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THERMO-MECHANICAL AND BREADMAKING PROPERTIES OF WHEAT-SORGHUM FLOUR BLENDS

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Abstract

Sorghum flour is a valuable ingredient for breadmaking. The thermo-mechanical properties of dough prepared out of wheat flour supplemented with 10, 20, 30, 40 and 50% sorghum flour and the bread characteristics in terms of specific volume, crumb firmness, resistant starch, total phenols and antioxidant activity were investigated. Water absorption and dough stability decreased when increasing the level of sorghum flour as a consequence of the dilution effect of gluten. Starch gelatinization speed was 0.50 Nm/min in case of wheat flour and increased up to 0.70 Nm/min for sample with 50% sorghum flour. In addition, gel stability during heating increased with the level of sorghum flour. Although wheat flour substitution by sorghum flour affected the specific volume of the bread and crumb firmness, the level of biologically active compounds in the final products was significantly increased. In particular, the addition of 50% sorghum flour caused the increase of the total phenols content and DPPH-RSA of bread from 122.41 to 527.59 µmol FAE/g d.w., and from 3.90 to 25.59%, respectively. Moreover, the content of resistant starch of the breads increased with the level of sorghum flour, most probably as a consequence of the presence of polyphenols from sorghum flour and of the interaction between sorghum starch and proteins.

Key words: *wheat, sorghum, thermo-mechanical properties, bread, resistant starch.*

INTRODUCTION

Sorghum has a major role in sustainable grain production and an increasing importance to food security (Khan et al., 2013). It is a cereal with wide adaptation to the environmental conditions, to the abiotic stress tolerance, having good adaptation on the increase of temperatures and decrease of precipitation, and low requirements of fertilization and crop protection products (Berenji and Dahlberg, 2004).

In recent years several studies highlighted the nutritional potential of sorghum. Sorghum contain a large spectrum of phenolic compounds, the most important being phenolic acids and flavonoids (Taylor et al., 2014). The types and levels of the phenolic compounds depend by the sorghum variety: white variety contains especially simple phenolic acids, while red and brown varieties contain phenolic acids, anthocyanins and condensed tannins. Additionally, sorghum is a source of other functional ingredients such as resistant starch (Khan et al., 2013; Yousif et al., 2012). Due to all these components sorghum is considered a cereal with valuable health promoting potential, being used as ingredient in baked products based on either wheat or non-wheat flours, including gluten free flours (Khan et al., 2013; Yousif et al., 2012; Onyango et al., 2009; Onyango et al., 2011; Vasquez et al., 2016; Rai et al., 2014; Ferreira et al., 2016).

There are certain properties of some components, such as proteins and starch, which might limit the use of sorghum for obtaining baked products (Onyango et al., 2011). Taylor et al. (2006) identified the main problems that limit sorghum applications in breadmaking, namely the lack of viscoelastic protein network and quick staling. According to Duodu et al. (2002) and Onyango et al. (2011), sorghum proteins form aggregates during cooking. Schober et al. (2007) reported that sorghum proteins found in the batter are prone to strands and lumps formation due to aggregation, which interfere with the starch gel during baking, therefore resulting in flat breads with holes in the crumb. These final products usually have poor capacity to retain the fermentation gases produced during proofing and in the early stages of baking. Sorghum starch has high gelatinization temperature that can lead to a poor gelatinization during baking, with negative impact on sensorial properties of the final products (Torbica et al., 2019; Onyango et al., 2011).

The aim of the presents study was to investigate the effect of the wheat flour supplementation with sorghum flour on the thermo-mechanical properties of dough and on the physical-chemical characteristics of the bread. In particular, the presence of resistant starch, the content of total phenols and antioxidant activity of the final products prepared with different amounts of sorghum flour were tested.

MATERIALS AND METHODS

Materials

The commercial white wheat flour (WF) (Boromir, Romania) and sorghum whole flour (SF) (origin Hungary, distributed by Adams Vision SRL, Târgu Mureș, Romania) were purchased from the local market (Galați, Romania).

Proximate analyses

In order to establish the proximate composition of the flour samples, the following standard methods were used: SR ISO 712:2005 (ASRO, 2008) for moisture, semimicro-Kjeldahl method (Raypa Trade, R Espinar, SL, Barcelona, Spain) for protein (nitrogen conversion factor of 5.75 for wheat flour, and 5.81 for sorghum flour), Soxhlet extraction method with ether (SER-148; VELP Scientifica, Usmate Velate (MB), Italy) for fat, Fibretherm Analyser based method (C. Gerhardt GmbH & Co. KG, Germany) for crude fiber, and SR ISO 2171/2002 (ASRO, 2008) for ash. The starch content was established by subtracting the total percentage of the assayed chemical components from one hundred.

Amylose content was determined using Amylose/Amylopectin assay kit (Megazyne International Ireland Ltd. Wicklow, Ireland), following the manufacturer's procedure based on the methods of Gibson et al. (1997).

Starch damage was determined by spectrophotometric method (AACC Method 76-31.01) using dedicated assay kit from Megazyne International (Ireland Ltd. Wicklow, Ireland).

Physical and functional properties

Fineness modules were determined according to Godon and Willm (1994) method, using in sequence sieves with 400, 315, 160 and 125 µm mesh.

The brightness value L*, redness value a* and yellowness value b* were measured by means of Chroma Meter CR-410 (Konica Minolta Business Solutions Europe GmbH).

Solvent retention capacity (SRC) test was performed according to AACC Method 56-11.02, by independently testing the retention of the following solvents: water (W-SRC), 5% lactic acid (LA-SRC), 5% sodium carbonate (SC-SRC) and 50% sucrose (S-SRC).

The method proposed by Abebe et al. (2015) and slight modified by Villanueva et al. (2018) was employed for determining the water absorption index (WAI), water solubility index (WSI), and swelling power (SP). The flour samples (2.5 g) were mixed with 30 ml distilled water in pre-weighed centrifuges tubes, cooked at 30 and 90°C in water bath for 10 min, cooled down to room temperature and further centrifuged at 4,000 x g for 10 min. The WAI was determined as ratio between the weights of the sediment resulted after centrifugation, and of the flour sample. The soluble solid of the supernatants was measured after evaporation overnight at 110ºC. The WSI was determined as ratio between soluble solid of the supernatant, and the weight of the flour sample. The SP was calculated by dividing the soluble solid of the supernatant and by the difference between weight of flour sample and soluble solid resulted after evaporating.

Thermo-mechanical properties

The thermo-mechanical properties of white wheat flour (control), sorghum flour and mixtures of different ratios of wheat flour: sorghum flour (90: 10, 80: 20, 70: 30, 60: 40, 50: 50) were determined using the Mixolab device (Chopin Technology, Villeneuve La Garenne, France). The Chopin+ protocol was applied for all wheat flour based samples, while for the sorghum whole flour the Chopin+ protocol was adapted by modifying the dough weight to 90 g instead of 75 g. The following thermo-mechanical parameters were registered from the typical Mixolab curves: C2, C3, C4 and C5 torques related to protein weakening while mixing and heating, starch gelatinization, hot gel stability and retrogradation in the cooling phase, respectively.

The cooking stability and breakdown were additionally estimated through the (C4/C3) and (C3-C4), while protein weakening speed during heating, starch gelatinization speed and enzymes degradation speed, through the alpha, beta and gamma slopes of Mixolab curve, respectively (Dubat and Boinot, 2012; Svec and Hruskova, 2015).

The bread-making procedure

The white wheat flour was blended with sorghum whole flour in the ratios of 100: 0, 90: 10, 80: 20, 70: 30, 60: 40, 50: 50.

The doughs were prepared through the one stage method using the following formula on the 100 g mixture of white wheat flour and sorghum whole flour: 1.5% salt, 3% compressed baker's yeast, and water (according to the water absorption capacity established through Mixolab tests for each flour mixture). The bread-making procedure is described in Banu et al. (2010).

Bread analysis

Specific volume and crumb firmness

The specific volume of the bread and crumb firmness were determined after storing the samples for one hour at room temperature. The specific volume was determined using SR 91/2007 method (ASRO, 2008) based on rapeseed displacement.

The MLFTA apparatus (Guss, Strand, South Africa) and a probe with diameter of 7.9 mm were used to measure crumb firmness on two bread slices from the center of every sample. The following parameters were used for measuring crumb firmness: penetration wide of 25 mm, test speed of 5 mm/s, and trigger threshold force of 1.96 N (Banu et al., 2017).

Resistant starch

Resistant starch was determined using the Megazyne assay kit (Megazyne International Ireland Ltd. Wicklow, Ireland), according to the manufacturer's procedure based on the AACC Method 32-40.01.

Total phenol and antioxidant activity

In order to determine the total phenolic contents (TPC) and DPPH-radical scavenging activity (DPPH RSA) of bread an extraction procedure with 80: 20 methanol/water (v/v) solvent mixtures was used. The total phenolic contents (TPC) were determined following the Folin-Ciocalteu method proposed by Singleton and Rossi (1965) and modified by Gao et al. (2002). The results were expressed as mg ferulic acid equivalent (FAE) per g d.w., ferulic acid being used as standard. DPPH-radical scavenging activity was measured using the method described by Brand-Williams et al. (1995) and modified by Beta et al. (2005).

Statistical analysis

Triplicate experiments were carried out in, and the results are reported as average values together with standard deviation. Analysis of variance, performed with Minitab 18 Statistical Software, was used to check any significant differences among samples with different percentages of sorghum flour. The normality and variance equality conditions were initially check and differences were afterwards quantified using one-way ANOVA with a 95% confidence interval.

RESULTS AND DISCUSSIONS

Proximate composition of flours

The proximate composition of sorghum and wheat flours is presented in Table 1. When compared to the wheat flour, sorghum flour had higher contents of fat (3.17%), crude fiber (3.43%), and ash (1.61%). According to Vargas-Solorzano et al. (2014), the composition of sorghum flour is related to the genotype of the grain – white, red and brown sorghum. The authors noted that the flour obtained from brown sorghum had higher fat, ash and fiber, compared to the flour resulted from red and white sorghum. The brown sorghum flour can get 3.32-3.18% fat, 1.59-2.47% ash, and 12.86-11.58% neutral detergent fiber, as against 1.73-1.76% ash, 2.96-3.05% fat, and 8.52-8.93% neutral detergent fiber in case of red and white sorghum flour. Rai et al. (2014) reported for the whole sorghum flour the following composition: 4% fat, 2.2% ash, 2.30% crude fiber, and 72.2% starch. The amylose content of the flour has a major role in starch digestibility and in further formation of resistant starch (Yousif et al., 2012). As indicated in Table 1, the amylose content of sorghum and wheat flours was 23.03 and 27.57%, respectively. Our results are in agreement with Yousif et al. (2012), who reported amylose contents of 24.7 and 27.6%, in case of white and red sorghum flours, respectively, while other studies quoted by these authors indicated amylose contents ranging from 24 to 33%.

Regarding starch damage, the results presented in Table 1 revealed higher value (8.17%) for sorghum flour, compared to the wheat flour (5.13%). However, Yousif et al. (2012) reported higher values for starch damage of white sorghum flour and red sorghum flour, of 12.03 and 9.43%, respectively.

Table 1. Proximate composition of the sorghum and wheat flours

Component	Sorghum flour	Wheat flour
Moisture (%)	10.29±0.02	12.30±0.02
Protein (% d.w.)	7.88±0.07	9.29±0.04
Fat (% d.w.)	3.17±0.07	1.04±0.03
Crude fiber (% d.w.)	3.43±0.04	2.28±0.03
Ash (% d.w.)	1.61±0.01	0.48±0.01
Starch (% d.w.)	73.57±0.07	74.65±0.04
Amylose (% d.w.)	23.03±0.15	27.57±0.43
Damage starch (% d.w.)	8.17±0.15	5.13±0.15

Physical and functional properties of flours

The wheat flour had lower fineness module (1.13), compared to the sorghum flour (1.53) (Table 2). Sorghum flour contained a higher percentage (~ 62%) of large particles, with size ranging from 160 to 315 μm, while in the wheat flour prevailed the particles having size between 125 and 160 μm (68.5%). The particles size distribution, along with chemical composition of flours, influenced the hydration properties. If in case of wheat flour the presence of appropriate amounts of water is necessary for developing the gluten network, in case of gluten free flour water is necessary to hydrate the flour constituents. Moreover, Collar and Angioloni (2014) appreciated that hydration properties pays a key role in modulating dough workability and the properties of the end-products.

Solvent retention capacity, measured using as solvents water, lactic acid, sucrose and sodium carbonate, represents a useful method which allows describing the functional profile of the flour. It is considered that a well performing system of sponge and dough should have the following solvent retention capacity profile: W-SRC ≤ 57%, S-SRC ≤ 96%, LA-SRC ≥ 100%, SC-SRC ≤ 72% (AACC method 56-11.02). The results presented in Table 2 revealed important differences between SRC profiles of sorghum and wheat flour. The higher levels of fiber and starch damage of sorghum flour resulted in higher values of S-SRC, SC-SRC and W-SRC. The LA-SRC value is quite large due to the kafirins and glutelins from sorghum flour composition. The SRC profile of sorghum flour is quite similar to SRC profile to teff flour reported by Collar and Angioloni (2014): W-SRC of 111%, S-SRC of 145%, LA-SRC of 129% and SC-SRC of 120%. As expected, the gluten performance index (GPI), which is a measure of the overall performance of glutenin in the complex network (Kweon et al., 2011), was lower for sorghum flour (0.48) than wheat flour (0.69). Mariotti et al. (2016) reported lower GPI values of 0.439 and 0.527 for commercial gluten free flours, compared to the hard wheat flours (GPI of 0.628).

The color parameters of flours are depicted in Table 2. The lightness value (L*) of wheat flour was high, over 93, being specific to a white flour, while the L* value of sorghum flour was much lower, about 82, due the high content of tannins and phenolic compounds from sorghum (Vargas-Solorzano et al., 2014). Similar yellowness values were measured for both investigated flours, while the a* values varied from redness (+4.50) for sorghum flour to greenness (-1.28) for wheat flour (Table 2).

The hydration properties, appreciated in terms of WSI, WAI and SP, increased with the temperature increase from 30 to 90°C. The most significant increase was noticed for the wheat flour. The lower values of WSI registered for sorghum flour can be explained by the complexed formed between starch and kafirins (Chandrashekar and Kirleis, 1988) or lipids (Kraithong et al., 2018), the latter being in higher amount in sorghum flour compared to the wheat flour. Chandrashekar and Kirleis (1988) suggested that, because of the high content of kafirin, sorghum is prone to higher gel consistency and lower degree of starch gelatinization. It was suggested that kafirin might organize as a barrier around the starch granule, limiting starch gelatinization. The authors noted that the enthalpy of dissociation of amylose-lipid complexes is higher in case of sorghum than in millet, but is lower compared to oat. The same complexes formed between starch and kafirin and lipids seem to have the main influence on WAI and SP value.

Table 2. Physical and functional properties of sorghum and wheat flours

Component		Sorghum flour	Wheat flour
Physical properties			
Fineness modules		1.53±0.03	1.13±0.03
Color values	L*	81.92±0.30	93.16±0.04
	a*	4.50±0.01	-1.28±0.01
	b*	12.49±0.04	12.38±0.05
Solvent retention capacity			
Water, %		117.50±3.52	73.30±3.25
Sucrose, %		149.30±2.26	95.70±2.73
Sodium carbonate, %		121.30±2.28	87.20±2.17
Lactic acid, %		130.40±3.36	126.90±2.24
GPI		0.48±0.00	0.69±0.01
Hydration properties			
Water solubility index, %	30°C	2.16±0.05	1.79±0.08
	90°C	4.28±0.07	6.43±0.04
Water absorption index, g/g	30°C	4.29±0.05	4.58±0.08
	90°C	4.83±0.05	10.11±0.10
Swelling power, %	30°C	4.48±0.08	4.80±0.05
	90°C	5.08±0.07	11.25±0.09

Thermo-mechanical properties of dough prepared from wheat flour supplemented with sorghum flour

The parameters describing the thermo-mechanical behavior of the dough prepared from wheat flour supplemented with different percentages of sorghum flour are shown in Table 3. Additionally, the Mixolab curves are depicted in Figure 1. Water absorption of wheat flour was 56.8% and gradually decreases to 55.4% with the increase of the sorghum flour level. This trend might be explained by the differences in terms of water absorption capacity of proteins from wheat and sorghum. The gluten proteins from wheat are able to bind higher amounts of water, while kafirins, the major proteins from sorghum, are more hydrophobic and bind lower amount of water (Yousif et al., 2012; Belton et al., 2006). However, the difference between WA of control and sample with 50% sorghum flour addition is not very large, most probably due the contribution of starch damage to the WA; higher starch damage was obtained in case of sorghum flour compared to the wheat flour (Table 1).

Dough stability decrease from 9.50 min for wheat flour to 4.90 min for wheat sample supplemented with 50% sorghum flour, due to the gluten dilution effect, coupled with gluten network disruption by chemicals components from sorghum flour. Yousif et al. (2012) reported that the levels of dough stability decrease depend by the type of sorghum flour incorporated into the wheat flour. Thus, in case of using white sorghum flour, dough stability decrease from 12.7 min to 9 min with increasing the levels of sorghum flour addition from 0 to 50%, while the same levels of red sorghum flour addition resulted in dough stability decrease to 5.8 min.

The C2 values slightly increased with the addition level of sorghum flour (Table 3), and this resistance of dough against deformation during kneading and heating is most likely due to the fiber content and fiber compositions. According to Vargas-Solorzano et al. (2014), the sorghum arabinoxilans are highly substituted and contain uronic acids, acetyl and feruloyl substituents, which result in a matrix which lacks flexibility (Nandini and Salimath, 2001). The C3 was in general reduced when increasing the level of sorghum flour; only a slight increase was observed for dough samples with 10 and 20% sorghum flour (Table 3). The starch gelatinization temperature decreased with increasing the wheat flour substitution level by sorghum flour. Torbica et al. (2019) and Onyango et al. (2011) indicated gelatinization temperature of 71-72°C for sorghum flour, lower compared to the wheat flour. Our results indicated that sorghum flour addition caused the significant decrease of the temperature corresponding to the C3 torque, from 81.6°C, obtained in case of wheat flour, to 77.4°C, for sample with 50% sorghum flour (Table 3). Starch gelatinization speed (beta slope) increased from 0.50 Nm/min, for wheat flour, to 0.70 Nm/min for dough sample with 50% sorghum flour. Hot gel stability (C4), cooking stability (C4/C34) and retrogradation in the cooling phase (C5) followed the same trend (Table 3). Different trends were registered between the C3 and C4 torques in the Mixolab curves of dough samples with increasing levels of sorghum flour; wheat flour substitution resulted in the increase torque values, thus the breakdown (C3-C4) registered negative values. This suggests a higher stability of gel during heating due to the decrease of amylase activity through wheat substitution by sorghum flour.

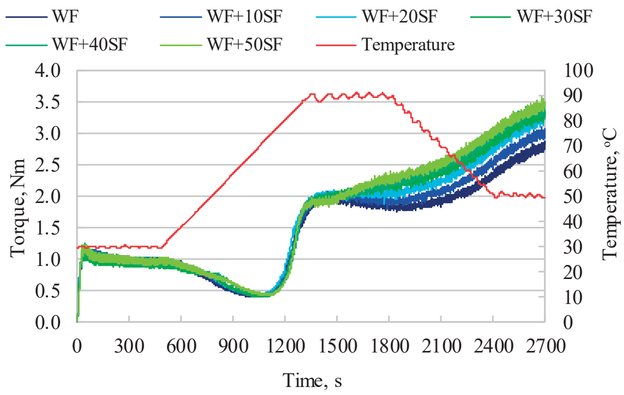

Figure 1. The Mixolab curves recorded for the blends consisting of wheat flour (WF) supplemented with different percentages (10-50%) of sorghum flour (SF)

Bread analysis

Table 4 shows the physical properties of bread samples in terms of specific volume, crumb firmness and color of bread crumb. The specific volume of the bread samples decreased with the level of sorghum flour. This decrease can be mainly attributed to the gluten dilution effect. Additionally, Taylor et al. (2006) suggested that responsible for lower volume of the bread prepared with sorghum flour might be also lipid properties, more precisely the lack of glyco and phospholipids in sorghum, when compared to the wheat. The properties of lipids as well as those of starch influence the crumb firmness. Thus, crumb firmness increased with the level of sorghum flour in the bread formulation (Table 4). The lightness value (L*) presented a significant decrease from 73.32, corresponding to the wheat flour bread, to 54.64 measured on bread sample with 50% sorghum flour. A decreasing trend was observed also in the yellowness values (b*), but to a lesser extent compared to L*. Regarding a*, all values were positive, suggesting that the red tone is dominant, most probably due the presence of high levels of anthocyanins (Yousif et al., 2012).

Table 5 shows the results of total phenol contents, DPPH-radical scavenging activity and resistant starch of bread samples. When increasing the wheat flour substitution level by sorghum flour from 0 to 50%, the TPC and DPPH-RSA of bread samples increased from 122.41 to 527.59 µmol FAE/g d.w., and from 3.90 to 25.59%, respectively. These results are explained through the TPC of wheat and sorghum flours used for preparing the breads. Thus, TPC and DPPH-RSA of wheat flour were 208.62 µmol FAE/g d.w. and 5.99%, respectively, while in case of sorghum flour, the TPC and DPPH-RSA were 1717.24 µmol FAE/g d.w. and 68.77%, respectively. According to Dlamini et al. (2007) the total phenolic content depends by the type of sorghum. Thus, the sorghum with pigmented testa, that has higher tannin content, had higher levels of TPC. Additionally, these types of sorghum had higher antioxidant activity. The phenolic acids are spread in different parts of the kernel: the free phenolic acids, represented by ferulic, p-cumaric, vanilic, caffeic, p-hydroxybenzoic and protocatechuic, are concentrated in the outer layers, namely pericarp, testa, and aleurone, while the bound form of phenolic acids, represented by gallic and cinnamic acids, are mainly associated with the cell walls (Dykes and Rooney, 2006).

The resistant starch of the bread samples increased with the level of sorghum flour used to substitute the wheat flour. Austin et al. (2012) and Taylor and Emmambux (2010), quoted by Khan et al. (2013), suggested that the inhibitory effect exerted by the sorghum polyphenols on digestive enzyme activity and the particularities of the interactions between starch and proteins from sorghum are mainly responsible for the higher content of resistant starch found in case of sorghum flours compared to the durum wheat semolina. Khan et al. (2013) reported the increase of the resistant starch of pasta prepared with wheat flour semolina and different levels of sorghum flour. Moreover, the authors noted that when red sorghum flour was used, the resistant starch from pasta was higher compared to the corresponding white sorghum flour based samples.

Table 3. Thermo-mechanical properties of the dough samples based on wheat flour (WF) supplemented with different percentages (10-50%) of sorghum flour (SF)

Parameters	Samples					
	WF	WF+10SF	WF+20SF	WF+30SF	WF+40SF	WF+50SF
WA, %	56.80±0.13^{a}	56.00±0.13^{b}	55.80±0.10^{b,c}	55.60±0.10^{c,d}	55.60±0.10^{c,d}	55.40±0.13^{d}
S, min	9.50±0.13^{a}	8.70±0.13^{b}	8.00±0.13^{c}	7.50±0.13^{d}	5.20±0.09^{e}	4.90±0.13^{e}
C2, Nm	0.42±0.02^{b}	0.42±0.01^{a,b}	0.43±0.01^{a,b}	0.43±0.01^{a,b}	0.44±0.01^{a,b}	0.44±0.01^{a}
C3, Nm	1.95±0.01^{c}	2.01±0.00^{a}	1.99±0.01^{b}	1.94±0.01^{c}	1.93±0.01^{c}	1.91±0.01^{d}
TC3°C	81.60±0.17^{a}	80.90±0.17^{b}	79.90±0.10^{c}	77.60±0.10^{d}	75.60±0.17^{e}	77.40±0.10^{d}
C4, NM	1.82±0.01^{f}	1.91±0.02^{e}	2.06±0.01^{d}	2.16±0.01^{c}	2.21±0.01^{b}	2.27±0.01^{a}
C5, Nm	2.80±0.01^{e}	3.01±0.01^{d}	3.24±0.01^{c}	3.30±0.01^{b}	3.44±0.01^{a}	3.45±0.01^{a}
C3-C4, Nm	0.14±0.00^{a}	0.10±0.02^{a}	-0.07±0.02^{b}	-0.22±0.02^{c}	-0.27±0.02^{d}	-0.36±0.00^{e}
C3/C4	0.93±0.00^{f}	0.95±0.01^{e}	1.04±0.01^{d}	1.12±0.01^{c}	1.14±0.01^{b}	1.19±0.01^{a}
Alpha, Nm/min	-0.09±0.01^{c}	-0.10±0.01^{c}	-0.11±0.01^{c}	-0.09±0.01^{c}	-0.01±0.01^{a}	-0.05±0.01^{b}
Beta, Nm/min	0.50±0.01^{e}	0.66±0.01^{b}	0.55±0.01^{d}	0.53±0.01^{d}	0.59±0.01^{c}	0.70±0.01^{a}
Gamma, Nm/min	-0.02±0.01^{d}	-0.02±0.01^{d}	0.020.01^{c}	0.06±0.01^{b}	0.06±0.01^{b}	0.08±0.01^{a}

The mean values in each line that do not share a letter are statistically significant (p≤0.05).

Table 4. Physical properties of bread samples prepared with blends consisting of wheat flour (WF) supplemented with different percentages (10-50%) of sorghum flour (SF)

Breads	Specific volume, cm^3/g	Crumb firmness, g force	Color of bread crumb		
			L*	a*	b*
WF	3.66 ±0.10^{a}	763.05±3.69^{f}	73.32±0.14^{a}	0.40±0.05^{f}	24.78±0.11^{a}
WF+10SF	3.45±0.08^{b}	1045.00±2.65^{e}	67.37±0.10^{b}	2.38±0.08^{e}	19.91±0.09^{b}
WF+20SF	3.28±0.05^{b}	1086.41±2.12^{d}	63.07±0.12^{c}	4.00±0.05^{d}	19.33±0.04^{c}
WF+30SF	2.87±0.05^{c}	1154.22±3.01^{c}	59.05±0.09^{d}	5.03±0.05^{c}	18.54±0.07^{d}
WF+40SF	2.76±0.05^{c}	1321.24±2.39^{b}	56.67±0.12^{e}	6.27±0.10^{b}	18.68±0.09^{d}
WF+50SF	2.41±0.08^{d}	1351.94±2.25^{a}	54.64±0.07^{f}	6.79±0.12^{a}	17.82±0.03^{e}

The mean values in each column that do not share a letter are statistically significant (p≤0.05).

Table 5. Total phenol, antioxidant activity and resistant starch of bread samples prepared with blends consisting of wheat flour (WF) supplemented with different percentages (10-50%) of sorghum flour (SF)

Breads	Total phenol content, µmol ferulic acid equiv/g d.w.	DPPH-radical scavenging activity, %	Resistant starch, %
WF	122.41±0.72^{f}	3.90±0.10^{f}	1.09±0.10^{f}
WF+10SF	156.90±0.45^{e}	8.47±0.16^{e}	1.40±0.11^{e}
WF+20SF	329.31±0.54^{d}	12.98±0.21^{d}	2.04±0.08^{d}
WF+30SF	372.41±0.72^{c}	15.93±0.18^{c}	2.63±0.10^{c}
WF+40SF	450.00±0.72^{b}	19.60±0.15^{b}	3.04±0.09^{b}
WF+50SF	527.59±0.76^{a}	25.59±0.23^{a}	3.45±0.08^{a}

The mean values in each column that do not share a letter are statistically significant (p≤0.05).

CONCLUSIONS

Thermo-mechanical properties of dough are modified with increasing the substitution level of wheat flour by sorghum flour. Water absorption and dough stability decreases due the dilution effect of gluten coupled with gluten network disruption caused by different compounds arising from sorghum flour. The protein weakening slightly increased with the addition level of sorghum flour. The dough resistance to deformation during kneading and heating was mainly ascribed to the presence and profile of fibers in the complex dough matrix. Starch gelatinization speed, hot stability and cooking stability increased with levels of wheat flour substituted with sorghum flour. The baking test indicated that the specific volume of the wheat flour based bread samples decreased, while the crumb firmness increased with the level of sorghum flour in the mixture. The red tone was found to be dominant in the breads crumb and was ascribed to the presence of anthocyanins. Finally, the addition of sorghum flour to the wheat flour resulted in bread samples with increased total phenols content, antioxidant activity and resistant starch.

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