due to the poor proteins quality residing from the wheat germ compared to the gluten protein from wheat flour. A significant positive correlations of 0.98 ($p<0.01$) between gluten index and C2 (0.98, $p<0.01$) was observed, while between gluten index and α, a significant negative correlation of 0.92 ($p<0.05$) was registered.

However, the decrease of C2 through wheat germ powder addition is not so pronounced, mainly in case of the sample with 5% addition. A possible explanation of this behaviour could be the high thermo-stability of the globulin fractions (Zhu et al., 2006), prevailing in the wheat germ. In fact, C2 is registered in the case of samples with the 10% wheat germ powder addition after a longer mixing time, about 18 minutes, and at a temperature of about 58°C, compared to 17 minutes and at 55-56°C in case of dough prepared from white wheat flour. All these appear over the effect of glutation from wheat germ powder on protein network during kneading.

Table 5. The effect of wheat germ powder (G) addition on the rheological properties of the white wheat flour (WF) measured using Chopin+ protocol

	Sample	C2, Nm	α, Nm/min	C3, Nm	TC3, °C	β, Nm/min	C4, Nm	C5, Nm	C5-C4, Nm
WF	WF1	0.46	0.07	1.98	77.3	0.65	1.98	3.22	1.24
	WF2	0.35	0.11	2.00	77.1	0.58	1.82	2.83	1.01
	WF3	0.46	0.09	2.09	78.5	0.52	2.00	3.48	1.48
	WF4	0.38	0.10	2.06	78.2	0.59	1.99	3.30	1.31
	Average± SD	0.41± 0.06	0.09± 0.02	2.03± 0.05	77.78± 0.68	0.59± 0.06	1.95± 0.08	3.21± 0.27	1.26± 0.20
	CV, %	13.70	18.46	2.45	0.87	9.66	4.32	8.51	15.49
WF +5G	WF1+5G	0.43	0.06	1.84	78.6	0.52	1.96	2.96	1.00
	WF2+5G	0.32	0.10	1.82	79.2	0.57	1.78	2.62	0.84
	WF3+5G	0.43	0.08	1.98	82.1	0.49	1.93	3.00	1.07
	WF4+5G	0.38	0.08	2.03	82.0	0.57	1.94	2.89	0.96
	Average± SD	0.39± 0.05	0.08± 0.02	1.92± 0.10	80.48± 1.84	0.54± 0.04	1.90± 0.08	2.87± 0.18[b]	0.97± 0.10
	CV, %	13.36	20.41	5.32	2.28	7.57	4.47	6.16	10.20
WF +10 G	WF1+10G	0.39	0.07	1.88	84.3	0.20	1.84	2.72	0.88
	WF2+10G	0.31	0.07	1.76	84.6	0.24	1.63	2.42	0.79
	WF3+10G	0.40	0.08	1.94	84.8	0.30	1.84	2.79	0.95
	WF4+10G	0.37	0.09	2.00	83.3	0.35	1.93	2.78	0.85
	Average± SD	0.37± 0.04	0.08± 0.01	1.90± 0.10	84.25± 0.67	0.27± 0.07	1.81± 0.13	2.68± 0.17	0.87± 0.07
	CV, %	10.97	12.35	5.44	0.79	24.23	6.95	6.48	7.67

SD - standard deviation; CV – coefficient of variation

Our results indicated a significant positive correlation of 0.86 ($p < 0.01$) between C2 and C_{start} FII-C_{end} FII. Smaller but significant positive correlations of 0.46 ($p<0.01$) were observed between C2 and C_{end} FII, as well as between C_{start} FII-C_{end} FI.

The addition of wheat germ powder decreased the maximum consistency of the dough due to the starch gelatinization (C3), decreased the starch gelatinisation speed (β), and increased the starch gelatinization temperature (TC3) and time when the dough reached the maximum C3 value. Thus, in case of the samples including wheat germs powder the C3 values were reached after 25-27 minute and at temperatures of 81-83°C, compared to the about 23 minute and 77-78°C in case of wheat white flour. These differences are mainly due to the fact that the wheat germ powder has high fiber content.

The wheat germ powder addition decreased the dough consistency during heating to 90°C (C4) from 1.95 to 1.81 Nm, indicating a reduced starch gel stability during heating. This reduction of the consistency can be attributed to the intake of amylase brought by the wheat germ powder (Sun et al., 2015). Starch retrogradation during cooling from 90 to 50°C and the starch retrogradation degree, (C5-C4), decrease through wheat germ powder addition to the white wheat flour (Table 5).

Bread properties

The effect of the wheat germ powder addition on the properties of the bread samples prepared using the four different types of white wheat flour was estimated by determining the bread specific volume, crumb firmness and colour (Table 6). Overall, the specific volume of the bread samples decrease, from 452.1 to 394.33 and 310.50 cm^3/100 g, with increasing the level of wheat germ powder to the white wheat flour from 0 to 10%. A significant positive correlation of 0.57 ($p<0.01$), was registered between specific volume and C2. A small decrease by 12.8% of the specific volume was registered in case of samples with 5% wheat germ powder addition, compared to the control sample, while further increase of the wheat germ powder level in the samples up to 10% caused an additional decrease of 21.3% of the specific volume. The addition of wheat germ powder influenced the crumb firmness. When compared to the control samples, a 17% increase of the crumb firmness was observed in case of the bread samples supplemented with 10% wheat germ powder, whereas in case of the bread samples with 5% wheat germ powder, the firmness increase was of 3.8%. Significant correlations of 0.77 ($p<0.01$) between crumb firmness and specific volume, and of 0.84 ($p<0.01$) between firmness and C2, were registered.

The specific volume decrease and the crumb firmness increase with the level of wheat germ powder addition to the white wheat flour might be the result of the following factors: the gluten network was affected, the competition of the different constituents of the flours for moisture varied with the mixture formula, the presence of glutathione, and the interaction between wheat flour and germ constituents. Any of those factors could affect the gas holding capacity of the dough during. Moreover, the reduction of the dough viscoelasticity due to changes occurring in the starch hydration capacity could negatively affect the bread quality (Gomez et al., 2012; Ma et al., 2014; Sun et al., 2015).

The wheat germ powder addition increase the total color change (ΔE) of the bread crumb (Table 6). The ΔE had lower values (ΔE of 1.76±0.10) in case of the bread samples with 5% wheat germ powder addition, compared to the samples with 10% wheat germ powder addition (ΔE of 7.89±0.34).

Table 6. The effect of wheat germ powder (G) addition on the proprieties of the bread prepared with white wheat flour (WF)

Sample		Specific volume, cm^3/100 g	Firmness, g force	ΔE
WF	WF1	483.10	561.84	-
	WF2	403.40	755.51	-
	WF3	470.90	617.41	-
	WF4	452.10	685.32	-
	Average±SD	452.38±35.05	655.02±83.89	-
	CV, %	7.75	12.81	-
WF+5G	WF1+5G	443.94	584.56	1.62
	WF2+5G	333.48	793.66	1.84
	WF3+5G	422.84	638.73	1.79
	WF4+5G	377.06	704.32	1.79
	Average±SD	394.33±49.24	680.32±90.04	1.76±0.10
	CV, %	12.49	13.24	5.58
WF+10G	WF1+10G	340.30	676.01	8.12
	WF2+10G	280.50	857.08	8.09
	WF3+10G	320.50	755.23	7.96
	WF4+10G	300.70	775.06	7.40
	Average±SD	310.50±25.72	795.79±74.37	7.89±0.34
	CV, %	8.28	9.35	4.29

SD - standard deviation; CV – coefficient of variation

CONCLUSIONS

The addition of defatted wheat germ powder to the wheat white flour influenced dough behavior measured using the Mixolab device under different conditions: during dual mixing and temperature constraints (Chopin+ protocol), during mixing at constant speed of 80 rpm and temperature of 30°C (Simulator protocol), and during mixing at constant temperature of 30°C and subsequent mixing speeds of 80 and 240 rpm (Wixo protocol). Significant correlations were obtained between different parameters defined by Simulator, Wixo and Chopin+ curves. The baking test indicated that the use of 10% defatted wheat germ powder in admixture with the white flour significantly altered the bread specific volume and crumb firmness.

REFERENCES

ASRO. (2008). *Romanian standards catalog for cereal and milling products analysis*. SR 877:1996, SR ISO 712:2005, SR ISO 2171:2002, SR ISO 21415-2:2007 and SR 91:2007. Bucharest, RO: Romanian Standards Association - ASRO.

Banu, I., Măcelaru, I., & Aprodu, I. (2017). Bioprocessing for Improving the Rheological Properties of Dough and Quality of the Wheat Bread Supplemented with Oat Bran. *Journal of Food Processing and Preservation*, *41*(5), 1-9.

Banu, I., Stoenescu, G., Ionescu, V., & Aprodu, I. (2010). Physico-Chemical and Rheological Analysis of Flour Mill Streams. *Cereal Chemistry*, *87*(2), 112-117.

Bordei, D., Bahrim, G., Paslaru, V., Gasparotti, C., Elisei, A., Banu, I., Ionescu, L., & Codina, G. (2007). *Quality control in the bakery industry. Methods of analysis*. Galati, RO: Academica Publishing House.

Boukid, F., Folloni, S., Ranieri, R., & Vittadini, E. (2018). A compendium of wheat germ: Separation, stabilization and food applications. *Trends in Food Science & Technology*, *78*, 120-133.

Collar, C., Bollain, C., & Rosell, C.M. (2007). Rheological Behaviour of Formulated Bread Doughs During Mixing and Heating. *Food Science and Technology International*, *13*(2), 99-107.

Dubat, A., & Boinot, N. (2012). *Mixolab applications handbook. Rheological and enzymes analyses*. Villenueve, FR: Chopin Technology.

Dubat, A., & Lebrun, O. (2019). *Use of a dual speed mixing protocol as a rapid screening tool for estimation of Alveograph values*. Villenueve, FR: Chopin Technology.

Gomez, M., Gozales, J., & Oliete, B. (2012). Effect of Extruded Wheat Germ on Dough Rheology and Bread Quality. *Food Bioprocess Technology*, *5*(6), 2409-2418.

Ma, S., Wang, X.X., Zheng, X.L., Tian, S.Q., Liu, C., Li, L., & Ding, L.F. (2014). Improvement of the quality of steamed bread by supplementation of wheat germ from milling process. *Journal of Cereal Science*, *60*, 589-594.

Marti, A., Torri, L., Casiraghi, M.C., Franzetti, L., Limbo, S., Morandi, F., Quaglia, L., & Pagani, M.A. (2014). Wheat germ stabilization by heat-treatment or sourdough fermentation: Effects on dough rheology and bread properties. *LWT - Food Science and Technology*, *59*(2), 1100-1106.

Mironeasa, S., Codina, G.G., & Mironeasa, C. (2016). Optimization of Wheat-Grape Seed Composite Flour to Improve Alpha-Amylase Activity and Dough Rheological Behavior. *International Journal of Food Properties*, *19*(4), 859-872.

Pătraşcu, L., Banu, I., Vasilean, I., & Aprodu, I. (2017). Effect of gluten, egg and soy proteins on the rheological and thermo-mechanical properties of wholegrain rice flour. *Food Science and Technology International*, *23*(2), 142-155.

Sun, R., Zhang, Z., Hu, X., Xing, Q., & Zhuo, W. (2015). Effect of wheat germ flour addition on wheat flour, dough and Chinese steamed bread properties. *Journal of Cereal Science*, *64*, 153-158.

Torbica, A., Hadnadev, M., & Dapcevic, T. (2010). Rheological, textural and sensory properties of gluten-free bread formulations based on rice and buckwheat flour. *Food Hydrocolloids*, *24*(6-7), 626-632.

Zhan, J., Ma, S., Wang, X.X., Li, L., & Zheng, X.L. (2019). Effect of baked wheat germ on gluten protein network in steamed bread dough. *International Journal of Food Science and Technology*, *54*(10), 2839-2846.

Zhu, K. X., Zhou, H. M., & Qian, H. F. (2006). Proteins extracted from defatted wheat germ: nutritional and structural properties. *Cereal Chemistry*, *83*(1), 69–75.