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Physicochemical and rheological properties of Sudanese wheat flours in comparison with imported flour

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Abstract

The chemical composition and relative concentration of major and minor fractions in wheat flour differs with cultivar and growth conditions that may influence the dough's rheological properties. Thus, the current study was conducted to compare the physicochemical and rheological properties of wheat flour obtained from two Sudanese cultivars namely, Alneelain and Imam, and imported cultivars. Alneelain flour presented significantly ($p \leq 0.05$) higher crude fat, crude fiber and minerals compared to Russian and Australian wheat flour. Similarly, Imam flour showed relatively higher crude proteins, crude fiber and ash compared to imported wheat cultivars. Australian variety had the highest wet gluten (33.77g) and dry gluten (11.23%) and gluten index (93.93%), whereas the Alneelain depicted the least. Similarly, significantly ($p \leq 0.05$) higher falling number was seen for the Australian wheat in comparison with Sudanese wheats. Amylograph data showed the highest gelatinization temperature with a gelatinization maximum (1568 Au) for the Imam wheat flour. However, Australian wheat flour portrayed the highest dough stability (5.6 min), dough development time (4 min) and water absorption (59.7%) compared to Sudanese counterparts. Extensograph results indicated that the Alneelain dough has the highest resistance to uniaxial extension (624 BU), which improved further with increasing proofing time. Conversely, the highest energy (126 cm^2) and extensibility (189 mm) were seen for the dough developed from Australian wheat. Thus, Australian wheat provided better dough rheological properties in comparison to the local cultivars.

Keywords: Alneelain wheat, falling number, gelatinization temperature, dough stability, dough extensibility

1. Introduction

Wheat consumption has expanded dramatically in recent years as a result of worldwide population expansion, and consequently, wheat production plays a critical role in food security and the global economy. As a result, horizontal expansion of wheat production has occurred in recent years, with wheat being moved into previously considered unsuitable producing locations. However, global warming has brought a variety of abiotic challenges such as drought, temperature extremes, and salt, all of which have a negative impact on wheat production and grain quality (Huseynova and Rustamova, 2010). Wheat agriculture was recognized in northern Sudan, although the area planted never surpassed 1500 hectares until the end of the 1950s. The output was sufficient to meet the consumption demands of northern Sudan and the major towns. The rest of Sudan's population is dependent on sorghum in the center and east, dukhn in the west, and cassava in the south. With the exception of wheat, all of these crops are grown in wet conditions (Ministry of Agriculture and Forestry, 2007). Wheat consumption in Sudan has risen considerably, from around 220,000 tons in 1970/71 to 2,652,000 tons in 2022, owing to population increase and growing per capita consumption.

Bread can only be produced with imported high gluten wheat, which is climatically unsuitable for growing in tropical climates (Edema *et al*., 2005). Sudan's regional grain production is inadequate and is considered scarce for baking purposes due to the low quality and quantity of protein and gluten and low alpha-amylase activity (Ishag, 1994). Mills in Sudan spend a lot of foreign currency importing grain for bread and other baked goods. Wheat varieties have a high gluten level, they are known as "white" or "brown," and if the gluten concentration is low, they are known as "soft" or "weak flour." Hard flour, also known as "bread" flour, is high in gluten and thus has a toughness that helps it keep its shape once baked (Barry, 1981). Wheat flour is so widely used because of an important property: when wheat flour is mixed with water, a complex protein called gluten develops. The gluten development is what gives the wheat dough an elastic structure that allows it to be worked in a variety of ways, and which allows the retention of gas bubbles in an intact structure, resulting in a sponge-like texture to the final product. This is highly desired for bread, cakes, and other baked products. Flour is always based on the presence of starches, which are complex carbohydrates (Allen, 2000). Rheological properties of dough are determined by factors during kneading, bread formation, and ascent, and some studies have reported a significant association between rheological properties and baking performance (Tronsmo *et al*., 2003). Rheological analysis is often used to investigate the function of dough formulations because it is closely related to component interactions (Noorfarahzilah *et al*., 2014; Tronsmo *et al*., 2003).

Starch grain size has been reported to effect on the dough rheology properties and smaller grains increase the elasticity of the dough (Edwards *et al*., 2002; Tao *et al*., 2016). The composition of the dough has a significant impact in the preparation of bread. Contains all components and creates a unique viscoelastic gluten network (Letang *et al*., 1999). Gluten related tissue water absorption, mixing time, and strength index. More than 80% of the gluten protein is composed of gliadin and glutenin (Shewry *et al*., 2002; Shewry, 2009). Gliadin (ω, α,) is a relatively small, alcohol-soluble molecule that acts as a plasticizer for the dough system (Goesaert *et al*., 2005). Gluten, on the other hand, is a heterogeneous polymer as the high molecular weight (HMW-GS) glutenin subunit and the low molecular weight (LMW-GS) glutenin subunit (Shewry *et al*., 2002). Glutenin also contributes to the mixing resistance, elasticity, and cohesion of the dough web (Wieser and Kieffer, 2001). The gluten portion is hydrated and forms a protein network when water is added to the flour, which is a key aspect in determining the characteristics of dough (Autio *et al*., 2005). This study was aimed to evaluate the physicochemical properties and rheological properties of Sudanese wheat flours (Alneelain and Imam) in comparison with imported flour (Russian and Australian).

2. Methodology and methods

2.1. Materials

Australian and Russian wheats were obtained from local Flour Mills and the Sudanese wheats (Alneelain and Imam) were obtained from Agricultural Research Corporation, Wad medani, Sudan. While the chemicals were obtained from Sesaban Company (Sudan) and Department of Food Industries (Industrial Research and Consultancy Center).

2.2. Proximate analysis

Moisture content, Protein content, Ash content, Crude Fat and Crude Fiber were done according to AOAC (2003). Available carbohydrate was calculated by difference according to Pearson (1970) using the following formula: Available carbohydrates% = 100 -(moisture%+ crude fat %+ crude protein %+ ash% + crude fiber %).

2.3. Gluten quantity and quality

About 10 g from samples were mixed with 5 ml distilled water by using Glutomatic according to ICC method (ICC, 2001a) to determine the gluten quantity and quality, after obtaining the dough then washed with a NaCl 2%, gluten was centrifuged and weighed. The % wet gluten was calculated by (the dried gluten multiplying by 10).

2.4. Falling number test

To measure the enzyme activity in flour samples we used the falling number according to AACC, method #56–81.03, (2000).

2.5. Dough development by farinograph

The Brabender farinograph was used to determine the water absorption capacity to reach a peak of 500 FU using a 300 ± 0.01 g sample at a 14% moisture basis after moisture correction. Samples were mixed at a speed of 63 rpm and at a temperature of 30 ◦C. For each sample, measurements were taken three times at least. The water absorption (%), dough development time (min), stability (min), softening (FU), and the quality number was calculated by using the mixing curve.

2.6. Extensograph analysis

A Brabender extensograph was used according to ICC (2001b) for determining the rheological properties of flours in terms of Energy (cm2), Resistance to extension (BU), Extensibility (mm), and Maximum Resistance (BU). The dough samples were prepared by farinograph, but due to the addition of 2% salt, the amount of water used for mixing was reduced by 2%, and the dough samples were mixed for 5 min. Then each dough was divided into 3 pieces of 150g, shaped on a baler, roll them into cylindrical test pieces with a rolling pin, fix them on a dough rack, and store in a standing cabinet for 45 minutes. Place the dough on the balance arm of the extensometer and stretch through the tension hook until it breaks. The test is performed at 45, 90, and 135 min intervals.

2.7. Amylograph analysis

The gelatinization properties of flour samples were measured according to the (ICC,2001c) method by Amylograph. Briefly, 80g of sample with 450 ml of distilled water was heated 30°C to 90°C at a heating rate of 1.5°C/min. The viscosity of the slurry was recorded as a function of temperature. The resulting profile shows the beginning and maximum gelatinization and gelatinization temperature.

2.8. Statistical analysis

All data were obtained in three replicates, and the variance was analyzed by A one-way analysis of variance (ANOVA) using SAS software (SAS Institute, Inc., Cary, NC, USA), and Duncan's multiple range tests were used to compare the means at $p \leq 0.05$ (Montgomery, 2001).

3. Results and discussion

3.1. Proximate composition

The proximate composition of Sudanese wheat samples in comparison to Russain and Australian wheat samples are shown in Table 1. The moisture contents of Alneelain, Imam, Russian and Australian wheat were 10.67%, 10.36%, 10.37% and 10.51%, respectively. The results of moisture content for Alneelain, Imam, and Australian wheat showed a significant difference ($p \leq 0.05$). However, the wheat samples for Imam and Russain wheat samples were found non significant for moisture contents. All the tested samples were low in moisture content, this allow greater stability against spoilage as the flour with low moisture is more stable during the storage time (Mustapha et al., 2014). Therefore, the moisture of flour must be less than 15% (Kunkulberga and Seglins, 2010). Ash content ranges from 1.79% for Alneelain, 1.82% for Imam, 1.45% for Russia and 1.40% for Australian wheat. We found a significant difference ($p \leq 0.05$) in ash content between all samples. In addition, these results were higher than the finding of Mutwali et al. (2016) which was 0.47-0.85% in 20 Sudanese wheat varieties. The differences in these results revealed that the location of wheat production had a considerable influence on ash content of flour, the differences in soil conditions, temperature, water, and fertilizers could be had also a role. The percentage of ash in flour has long been considered to be a good marker of its quality. It is closely related to the amount of bran in wheat and hence has a rough inverse relationship to flour yield, and it gives some indication of the miller's talents and the degree of refinement in processing (Zeleny, 1971). The protein contents of two Sudanese wheat varieties, Alneelain and Imam, and two imported wheat varieties were 12.4%, 13.81%, 12.87% and 13.70%, respectively. The results of protein content for imam and Australian flours was not significantly different ($p \leq 0.05$), but a significant difference ($p \leq 0.05$) between alneelain and Russian flours. These results in the range with Anjum et al. (2005) and Khan et al. (2009) studies, they reported that the protein content of Pakistani wheat varieties ranged from 9.68% to 13.45% and from 10.23% to 11.60%, respectively, but Elagib (2002) reported that the protein content of whole wheat flours varied from 9.37% to 11.77% between Sudanese varieties range fluctuations. This may be due to differences in growth conditions and genotypes. Wheat crude protein content is thought to be affected significantly by environmental factors, available nitrogen, and cultivar (Khan et al., 2009). Analysis showed no significant difference in protein content between Iman and Australian wheat ($p \leq 0.05$). Furthermore, the results are also within the optimal range that was found by Mailhot and Patton (1989). The crude fat contents of Alneelain, Imam, Russian and Australian wheat were 1.88%, 1.58%, 1.80% and 1.71%, respectively. Significant differences ($p \leq 0.05$) in fat content were observed for Alneelain, Imam, Russia, and Australia. These values are consistent with the results of Elagib (2002), who found that the Debaira and Alneelain varieties had a fat content of 2.0% and 1.8%, respectively. The fiber content of Sudanese wheat varieties is 3.19% (Alneelain) and 3.21% (Imam), while imported wheat contains 2.50% (Russian wheat) and 1.46% (Australian wheat). These results were higher than Ahmed (1995) and Mohammed (2000) notes, they reported that the dietary fiber content of whole grains was 1.75% to 2.34% and 1.85% and 2.25%, respectively.

Wheat flour	Moisture (%)	Ash (%)	Crude protein (%)	Crude Fat (%)	Crude fiber (%)	Available carbohydrates (%)
Alneelain	10.67±0.01[a]	1.79±0.01[b]	12.41±0.04[c]	1.88±0.03[a]	3.19±0.01[a]	70.06±0.10[a]
Imam	10.36±0.01[c]	1.82±0.01[a]	13.81±0.08[a]	1.58±0.02[d]	3.21±0.20[a]	69.22±0.06[b]
Russian	10.37±0.01[c]	1.45±0.02[c]	12.87±0.02[b]	1.80±0.02[b]	2.50±0.02[b]	71.01±0.10[c]
Australian	10.51±0.02[b]	1.40±0.01[d]	13.70±0.07[a]	1.71±0.02[c]	1.46±0.05[c]	71.22±0.17[c]

Table 1: Proximate composition of wheat flour samples
Values are means (±SD) of triplicate

3.2. Gluten quality and quantity

Table (2) shows the amount of gluten (wet, dry, gluten index) in wheat flour Alneelain, Imam, Russia, and Australia. Wet gluten content ranged from 25.40% to 33.77%. A smaller amount was found in Alneelain, but a higher amount was found in Australian flour. Wet gluten content in Pakistan's spring cultivars has been reported between 28.47% and 38.83% (Khan et al., 2009).

The dry gluten content of Alneelain, Imam, Russian and Australian wheat flours was 8.47%, 8.97%, 9.57%, and 11.23%, respectively. A significant difference ($p \leq 0.05$) in dry gluten content between wheat flours of the four cultivars investigated was observed. Moreover, Mutawali et al. (2016) found that the wet gluten value of 20 Sudanese cultivars was (28.63% - 46.94%). However, Sudanese Standard Specification recommended minimum wet gluten value in wheat flour to be 27% for bread making (SDS 036/2007). Table 2 shows the gluten index values for Sudanese (Alneelain, Imam), Russian and Australian flour. The gluten index ranged from 65.57% to 93.93%. It is worth saying that the gluten index for Sudanese wheat that is used for bread is between (55-100). Curic et al. (2001), note that the gluten index between (75-90) is good for bread in Central European varieties. while, in Israel, the grain that has a gluten index lower than 40 is used only for an animal feed so their price is lower than for bread-making grain. Analysis of variance showed no significant difference between Russian and Australian wheat flour in their gluten index values. Imam wheat flour gained higher values of gluten index than Alneelain wheat flour.

Table 2: Gluten quality and quantity of wheat flour samples

Wheat flour	Wet gluten (g)	Dry gluten (%)	Gluten index (%)
Alneelain	25.40±0.70[d]	8.47±0.06[d]	65.57±0.49[c]
Imam	26.97±0.15[c]	8.97±0.06[c]	75.87±3.44[b]
Russian	28.77±0.25[b]	9.57±0.25[b]	93.27±1.71[a]
Australian	33.77±0.10[a]	11.23±0.25[a]	93.93±0.21[a]

Values are means (±SD) of triplicate

3.3. Falling number

The falling number data of the two Sudanese cultivars and the two imported wheat flours were presented in Fig 1. The activity of α-amylase for samples were between 367.00 sec to 1031.33 sec. The falling number of Alneelain, Imam, Russian and Australian wheat flours was 870.67 sec, 750.00 sec, 367.00 sec and 1031.33 sec, respectively. The falling number of Australian flour was higher than the normal limit compared with other wheat flour, this could be due to dry harvest season of Australian wheat which caused low activity of alpha-amylase and leading to an increase in falling number. This result is in agreement with Makawi et al. (2013) who found that the falling number of Australian flour was 1027.00 sec. Likewise, Mutwali et al. (2016) reported higher falling numbers for 20 Sudanese wheat varieties, ranging from 508 to 974 seconds. The higher drop figures might be due to a dry harvest season, which affected alpha-amylase activity. In contrast, Ahmed (1995) showed that some Sudanese wheat varieties experienced falling numbers between 396 and 486 seconds. However, Mohammed (2000) found reductions between 425 and 675 seconds for four Sudanese wheat varieties (Debaira, Alneelain, Condor and Sasaraib). Differences in wheat flour declines can be attributed to changes in genotype and environmental conditions. Drop numbers over 400 seconds indicate a lack of alpha-amylase, which should be added to flour to obtain the desired enzymatic activity (Cauvain and Young, 2001).

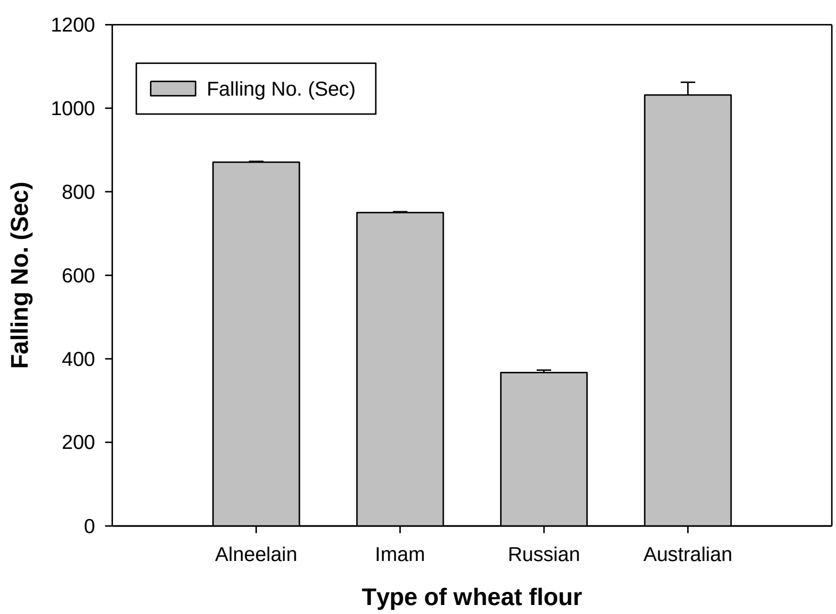

Fig 1: Falling number of local and imported wheat flour samples

3.4. Amylograph analysis

The amylograph results of the wheat flours are presented in Table 3. The maximum gelatinization temperature of Alneelain, Imam, Russian and Australian wheat was 87.5°C, 88.9°C, 88.1°C, and 89.1°C, respectively. Alneelain flour shows lower gelatinization temperature while the highest was observed in Australian flour. The high gelatinization temperature of starch is beneficial for the volume expansion that is to say there is more time for the volume to increase before the fixation of the crumb. Kim and Shin (2014) reported that the pasting properties were influenced by the quantity and quality of starch and the particle size of flour. As well as, the protein content has a great influence on the paste temperature of the samples (Barak et al., 2013).

Table 3: Amylograph data of wheat flour samples

Wheat flour	Beginning of gelatinization (°C)	Maximum Gelatinization temperature (°C)	Gelatinization maximum (Au)
Alneelain	74.5±1.20[a]	87.5±0.45[a]	700.0±3.76[d]
Imam	61.5±0.44[b]	88.9±0.67[a]	1568.0±5.98[a]
Russian	61.1±0.18[b]	88.1±1.07[a]	925.0±4.59[c]
Australian	59.5±0.42[c]	89.1±0.22[a]	1309.0±8.99[b]

Values are means (±SD) of triplicate samples; Means not sharing a common superscript letter in a column are significantly different ($p \leq 0.05$).

3.5. Dough development by farinograph

Table 4 shows the farinograph results. The results showed that the water absorption values of the flour samples varied between 56.1% and 59.7%. Generally, if the wheat flour had a high water absorption it meaning that a good baking performance. Alneelain (56%) had lower water absorption, followed by Imam flour (58.5%), Russian flour (59.6%) and Australian flour (59.7%). Due to the high protein content, Australian flours have the highest water absorption and therefore have good baking properties. Mutwali et al. (2016) study, notes that the water absorption was (57% -62%) for different Sudanese wheat varieties that are grown at three different sites. on the other hand, Mailhot and Padlon (1989) reported that the optimum water absorption of wheat flour for bread making is between (60%- 64%).

Table 4: Farinograph data of dough development of different wheat flours

Wheat flour	Water absorption %	Dough development time (min.)	Dough stability (min.)	Degree of softening (F.U.)	Farinograph quality number
Alneelain	56.1±0.21[c]	1.5±0.01[c]	2.0±0.01[c]	181.0±0.67[a]	22.0±0.01[c]
Imam	58.5±0.10[b]	1.5±0.02[c]	1.8±0.02[c]	158.0±0.88[c]	22.0±0.03[c]
Russian	59.6±0.04[a]	2.3±0.03[b]	2.5±0.03[b]	176.0±0.36[b]	33.0±0.45[b]
Australian	59.7±0.09[a]	4.0±0.04[a]	5.6±0.08[a]	91.0±0.87[d]	66.0±0.88[a]

Values are means (±SD) of triplicate samples; Means not sharing a common superscript letter in a column are significantly different ($p \leq 0.05$).

The dough development times is important as it brings about the improvement in its ability to retain CO_2 gas varied between as highest as 4 min of Australian wheat and the lowest 1.5 min were found in both Sudanese wheat flours. Mutwali et al. (2016) study showed a higher dough development time for another Sudanese wheat (1.68 to 5.16 min). Alneelain flour recorded the highest degree of softening (181 F.U) followed by Russian wheat flour (176 F.U), Imam wheat flour (158 F.U.) and Australian wheat flour (91 F.U). The Farinograph quality number of Australian wheat flour was higher (66) than the other three wheat flours which gave 33 (Russian) and 22 (Imam and Alneelain). Dough stability time varies between 1.8 min (which was obtained from Imam wheat flour indicating weak flour) and 5.6 min (obtained from Australian wheat which is considered a strong flour). Recently it was noted that the dough stability of Sudanese wheat cultivars flour was (2.0 and 6.2 min) (Mutwali et al. 2016). Mailhot and Patton (1989) recommended minimum dough stability should be 7.5 min for bread making.

2.6. Extensograph analysis

Extensograph provides information on the viscoelastic behavior of dough (Rosell et al., 2001). The combination of good consistency and good extensibility leads to desired dough properties (Walker and Hazelton, 1996). According to extensograph data, the changes of dough consistency, impact of enhancing products, a total volume of products, can be predicted. Based on this, selection of appropriate type of flour, additives, and other quality-enhancing products can be made for the final desired properties of bakery products (Bojňanská et al., 2013). The extensogram results of the flours are shown in Table 5. The Australian, Russian, Imam, and Alneelain flour samples showed an increase in the energy and resistance to extension at 45 min, 90 min, and 135 min. The maximum resistance (BU) of all wheat flour increased during proofing time. Extensibility (mm) of Iman, Russian and Australian wheat flour doughs decreased during proofing time.

Rheological properties of the imported wheat flours compared with local wheat flour showed higher water absorption, resistance to extension, medium extensibility, longer development time and stability compared to local wheat. These results are in agreement with Williams et al. (1970) who reported that the strong wheat has high water absorption, resistance to extension coupled with good extensibility and longer development time and stability when compared with the weak one.

Table 5: Extensogram data of wheat flour samples

Wheat flour	**Proofing time**		
	45	**90**	**135**
Alneelain wheat flour			
Energy (cm^2)	69	94	112
Resistance to extension (BU)	432	543	624
Extensibility (mm)	104	113	117
Maximum Resistance (BU)	447	571	671
Imam wheat flour			
Energy (cm^2)	115	116	106
Resistance to extension (BU)	395	445	431
Extensibility (mm)	160	148	142
Maximum Resistance (BU)	510	571	538
Russian wheat flour			
Energy (cm^2)	101	108	98
Resistance to extension BU)	346	374	403
Extensibility (mm)	157	154	143
Maximum Resistance (BU)	509	547	554
Australian wheat flour			
Energy (cm^2)	101	126	124
Resistance to extension (BU)	256	359	366
Extensibility (mm)	189	179	173
Maximum Resistance (BU)	400	545	583

4. Conclusion

This study was designed to assessed the physicochemical and rheological behaviors of four wheat cultivars. Among the four cultivars, Alneelain and Imam were the two Sudanese cultivars while one Russian and one Australian cultivar was also studied. Sudanese wheat cultivars showed better proximate profile, i.e., crude protein, fat, ash and fiber, compared to the imported counterparts. Nonetheless, the Australian wheat flour presented the highest gluten quantity while Imam flour depicted the highest gelatinization temperature compared to other cultivars. The better dough rheological data, i.e., dough stability, water absorption and extensibility were seen for the Australian wheat dough followed by the Russian wheat and then by the Sudanese cultivars. This suggested that the imported wheat cultivar has strong flour with a probably good dough handling and bread-making properties compared to the Sudanese cultivars. Furthermore, bread baking should be conducted to evaluate the real time impact of all the wheat flours on the final bread quality and acceptability.

Conflict of Interest

The authors declare that they have no conflict of interest.

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