Quality of Bread from Composite Flour of Sorghum and Hard White Winter Wheat

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Dedication

To my mother,

father,

husband,

and my daughter

who inspired and encouraged me to undertake

this study.
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Abstract

This study was carried out to investigate the chemical, physical, rheological and baking properties of whole, decorticated sorghum-wheat composite flours as well as to determine the organo-liptic quality of the breads.

Moisture, ash, fat, crude protein, carbohydrate and mineral contents of whole, decorticated (70% extraction) sorghum and hard white winter wheat (72% extraction) flours were determined. The whole and decorticated sorghum flours were used to replace 5, 10, 15, and 20% of wheat flour to use in bread. Rheological properties of the dough and physical characteristics of both types of bread (pan and balady) as well as their organo-liptic evaluation were also determined.

The results indicated that wheat flour has higher protein, moisture and calcium values, and lower fat, ash, carbohydrates, iron, and phosphorous values compared to whole and decorticated sorghum flours. The results also revealed that the decortication process of sorghum grains decreased moisture, ash, fat, crude protein, iron and phosphorous content, however, it increased carbohydrates content.

Rheological properties showed that, the farinogram properties, dough water absorption, development time, stability time and farinograph quality number decreased as the amount of the substitution increased, while the mixing tolerance index increased. Moreover, at fixed gluten levels, with sorghum flours increased, wet gluten, dry gluten and gluten index decreased. The extensogram results showed that, the energy, resistance to extension, and extensibility of the dough decreased as the level of substitution was increased, while the ratio between resistance and extensibility increased. And as the fermentation time increased, the energy, resistance to extension, and ratio number increased, while the extensibility decreased.

As the amount of sorghum flours increased a reduction in circumference of balady bread and specific volume of pan bread was observed. On the other hand the pan bread samples with whole sorghum flour had lower L values and higher a and b values for crumb color when compared to those with decorticated sorghum flour. Texture properties, cohesiveness and resilience, of pan bread were decreased with increasing the level of substitution, while hardness and gumminess increased significantly (p ≤ 0.001). However, no significant difference was observed on
springiness and chewiness. The sensory evaluation results of breads (pan and balady) showed that the replacement of bread flour with up to 20% whole or decorticated sorghum flour produced acceptable pan and balady breads, although increasing the level of substitution caused decreases in all sensory properties, except odor.
خلاصة الأطروحه

هذة الدراسة لى استقصاء الخصائص الكيميائية، الفيزيائية والروبوتيه لدقيق القمح المخلوط، بدقة الذرة الكامل والمقصور، بالإضافة إلى معرفة التقييم الحسي للخبز المصنع منه.

تمّ تقدير نسبة محتوى الرطوبة، الدهم، البروتينات الخام، الكاربونيدات والمعدن تعينات الذرة الكامل والمقصور (درجة استخلاصه 70%) ودقيق القمح القوي الشتوي الأبيض (درجة استخلاصه 72%). كذلك تمّ استبدال 5، 10، 15 و 20% من دقيق القمح بدقيق الذرة الكامل والمقصور لتحضير الدقيق المخلوط، ومن ثمّ اختبار خواصه البروتيه وخبزه. أيضاً تمّ اختبار الخواص الفيزيائية والحسية لخبز البلدي والخبز الشرائح.

أظهرت النتائج أن دقيق القمح يحتوي على نسبة عالية من محتوى الرطوبة، البروتينات الخام، والكلسيوم، ونسبة أقل من محتوى الدهم، الكاربونيدات، الحديد، والفسفر عند مقارنته مع دقيق الذرة الكامل والمقصور. لذلك بُنيت النتائج أن عملية التقييض لحبوب الذرة أدت إلى تقليل محتوى الرطوبة، الدهم، البروتينات الخام، الحديد، والفسفور، بينما أرتفع محتوى الكاربونيدات.

كما أوضحت نتائج الفارينوفرف أن امتصاص الماء، زمن تكوّن العجين، موتر تحمل العجين لحلق، ورقم العجلة يخفض بأزيد من نسبة الدقيق المستبدل، بينما تزايد درجة الضعف. علاوة على ذلك، عند ثبات مستوى القلوتين، وزيادة نسبة دقيق الذرة المضافة، يخفض القلوتين الرطب والجاف وعمالة القلوتين في العجين.

كذلك أوضح نتائج الأكستسورراف أن الطاقة، المقاومة للتمدد، وقابلية العجين للتمدد تنخفض كمما زادت كمية الدقيق المستبدل، بينما تزداد النسبة بين المقامة وقابلية العجين للتمدد. بالإضافة إلى ذلك، كما زاد الزمن، زادت الطاقة، القابلية للتمدد، ورقم النسب للعجين، بينما تنخفض قابلية العجين للتمدد.

كما زادت نسبة دقيق الذرة المضافة، لوحظ انخفاض في محيط الخبز البلدي والحجم النوعي لخبز الشرائح، من ناحية أخرى اعتن لبابة خبز الشرائح المستبدل بدقيق الذرة الكامل أقل قيم L-value وأعلى قيم b-value عند مقارنتها مع تلك المستبدلة بدقيق الذرة المقصور. كذلك أظهرت خصائص القوام لخبز الشرائح أن عند زيادة نسبة الدقيق المستبدل يخفض الامساك والمرونة في الخبز (hardness and gumminess)، بينما تزداد الصلابة والنزوجة (cohesiveness and resilience) الخبز معنويو (0.001 ≤ p ≤ 0.001) من ناحية أخرى لا يوجد اختلاف معنوي في خصائص الاسترجاع والمضخ (Springiness and chewiness).

كما بُنيت نتائج التقييم الحسي أن الخبز (من كلا النوعين) المصنف بالدقيق المخلوط حتى 20% دقيق ذره كامل أو مقصور فهو مقبول، بالرغم من أن أزيد من كمية الدقيق المستبدل أدت إلى انخفاض كل الخواص الحسية، عدا النكهة.
CHAPTER ONE
1. INTRODUCTION

Bread is a baked product made from wheat or rye. Bread is an important staple food in both developed and developing countries. Wheat flour of both hard and soft wheat classes has been the major ingredient of leavened bread for many years because of its functional proteins. In the Sudan, the consumption of wheat bread is increasing in both rural and urban areas as a consequence of changing taste, convenience and consumer subsidies. However, bread is being made from imported wheat which is not suitable for cultivation in the tropical area for climatic reasons.

The local production of wheat, in the Sudan, is insufficient for local consumption, and the Sudanese mills spend much money to import wheat flour for bread and other baked products. This situation necessitated the need to find a replacement for wheat in bread making using a local cereal, legumes and root crops. Several developing countries have encouraged the setting up initiation of programs to evaluate the feasibility of alternative locally available flours as a substitute for wheat flour. Many efforts have been carried out to promote the use of composite flours in which flour from locally grown crops replace a portion of wheat flour for use in bread, thereby decreasing the demand for imported wheat. The United Nations Food and Agriculture Organization (FAO) launched a program known as “Composite Flour Project” (1964). This program was intended to introduce non-wheat cereals, root crops and tubers into bread baking. The out put of the program was encouraging when wheat was partially substituted with low quantities of non wheat flours or starches. However, the bread produced from non-wheat flours was acceptable compared to that made of wheat.

Moreover, many international institutions were invited by FAO to carry out research studies in order to develop composite bread that will include other cereals, roots and tubers. The findings of these researches were encouraging at the level of laboratories, with less acceptable results at the commercial level. In Africa, the Sudan, Nigeria, Ghana, Sierra Leone and Senegal successfully many composite bread programs were developed using both sorghum and millet flours.

Sorghum is the staple food crop in the Sudan where it is consumed in fermented forms, mainly as Kisra (local thin bread), aceda (thick porridge) and nasha
(thin porridge). Several studies have indicated the possibility of incorporating sorghum both as whole and decorticated grain in wheat flour at various levels to produce bread when wheat is in short supply.

The objective of this study was to evaluate the chemical, physical, rheological and baking properties of whole and decorticated sorghum-wheat composite flours as well as to determine the organoliptic acceptability of the resulting breads.
CHAPTER TWO

2. LITERATURE REVIEW

2.1. Wheat:

Wheat is one of the most important cereal crops grown worldwide and it ranks first among cultivated plants of the world and provides more nourishment to the people than any other food source. It contributes substantially to the feeding of domestic animals (Elshewaya, 2003). In the Sudan wheat is the second most important cereal, after sorghum, in terms of consumption. The Sudan has been cultivating wheat in the north for thousands of years. With urbanization, in the past 50 years, food traditions have changed, and wheat consumption has soared to about 1 million tones per year. Wheat is grown in the Sudan in the winter months only. Wheat planting takes place from the last week in October to the 2nd week in December (FAO, 2001).

The Sudan is one of the fastest growing wheat markets in the world; therefore the emphasis is on expanded wheat output. Wheat consumption in the Sudan is low when compared to other Middle Eastern countries, but high in comparison to other African countries (Tyler, 2003).

2.1.1. Chemical composition of wheat

The wheat grains contain 85% endosperm, 12.5% bran and 2.5% germs. The composition of wheat flour, however, varies considerably according to the class of wheat, its country of origin and the proportion of outer parts removal by particular milling process (Elias, 1972).

2.1.1.1. Moisture Content

Moisture content has a direct economic importance and a significant influence on the shelf life of wheat flours (Sluimer, 2005). Wheat generally contains 14% moisture resulting in an ambient relative humidity suitable for the growth of insects and other microorganisms whose presence will markedly reduce the grain quality (Williams, 1970; Zeleny 1971). On the other hand, Sluimer (2005) stated that the
moisture content of wheat flour usually varies between 12 and 16%, 12% being very dry and 16% very moist. The percentage might change overtime.

Pareds-Lopez et al. (1978) found that the moisture content of Mexican wheat flour was 11.2%. The moisture content of wheat flour of three Sudanese wheat cultivars, Sasaraib, El-Nielain and Debeira, (72% extraction rate) were found to be 13.57, 13.57 and 13.73% respectively (Hassan, 2005), while Badi et al. (1978) reported that the moisture content of Sudanese wheat flour range between 10-11%. However, the moisture content of soft wheat flour (82% extraction) that was milled from white Australian wheat was 12.9% as reported by Abdel-Kader (2000). The moisture content of two types of wheat flour, (whole meal [82% Ext.] and all purpose flour [73% ext.]), were 11.1 and 10.7% respectively (Abd Alrahman, 2005).

Codex alimentarius commission (CODEX) (1995b) reported that the maximum moisture content for wheat flour is 15.5% while lower moisture limits are required for certain destinations in relation to the climate, duration of transport and storage.

2.1.1.2. Ash Content

The minerals content of the various milling fractions is determined as ash percentage. The average ash content of the outer layers of the wheat kernel is 8%, the aleurone layer is 15%, and the starchy endosperm is 0.4%. For white flour, ash content is often used as a parameter for baking quality, where, flour with ash content higher than 0.60% results in lower loaf volumes (Sluimer, 2005). Ash content of wheat is directly related to the amount of bran in the wheat, and hence has a rough inverse relationship to flour yield (Elshewaya, 2003). Ash content varies between about 0.45% (dry matter basis) for patent flour, resulting in bread with a white crumb, and about 1.8% for whole wheat flour, which gives a dark crumb color (Sluimer, 2005).

The ash content of the wheat flour was found to be in the range of 1.4 to 2.0% (Zeleny, 1971), while Pareds-Lopez et al. (1978) reported that ash content of Mexican wheat flour (69% extraction) range between 0.31-0.62%. Egan et al. (1981) reported that ash content of whole meal wheat flour ranges between 1.2-1.8% and for
72% extraction rate about 0.45%. Badi et al., (1978) reported that ash content of Sudanese wheat flour ranges between 1.38 - 1.84%.

D'appolonia and Young (1978) found that ash content of wheat flour (whole meal) was 1.85%, while Pomeranz and Dikeman (1983) reported that the ash content of hard red winter wheat flour was found to be in the range of 1.82-2.0%. Whereas the ash content of soft wheat flour (82% extraction) milled from white Australian wheat was 0.61% as reported by Abdel-Kader, (2000).

Hassan (2005) studied the ash content of wheat flour of three Sudanese wheat cultivars, Sasaraib, El-Nielain and Debeira, (72% extraction rate). He found that the ash values were 0.53, 0.43 and 0.62% respectively. It was also found that the ash content of two types of wheat flour (whole meal and all purpose flour) were 1.01 and 0.627% respectively (Abd Alrahman, 2005).

2.1.1.3. Protein Content

Protein is the component in wheat flour that makes the greatest contribution to the typical flour properties. Wheat proteins are responsible for the unique visco-elastic properties of bread dough (Sluimer, 2005).

The comparatively high protein content of wheat grain makes it the most important source of human nutrition (Internet, 2005). The range of protein content of different wheat varieties is 10-14% (Kyomugisha, 2002). George (1973) reported that the protein content of wheat is highly affected by environmental conditions, grain yield and available nitrogen as well as the variety genotype. The percentage of wheat protein may be considered as a useful criterion for establishing the economic value of grain (Williams, 1970). Haldor et al. (1982) found that protein content of whole wheat flour ranges between 10-16%, while Passmer and Eastwood (1986) reported that the protein content of wheat was 12.2 gm/100gm. Ahmed (1995) reported that the protein content of four Sudanese wheat cultivars, Condor, Debera, Elneilein and Nasser, ranges between 8.21 to 12.26%.

Wheat gluten is the main flour component responsible for bread quality. Gluten, the protein of wheat, is a gray, tough, elastic substance, insoluble in water. On account of its great power of expansion, it holds the gas developed in bread dough by fermentation, which otherwise would escape (Farmer, 2000). Commercially it is the
term given to industrial by-products of wheat starch production via wet milling purposes. Its composition is: 70 - 80% crude protein, 6 - 8% crude lipids, 10 - 14% carbohydrates, 0.8 - 1.4% minerals (Internet, 2005).

Pomeranz et al (1977) reported that hard winter wheat cultivars (73% extraction) had a protein content of 12.3%. Finney et al. (1976) reported that protein content of five varieties of hard winter wheat flour were 10.8, 11.6, 11.8, 11.8, and 12.7%, while Magoffin et al., (1977) found that hard wheat (CS-73A – composite flour) flours had a protein content of 12.4%. Protein content of hard white winter wheat was found to be 123.0 g kg\(^{-1}\) as reported by Coskuner and Karababa (2005). While the protein content of soft wheat flour (82% extraction) milled from white Australian wheat was 12.5% as reported by Abdel-Kader (2000).

Carson and Sun (2000) found that protein content of hard wheat flour was 12.1%. Idowu (1996) reported that protein content of wheat flour was 12.8%.

Hassan (2005) studied the protein content of wheat flour of three Sudanese wheat cultivars, Sasaraib, El-Nielain and Debeira, (72% extraction rate). He reported that the protein values were 12.67, 10.44 and 13.08% respectively. The protein contents of two types of wheat flour (whole meal and all purpose flour) were 13.17 and 13.85% respectively (Abd Alrahman, 2005).

2.1.1.4. Fat Content

Lipids play a significant role in the shelf life of flours. Lipids also increase the demand on oxidative flour improvers; the higher the lipids content, the higher the demand (Sluimer, 2005). Wheat germ oil is contained at 8-12% in the wheat germ which is 2% of total grain weight (Internet, 2005).

The fat content of different cultivars of Sudanese wheat flour (100% and 72% extraction) ranged between 1.91-2.35% and 0.85-1.73% respectively (Ahmed, 1995). However, Mohamed (2000) found that the fat content of the Sudanese cultivars Debera, Elneilein, Condor and Sasaraib ranges between 2.15-2.35%. Moreover, Abdallah (2002) reported that the fat content of two Sudanese cultivars ranged between 2.74 and 2.37%. While the fat content of soft wheat flour (82% extraction) milled from white Australian wheat was 1.25% as reported by Abdel-Kader (2000). (Hassan, 2005) studied the fat content of wheat flour of three Sudanese wheat
cultivars, Sasaraib, El-Nielain and Debeira, (72% extraction rate). He reported that the fat contents were 1.17, 0.92 and 0.87% respectively. The fat content of two types of wheat flour, whole meal and all purpose flour was 1.67 and 1.65% respectively (Abd Alrahman, 2005).

2.1.1.5. Total Carbohydrates

Wheat consists of about 60% starch, which is found in the form of granules in the endosperm. Starch is one of the most abundant natural raw materials in nature and is consumed as a component of bread, pasta, rice, breakfast cereals, cakes, biscuits and potatoes (Internet, 2005).

Generally, it was reported that the total carbohydrates in wheat flour was 71.9% (Idowu, 1996). The total carbohydrate of soft wheat flour (82% extraction) milled from white Australian wheat was found to be 85.1% (Abdel-Kader, 2000).

Hassan (2005) reported that the carbohydrate contents of wheat flour of three Sudanese wheat cultivars, Sasaraib, El-Nielain and Debeira, (72% extraction rate) were found to be 72.06, 74.64 and 71.70% respectively. Moreover, the carbohydrate content of two types of wheat flour (whole meal and all purpose flour) was 71.7 and 72.97% respectively (Abd Alrahman, 2005).

2.1.1.6. Minerals

Minerals are important as buffering substances and trace elements in enzyme synthesis, in souring, mashing, and in fermentation (Narziss, 1976). The composition of minerals in the grain is obviously determined by the concentration of available minerals in the soil (Elshewaya, 2003).

2.1.2. Hard white wheat

The cultivars of common wheat are divided into two distinct types of hardness, hard and soft wheat. The hardness of wheat is under genetic control (Pomeranz, 1988). The hard one is of medium strength, and is suitable as filler in bread making grits. The soft type is weak, and its flour is good for biscuit and pastry production (Abd Alrahman, 2005).
Wheat is also classified as durum, soft winter, hard spring, and hard winter and semi-hard. Winter wheat as previously stated may be hard, semi hard or soft. Hard winter wheat has a fairly strong quality of gluten and it is suitable for bread making purposes (Abd Alrahman, 2005). Hard wheat is of two types, red and white. Hard white winter wheat is similar to hard red winter wheat. The plants are alike and both have hard grain endosperm for making bread, but the color of the seed coat (bran) is different (Paulsen, 1998). The white bran color does not alter the starch characteristics or protein functionality of the kernel (Ransom, 2006). Australia grows only hard white spring wheat varieties, some of which make excellent oriental style noodles as well as baked products. White grain can be milled at a slightly higher extraction rate to yield more flour than red grain, making each bushel of white wheat more valuable. The higher extraction rate often increases the protein content of flour, an essential component for bread making. The flour also has a better color score, a measure of flour quality used by some countries. Products baked from whole wheat flour, which are popular in the U.S. and overseas, or from flour milled at a high extraction rate have a more pleasing appearance when they are made from white grain instead of red grain (Paulsen, 1998).

Whole hard white wheat flour or bran can be used instead of non-wheat materials to increase fiber content of many existing products without altering color or flavor. Whole-wheat products made from white wheat have a favorable appearance, compared with similar products made from red wheat, since they have less pigmentation. In addition, with fewer phenolic compounds and tannins in the bran, white wheat imparts a less bitter taste to the final product. White wheat is also preferred for use in high-protein Asian noodle and bread products (Ransom, 2006). White bran is much less obvious than red bran in flour and food products (Lyon, 2003). Bran from white wheat is a co-product rather than a by-product. It is used in breakfast and snack-type foods (Bequette and Herrman, 1994).

Research results indicated that hard white wheat and its products were suitable for regular and whole wheat breads buns; american and middle eastern flat breads and chinese steamed breads (tortillas, pita, balady, etc.). Moreover, some studies concluded that, hard white wheat is the most desirable option for pasta manufacturers.
who use farina (from hard wheat) instead of semolina (from durum wheat) (Bequette and Herrman, 1994).

Nutritionally, hard white wheat and hard red wheat have about the same values. But there are some major differences as to what kind of bread could be made from it (Al Durtschi, 2000). Qarooni et al. (1988) showed that products made with flour from hard wheat were superior in quality to those made with flour from soft wheat. This is due to the higher level of starch damage associated with the milling of hard wheat; the resulting flour has a higher water absorption capacity and contributes to a superior crust color in the final product. Moreover, a recipe for bread dough was found to require less sugar when it was made with white wheat flour instead of red wheat flour. This difference would have important economic and nutritional benefits (Paulsen, 1998). It was reported that, generally, the ash content of hard white winter wheat was 6.0 g kg⁻¹ and its protein content was 123.0 g kg⁻¹ as reported by Coskuner and Karababa (2005).

2.2. Sorghum

Sorghum [Sorghum Bicolor (L.) Moench] is the world’s fifth most important cereal, after wheat, rice, maize, and barley (Serna-Salvador and Rooney 1995). Sorghum is an important staple in the semi-arid tropics of Asia and Africa for centuries. Sorghum is still the principal sources of energy, protein, vitamins and minerals for millions of the poorest people in these regions, (FAO, 1995).

The five largest producers of sorghum in the world are the United States (25%), India (21.5%), Mexico (almost 11%), China (9%) and Nigeria (almost 7%). Together these five countries account for 73% of total world production (FAO, 1995). Sorghum is a major crop used for food, feed, and industrial purposes worldwide (Rooney and Awika, 2005).

Sorghum is consumed in the world in various ways ranging from stiff and thin porridge, leavened and unleavened bread, boiled sorghum, baked and steamed product, snack foods, alcoholic and non-alcoholic beverages (Keregero and Mtebe, 1994). In the Sudan Sorghum is the most important cereal crop where it is consumed in fermented forms, mainly as Kisra (local thin bread), aceda (thick porridge) and nasha (thin porridge), (FAO, 1995).
2.2.1. Chemical composition of sorghum

Generally sorghum contains approximately 7-16% protein, 55-75% starch, 0.5-5% lipids 1-6% crude fiber, and 1-4.5 % ash, on a dry weight basis (Serna-Saldivar and Rooney, 1995).

2.2.1.1. Moisture content

Yousif and Magboul (1972) who studied fifteen sorghum varieties grown in the Sudan reported that the moisture content ranges between 5.7% and 10%, while Arbab (1995) analyzed two Sudanese sorghum cultivars, Gadam Elhamam and Keramaka, showed that the moisture content ranged between 8.89% and 9.88%. Torres et al. (1993) found that the moisture content of whole sorghum and decorticated sorghum (10% decortication) flours was 14.1% and 8.1%, respectively. Codex alimentarius recommended that the maximum moisture content for sorghum is 15% m/m (CODEX, 1995a).

2.2.1.2. Ash content

Studying some Sudanese sorghum cultivars, Yousif and Magboul (1972) reported that the ash content of sorghum grown in different parts of the Sudan ranged from 1.2% to 2.6%. Elshewaya (2003) found that the ash content of sorghum cultivars, Tabat and fatarita was 1.43% and 1.74% respectively. Torres et al. (1993) reported that the ash content of whole and decorticated sorghum(10% decortication) flours was 1.7% and 1.5% respectively, while the ash content of Sudanese cultivar, Gadamelhamam, was 1.92% as reported by Elmaki et al., (1999). Codex alimentarius recommended that the ash content of sorghum ranges between 0.9% and 1.5% on dry basis (CODEX, 1995a).

2.2.1.3. Fat content

The crude fat content of sorghum is 3 %, which is higher than that of wheat and rice but lower than that of maize. The germ and aleurone layers are the main contributors to the lipid fraction. The germ itself provides about 80% of the total fat (Rooney and Serna-Saldivar, 1991). The fat in sorghum grain is rich in polyunsaturated fatty acids (Glew et al., 1997).
Rooney and Miller (1981) reported that the fat content of sorghum was 3.4%, whereas Shephered et al. (1970) reported that the crude fat of sorghum cultivars ranged from 1.5% to 2.5%. Khattab et al., (1972) reported that crude fat of three sorghum cultivars, fatarita, safra and ahmer, ranged from 2.7% to 3.0%. Elshewaya (2003) found that the crude fat was 3.25% and 3.1% for Tabat and fatarita cultivars respectively. Torres et al. (1993) reported that the fat contents of whole sorghum and decorticated sorghum (10% decortication) flours were 3.8% and 2.5% respectively. Elmaki et al (1999) found that the fat content of Sudanese cultivar, Gadamelhamam, was 2.99%. Codex alimentarius recommended that the fat content of sorghum ranges between 2.2% to 4.7% (CODEX, 1995a).

2.2.1.4. Protein content

The second major component of sorghum grain is protein. Both genetic and environmental factors affect the protein content of sorghum. Sorghum proteins differed in their essential amino acid profile. However, the most common feature was that Lysine was always found to be the most limiting amino acid. (Hulse et al., 1980; Jambunathan et al., 1984). Approximately 80%, 16%, and 3% of the protein is contained in the endosperm, germ, and pericarp, respectively (Taylor and Schussler, 1986).

The protein content in whole sorghum grain is in the range of 7 to 15% (FAO, 1995; Beta et al., 1995). Sorghum contains about 9-14% proteins (Rooney & Serna-Saldivar, 2003). Abdelrahman (2000) reported that the protein contents of three sorghum cultivars, safra, fatarita and ahmer, were 10.1%, 13.6% and 11.1% respectively. Eggum et al. (1983) reported that the protein contents of three sorghum cultivars, tetron, deber and fatarita, were 10.9%, 11.6% and 13.4% respectively, while El tinay et al. (1979) reported that the protein content of sorghum grains ranged from 9.76% to 11.6%. Elshewaya (2003) found that crude protein was 8.74% and 12.38% for Tabat and Fatarita cultivars respectively. The protein content of Sudanese cultivar, Gadamelhamam, was 11.5% as reported by Elmaki et al., (1999). Morad et al. (1984) reported that the protein content of whole white sorghum was 11.6%. Torres et al. (1993) reported that the protein contents of whole sorghum and decorticated sorghum (10% decortication) flours were 10.4% and 10.2% respectively. Codex alimentarius
recommended that the minimum level of protein content of sorghum is 8.5% (CODEX, 1995a).

2.2.1.5. Total carbohydrates

Starch is the major storage form of carbohydrate in sorghum. With values ranging from 56% to 73%, the average starch content of sorghum is 69.5% (Jambunathan and Subramanian, 1988). About 70% to 80% of the sorghum starch is amylpectin and the remaining 20% to 30% is amylose (Deatherage et al, 1955). The carbohydrate content of whole sorghum flour, Tabat cultivar, was 78.96% (Elshewaya, 2003). Morad et al. (1984) reported that the starch content of whole white sorghum was 74.6%, while Taha (2000) found that the total carbohydrates of three Sudanese sorghum cultivars, Dabar, Fakimustahi, Tetron, (70% extraction) were 78.59, 75.54 and 77.15% respectively.

2.2.1.6. Minerals

In the sorghum kernel the mineral matter is unevenly distributed and is more concentrated in the germ and the seed-coat (Hubbard et al, 1950). Pedersen and Eggum (1983) reported that in milled sorghum flour minerals such as phosphorus, iron, zinc and copper decreased with lower extraction rates. Similarly, pearling the grain to remove the fibrous seed-coat resulted in considerable reduction in the mineral contents of sorghum (Sankara and Deosthale, 1980).

Sorghum is reported to be a good source of more than 20 minerals (BSTID-NRC, 1996). Sorghum is also rich in phosphorus, potassium, iron and zinc (an important element for pregnant women) (Glew et al., 1997; Anglani, 1998). Zinc deficiency is more common in corn and wheat than in sorghum (Hopkins et al., 1998). Ahmed (1993) reported that the calcium and phosphorous content of four Sudanese sorghum cultivars ranged between 20- 30 mg/100g and 380.25- 391.25 mg/100g respectively. FAO (1995) reported that the calcium in six cultivars of sorghum was 15 mg/100g on dry basis and 352 mg/100g on dry basis for phosphorous.
2.2.2. Characteristics and nutritive value of sorghum grains

The sorghum kernel varies in size, shape, color, density, hardness, composition, processing properties, taste, texture, and nutritional value (Rooney and Awika, 2005). The most common colors are white, bronze and brown (Purseglove, 1972). The basic kernel structure is similar in sorghum. The principal anatomical components are pericarp, germ or embryo and endosperm. In the sorghum kernel the distribution by weight is pericarp 6%, endosperm 84% and germ 10% (Hubbard et al, 1950). The ratio of endosperm to germ in the sorghum kernel is 8.4:1.

The future promise of sorghum in the developed world is for wheat substitution for people allergic to gluten (Fenster, 2003). The protein and starch in sorghum endosperm are more slowly digested than other cereals. The slower rate of digestibility of sorghum products may be beneficial to diabetics (Internet, 2000).

The nutritional quality of sorghum, generally, is poor and it is deficient in many nutrients such as lysine, an essential amino acid, which makes sorghum protein inferior in quality (Eggum et al, 1982). Therefore attempts have been made to fortify this cereal with legumes or other cereals to make nutritionally superior and acceptable products, (FAO, 1995). However, the protein and calcium contents of sorghum are higher than maize and rice; while iron content is higher than in wheat, rice and maize; carotene is also higher than in wheat and rice; and niacin and tryptophan contents are higher than in maize (Eggum et al, 1982).

Decortication is a successive process of removing bran from outside towards the center of the grain endosperm; the resultant product is starchier with very low fiber and reduced protein (Taha, 2000). Dehulling of sorghum grain also improves iron availability because the hull is rich in phytate, a compound that binds iron and certain other minerals and makes them biologically unavailable. Mbofung and Ndjouenkeu (1990) observed that the percentage of soluble and ionizable iron was higher in gruels prepared from mechanically dehulled sorghum than those prepared from grain milled traditionally using mortar and pestle. The increase in iron availability was attributed partly to the efficient removal of the phytate-rich hull in mechanical milling and partly to the greater destruction of phytate during soaking of the grain prior to dehulling. In studies on Indian women, absorption of iron was higher from tannin-free than from high-tannin sorghum cultivars (Gillooly et al.,
Pearling of the grain improved the absorption of iron from both high- and low-tannin cultivars.

It was reported that although bakery products can be produced from whole sorghum flour, the quality of the bread can be improved by using sorghum flour from which the bran fraction has been removed by passage through sieves (Casier et al., 1977).

2.3. Bread Making

Bread is the most important article of food, and history tells of its use thousands of years before the Christian era. Many processes have been employed in its making and baking; and as a result, from the first flat cake have come the perfect loaf. The study of bread making is of no slight importance, and deserves more attention than it receives (Farmer, 2000). The making of bread and the types of bread consumed are different in various parts of the world (Sluimer, 2005). Bread is made from flour of wheat, or other cereals, particularly rye. Wheat flour is best adapted for bread making, as it contains gluten in the right proportion to make the spongy loaf (Farmer, 2000).

Bread quality, such as crumb grain, volume, and texture, is affected by many factors including composition, dough properties, and processing conditions. Moreover, one of the major factors affecting dough rheological properties is the formation of a gluten matrix (Sun et al., 1999).

2.4. Technology of composite flour products

Composite flour technology initially referred to the process of mixing wheat flour with cereal and legume flours for making bread. However, the term can also be used with regard to mixing of non-wheat flours, roots and tubers, legumes or other raw materials (Dendy, 1992). For composite flour, proper blending to get the desired end properties requires understanding of the interactions of the different components at the physicochemical level (Sun et al., 1999).
Composite flour has been used commercially in bread in several countries, but it is usually accepted only when there is a shortage of wheat flour, (FAO, 1995). The use of composite flours in breads helps to improve its nutritional quality, reduce imports of wheat thereby improving the foreign exchange reserve, utilize indigenously grown cereals, reduce the cost of products and bring in varieties with different texture and flavor (Internet, 2004). In Africa there has been an ever-increasing demand for wheat products such as bread. Africa is not a major wheat-growing region, but it produces large quantities of other cereals such as sorghum. It has been reported that replacing wheat with 20% non-wheat flour for the manufacture of bakery products would result in an estimated saving in foreign currency of US$320 million annually (FAO, 1982). At 30% substitution the savings would be US$480 million annually. Thus composite flour technology holds excellent promise for developing countries. Although actual consumer trials have been rare, products made with composite flour have been well accepted in Colombia, Kenya, Nigeria, Senegal, Sri Lanka and the Sudan (Dendy, 1992).

Composite flour and its products have been dealt with in wider literature surveys sponsored by The United Nations Food and Agriculture Organization since 1964. Among cereals, sorghum was found to be a better substitute for wheat in composite flours (Idowu, 1989). The literature covered some aspects of sorghum, wheat composition and their products as used in bread and traditional diets (Taha, 2000). Significant interest exists in the use of sorghum flour in blends and alone for baked products (Gordon, 2001). Thus, whole-grain white sorghum flours can be utilized in a wide variety of food systems, in baking as a partial or complete substitute for wheat flours. The bland flavor of sorghum is particularly important because it allows a greater percentage of substitution without loss of flavor. Sorghum flour produces acceptable baked products with additives to compensate for its lack of gluten (Rooney and Awika, 2005).

The use of sorghum composite flour in bread-making has some advantages. The nutritional composition of sorghum is comparable to that of maize, a highly popular cereal. Phenolic compounds, especially flavonoids, have been found to inhibit tumor development (Huange and Ferraro, 1992). Grain sorghum has been
found to contain these useful compounds (Shahidi and Naczk, 1995). Also, the starches and sugars in sorghum were found to be released more slowly than those in other cereals (Klopfenstein and Hoseny, 1995), and so it is considered beneficial to diabetics (Toomey, 1988).

Many studies have been done to explore the potential for making loaf bread with composite flours that include sorghum. There is always a steady deterioration of bread quality as the percentage of non-wheat flour is increased. If the flour is colored, it is usually the extent of discoloration that limits the amount of non-wheat flour that can be used. In most other cases the limiting factor is the density of the loaf (FAO, 1995).

Acceptability studies conducted at the Food Research Centre in Khartoum, Sudan, indicated that breads made with composite flour of 70% wheat and 30% sorghum was acceptable (FAO, 1995). Consumer acceptance trials in Nigeria indicated that breads made with 30% sorghum flour were comparable to 100% wheat bread (Aluko and Olugbemi, 1989; Olatunji et al., 1989). Thiam and Ndoye (1977) reported that the protein content of composite flour was lower than that of wheat flour, while its crude fiber was higher. Bread with 30% sorghum and 70% wheat was also prepared in Senegal (FAO, 1995).

Bread made with composite flour containing sorghum is nutritionally valuable (Carson and Sun, 2000). However, Sorghum alone is not considered as a bread making cereal because of the lack of gluten, but addition of 20 to 50% sorghum flour to wheat flour produces excellent bread (Anglani, 1998; Carson et al., 2000; Hugo et al., 2000, 2003a).

Recent developments in the bread making process and the use of bread improvers and dough conditioners have helped in counteracting, to some extent, the adverse effect on the quality of bakery products with composite flours (Internet, 2004).

Unless other additives are used, the limit for most people to accept is about 10% of non-wheat flour, although many reports have claimed that breads made using
much higher rates of addition were acceptable (FAO, 1995). A higher level of substitution is possible with hard than with soft wheat flour (UNECA, 1985).

Milling at 72% to 75% extraction rate yielded fine sorghum flour that is more suitable for bread-making (FAO, 1995). Rao and Shurpalekar, (1976) reported that sorghum flour milled at 80% extraction rate could be blended with white wheat flour for bread-making without any adverse effect. The extraction rate of sorghum flour is intended to be low as it is an important parameter for the crumb color of the bread. It has been reported that the water absorption capacity diminished whenever the amount of sorghum flour increased in the mixture, and this point is contradictory to what was reported by the United Nations Economic Commission for Africa (UNECA, 1985).

Sun et al. (1999) reported on a research on two white sorghum cultivars from Kansas State (USA), were found to have potential for bread making. The outcome of that research indicated that selected sorghum cultivars can be used to make leavened bread that is compatible to rye composite bread. It was reported that the dough properties of sorghum-based composite flour were improved by using wheat gluten and dough improvers including xanthan gum, sodium stearoyl lactylate, and diacetyl tartaric ester of monoglycerides; volume of the bread with 50% sorghum flour has been increased by 80% using the designed composite-flour system. The appearance of the breads, such as crumb grain, color, and volume, were very comparable to those of most commercial rye breads (Sun et al., 1999).

Fermentation process, particularly applied in a simple sourdough type process, appears to be a more effective technology to improve the bread-making quality of sorghum flour; as it is simple to apply and also improves the volume and the protein quality of sorghum-wheat composite bread (Hugo, 2003b). Hamaker, (2001) found that, the addition of sorghum flour to wheat flour produced marked negative effects on rheological properties of dough and loaf volume.

Epuripur (Ugandan sorghum) was used at different levels of substitution of wheat (0%, 10%, 15%, and 20%) to produce bread of acceptable quality using the activated dough development method. The results showed that there were no significant differences in loaf attributes save for specific volume and overall acceptability. Generally the panellists accepted the bread with different levels of
Epuripur but preference was reduced with increasing levels of substitution (Kyomugisha, 2002).

Carson and Sun (2000) investigated the rheological properties and bread baking potential of a sorghum-based composite flour system containing various amounts of vital wheat gluten. They found that at fixed gluten protein levels, as sorghum flour increased, water absorption decreased slightly, dough strength and extensibility decreased, and mixing time increased significantly.

Badi et al. (1976) reported that addition of 10% millet flour to standard baking formula, slightly increased loaf volume and improved crumb grain. Adding sorghum flour (5-20%) to standard formula decreased loaf volume although the product was acceptable. Perten et al. (1980) carried out experimental studies in Food Research Center, Sudan, to assess the behavior of sorghum flour in bread making. They concluded that the addition of sorghum to wheat flour negatively influenced the volume of bread. Nevertheless, acceptable bread could be made in the ratio of 70% wheat and 30% sorghum (Taha, 2000). Wheat replacement up to a level of 20-30% with sorghum flour was also reported to produce acceptable bread (Olatunji et al., 1984).

2.5. Flat bread

Bread can be classified into three groups with respect to their specific volume. Those with high specific volume such as pan breads, those with medium specific volume such as French and rye breads, and those with low specific volume such as flat breads. Flat breads can be divided into two major groups according to their cross section: single-layered and double-layered. Flat breads are dense in texture, mostly crust with crumb, and usually round but some times triangular or rectangular. Their diameter varies from 5-10 cm up to 70 cm. In thickness, they range from paper-thin to 4 cm thick. The crust is thin and light with brown and dark spots. The crumb is small in quantity, coarse and dense. Flat breads have a higher crust-to-crumb ratio than do pan breads (Pomeranz, 1988). Over 1.8 billion people consume flat bread daily (Abughoush and Herald, 2005).

Generally, hard wheat having intermediate dough strength, high water absorption and high damaged starch are suitable to produce flat breads; these flours
absorb more water during mixing and produce softer and better flat breads (Coskuner and Karababa, 2005).

Flat breads are widely consumed in the Middle East, the Nile Valley and the Persian Gulf states. These breads are commonly referred to as Arabic bread, and to lesser extent as Balady bread, in the aforementioned regions and as Pita bread in Europe and North America. The formulation, processing and characteristics of Arabic bread have been reviewed (Toufeili et al, 1999). The formula of balady bread is simple: flour, water, a small amount of salt, and a source of yeast. The bread has two special characteristics. First, the absorption is very high, usually 75-85 % (flour basis), and consequently the dough has the consistency of a batter. Faridi and Rubenthaler (1983) used a dough with a farinograph water absorption of 200 Brabender units (BU), compared to 400-500 BU in regular white pan bread. The dough of balady bread tends to be sticky and is normally scaled by hand. Second, the baking temperature is high, in the range of 500-600°C, and the baking time is only a minute. The high temperature immediately causes the dough to rise, more from steam formation than from carbon dioxide production.

El-Saied and El-Farra, (1983) reported that, many third world countries in which flat breads are popular do not grow enough wheat to satisfy the demand for bread and thus must import an increasing amount of wheat. In most cases, this places a strain on the economy, and consequently efforts have been made to use alternative native grains or plant materials to replace part of the wheat flour required for bread making. Flat breads, in general, are more tolerant to the addition of non functional supplements than is pan bread, but undesirable effects are still noticed. Morad et al. (1984) reported that the replacement of bread flour with up to 30% ground sorghum produced acceptable Egyptian balady bread. Moreover, Awadalla (1974) and Awadalla and Slump (1974) reported that using 20% whole or decorticated millet flour with 80% Dutch wheat flour of 100, 80, or 70% extraction in the production of Egyptian flat breads. The baking quality was impaired, as judged by loaf volume and internal and external characteristics, but it was improved by the addition of dough conditioners. The sorghum flour had the greatest effect on the quality of the bread with wheat flour of 80% extraction. Mustafa (1973) found that, blending of sorghum flour (10%) with wheat flour was recommended for Sudanese breads.
Although dough moisture is higher in balady bread than in western white pan bread dough, the proportion of moisture loss during and after oven baking is higher for balady bread (Faridi and Rubenthaler, 1984).
CHAPTER THREE

3. MATERIALS and METHODS

3.1. Materials

The materials used in this study were:

Sorghum grains:

Sorghum \([\text{Sorghum bicolor} \text{ (L). Moench}]\) of the local cultivar Tabat was purchased from the local market in Khartoum, Sudan.

Wheat grains:

Wheat \((\text{Triticum aestivum} \text{ L.})\) Hard white winter wheat of the variety (SD97W609) was obtained from South Dakota State University – Brookings –USA.

Yeast: Instant dry yeast was obtained from local market.

Water: tap water at 100° to 110° F was used.

Sugar: Sucrose. Finely granulated, white, commercial grade was used.

Salt: NaCl finely granulated, obtained from the local market was used.

Shortening: partially hydrogenated vegetable oil (Crisco) was purchased from the local market, was used for bread making.

Chemicals: All chemicals used for analysis were of analytical range.

3.2. Methods

3.2.1. Preparation of sorghum and wheat grains for analysis

Wheat (HWWW) grains were milled using an experimental mill in Manhattan, Kansas, USA to 72% extraction rate flour. Sorghum grains were cleaned and freed from foreign materials. Grains were decorticated in The Food Research Center (Sudan) using an experimental mill (Schule, F. H. SCHULE GMBH.)
MASCHINENFABRIK, Hamburg - Germany 1976). Part of the grains was milled to whole sorghum flour and the rest was milled to 70% extraction rate.

Whole sorghum flour, decorticated sorghum flour (70%), and (HWWW) wheat flour (72%) were kept in the freezer for subsequent chemical analysis, physical characteristics, rheological properties and baking tests.

3.2.2. Chemical analyses

3.2.2.1. Moisture content

Moisture determination was conducted using the AOAC method (2000). Disposable aluminum weighing dishes, (<50 mm diameter and <40 mm deep) which had been numbered, dried in the oven for 30 minutes, cooled in a desiccator and weighed again were used. A two g sample was weighed out and repeated in triplicate. Using tongs, aluminum weighing dishes containing the samples were placed in an air drying oven at 130°C for about one hour. The samples were removed and placed in a desiccator to cool for 30 minutes and reweighed. The moisture content was calculated according to the following equation:

\[
\text{Moisture Content}\% = \frac{W_2 - W_1}{W_1} \times 100
\]

Where:
\( W_1 = \) weight of dish and dry sample.
\( W_2 = \) weight of dish and moist sample.

3.2.2.2. Ash Content

The ash content was determined according to the AOAC method (2000) using muffle furnace. Four grams of the sample were weighed and repeated in triplicate into porcelain crucibles, which have been ignited, cooled in a desiccator and weighed and placed in a cool electric muffle furnace. The temperature was 540°C overnight for complete ashing. The ash crucibles were transferred directly into a desiccator, then cooled for 30 minutes and weighed immediately. The ash was determined by calculation and expressed as percentage using the equation:

\[
\text{Ash Content} \% = \frac{W_1 - W_2}{W_1} \times 100 \times \frac{100}{100 - M}
\]
Where:
$W_1 =$ weight of crucible with dried ash.
$W_2 =$ weight of empty crucible.
$M =$ Moisture percentage of the sample.

3.2.2.3. Protein Content

Nitrogen was determined according to AACC method (2000) using combustion nitrogen analysis (CNA) protein analyzer (Flash EA 1112 Series, Thermo Finnigan). A sample of 0.15 – 0.20g was weighed and put in a small piece of aluminum then placed into a CNA protein analyzer. Each sample was repeated in triplicate. The process was fully automated and began by dropping the samples into a hot oven were it was burnt at 952°C. The amount of nitrogen gas released during burning was measured and a formula was applied to convert measurement to protein content in the sample. Protein content results were recorded in the computer and expressed as a percentage of the total sample weight, at 14% moisture basis.

3.2.2.4. Fat Content

The fat content was determined according to the AOAC method (2000) with some modification. It was extracted by petroleum ether on a Goldfish extractor. Gold fish beakers were washed, dried and labeled by placing in an air oven at 130°C for one hour; then cooled in a desiccator for 30 minutes and weighed; repeated to constant weigh. Samples of 2g in triplicate were wrapped in filter paper and placed in a cellulose thimble condenser. 40ml of the solvent petroleum ether were added to the weighed Gold fish beakers. The extraction was carried out for 4 hours until all the soluble components of the sample were removed. Burners were allowed to cool for 30 minutes then the beakers were moved to a tray, covered with evaporation-type watch glass, and set in a hood to allow all ether to evaporate over night. The air oven removed the traces of solvent at 130°C for 15 minutes; cooled in a desiccator for 30 minutes and re-weight.

The fat content was calculated according to the following equation:

$$Fat \ Text\ Content\ % = \frac{W_2 - W_1}{\text{Weight Of Sample (moist)}} \times 100 \times \frac{100}{100 - M}$$

Where:
W₁ = Weight of empty beaker.
W₂ = Weight of beaker with fat.
M = Moisture percentage of the sample.

3.2.2.5. Total Carbohydrates

The amount of carbohydrates was calculated by difference. The values refer to “total carbohydrate by difference” that is, the sum of the figures for moisture (MC %), protein (PC %), fat (FC %), and ash (Ash %) are subtracted from 100.

Total Carbohydrate % = 100 – [MC% + PC% + FC% + Ash C%].

3.2.2.6. Minerals

According to AOAC Official Method (2000), samples were dried and ashed at 525°C for 4 hours. The ash was dissolved in (1 ml hydrochloric acid +3 ml distilled water) and a few drops of nitric acid, brought to a final volume of 250 ml with distilled water and filtered. Calcium and iron were determined by flame atomic absorption spectroscopy according to AOAC Official Method (2000). Phosphorus was determined colorimetrically using the ammonium molybdate method according to AOAC Official Method (2000).

3.2.3. Bread making

3.2.3.1. Preparation of composite flour blends

Wheat flour which was used for bread making had 0, 5, 10, 15, and 20 % whole sorghum flour. The same was repeated with decorticated sorghum flour. A blender was used to mix the blends well with an amount of 1 kg flour for about one hour per cycle using a Twin shell dry blender of the type (The Patterson Kelly Co. Inc. East Stroudsburg, Pennsylvania - patents no 2, 514, 126). The composite flours were stored in an air tight container and kept in the freezer until required.

3.2.3.2. Preparation of bread samples

The various wheat/sorghum blends and the control (wheat flour) were used to make the samples of pan and balady flat bread.
3.2.3.2.1. Pan bread

Standard formula:

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flour</td>
<td>300g</td>
</tr>
<tr>
<td>Yeast</td>
<td>4.5g</td>
</tr>
<tr>
<td>Salt</td>
<td>4.5</td>
</tr>
<tr>
<td>Shortening</td>
<td>9g</td>
</tr>
<tr>
<td>Sugar</td>
<td>9g</td>
</tr>
<tr>
<td>Water</td>
<td>Variable</td>
</tr>
</tbody>
</table>

All ingredients mentioned above were weighed and placed in a mixture (Cuisinart Food preparation center) for mixing. The mixture ran for 5 seconds to mix dry flour, salt, shortening and sugar. Then a solution of the yeast in water was added. The mixture was run at high speed for one minute and 32 seconds mixing time; water was added to the mixture according to the farinogram result. The dough temperature was 84° – 90° F after mixing. Dough was transferred and scaled into three portions, rounded into balls by hand then placed in lightly greased fermentation bowl and placed in the fermentation cabinet at 86° F and 85% relative humidity for 20 minutes. Furthermore, dough was passed through sheeter length wise using 3-in.roll width and 3/16-in. roll spacing then molded by hand and placed in lightly greased pans (size 5 5/8" × 3 3/16" × 1 15/16") and returned to the fermentation cabinet for final proof for 50 minutes. When the height of dough had risen to about 1 – 2 cm from the pans, the pans were baked into bread in a convection oven (DESPATCH oven Co. – JENN. AIR convection oven) at 415°F for 18 minutes. The oven was preheated to 415°F and conditioned with 1-L beaker full of water placed on the same shelf throughout baking. Loaves were weighed and the volume was recorded immediately after removal from the oven. Then bread was left to cool for 25 minutes and sliced using an electric knife of 1 cm width. Some slices were kept at room temperature in sealed plastic bags for sensory evaluation and physical characteristics.
3.2.3.2.2. Balady bread

Standard formula:

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flour</td>
<td>250g</td>
</tr>
<tr>
<td>Yeast</td>
<td>1.5 g</td>
</tr>
<tr>
<td>Salt</td>
<td>0.5 g</td>
</tr>
<tr>
<td>Ascorbic acid</td>
<td>80 ppm</td>
</tr>
<tr>
<td>Water</td>
<td>Variable</td>
</tr>
</tbody>
</table>

All ingredients mentioned above were weighed and made into dough in a Mono-Universal laboratory dough mixer for 5 minutes at medium speed. The dough was placed in a fermentation cabinet at 28°C and 85% relative humidity for 1 hour. After removal from the fermentation cabinet, the dough was divided into three pieces of 140-148g each and formed into balls by hand, then, rested for 30 minutes at the same conditions, then dusted with flour and shaped into a round flat form by hand. The flattened dough pieces were returned to the fermentation cabinet and proofed for 45 minutes, then baked in a commercial oven (Real Forni-VERONA) at 250°C for 8-10 minutes.

The bread was left to cool for 7 minutes, then kept closed in polyethylene bags at room temperature 25°C for sensory evaluation and physical characteristics.

3.2.4. Dough Rheological Properties

3.2.4.1. Gluten content

Wet gluten content was determined by washing the flour sample by a salt solution to remove the starch and other soluble from the sample. The residue remaining after washing was the wet gluten. This determination was adapted according to the AACC method (2000).

A 10g sample was weighed and placed into the glutomatic washing chamber on top of the polyester screen. The sample was mixed and washed with 2% salt solution (NaCl) for 5 minutes. At the end of the wash cycle, the wet gluten was removed from the washing chamber, placed in the centrifuge holder, and centrifuged. The residue retained on top of the screen and through the screen was weighed to get total gluten. Wet gluten content results were expressed as a percentage on 14% moisture basis. It was then dried in a heater to give the dry gluten.
Calculation of wet, dry, and gluten index was as follows:

\[
\text{Wet gluten \%} = \left( \frac{\text{total gluten (g)}}{\text{sample weight (g)}} \right) \times 100.
\]

\[
\text{Dry gluten \%} = \left( \frac{\text{weight of dry gluten (g)}}{\text{sample weight (g)}} \right) \times 100.
\]

\[
\text{Gluten index} = \left( \frac{\text{wet gluten remaining in the sieve (g)}}{\text{total wet gluten (g)}} \right) \times 100.
\]

3.2.4.2. Farinograph test

The farinograph determined dough and gluten properties by measuring the resistance of the dough against the mixing action of paddles. This determination was carried according to the AACC method (2000).

A sample of 50 g of flour on a 14 % moisture basis was weighed and placed into the corresponding farinograph mixing bowl. Distilled water from a burette was added to the flour and mixed to form dough. As the dough was mixed, the farinograph recorded a curve on graph paper. The amount of water absorption affected the position of the curve on the graph paper. The graph was centered on the 500-Brabender Unit (BU) line ± 20 BU by adding the appropriate amount of water and was run until the curve left the 500-BU line.

Significant readings taken from farinogram were:

1. Water absorption: is the amount of water required to center the farinograph curve on the 500-Barabender Unit (BU) line. This relates to the amount of water needed for flour to be optimally processed into end products. Absorption is expressed as a percentage.

2. Peak Time: indicates dough development time, beginning from the moment water is added until the dough reaches maximum consistency. This gives an indication of optimum mixing time under standardized conditions. Peak time is expressed in minutes.

3. Stability Time: is the difference in time between arrival time and departure time. This indicates the time the dough maintains maximum consistency and is a good indication of dough strength. Stability time is expressed in minutes.

4. Mixing Tolerance Index (MTI) is the difference in BU value at the top of the curve at peak time and the value at the top of the curve 5 minutes after the peak. This indicates the degree of softening during mixing, (WMC, 2004).
5. Farinograph quality number (FQN): is the distance in mm from the beginning of the diagram up to the point where the diagram has decreased by 30 BU (Brabender, 2000).

These readings represent the principal flour characteristics, in which the baker is interested. All dough eventually breaks down into sustained mixing, which is indicated in the farinogram by the point at which the curve starts to descend (Elshewaya, 2003).

3.2.4.3. Extensograph Test

The constant flour method AACC (2000) was used for extensographic characteristics of flours with some creativity. A 300gm flour sample on a 14% moisture basis was combined with a salt solution and mixed in the farinograph to form dough and get water absorption and mix time for the dough. After the dough was rested for 5 minutes, it was mixed to maximum consistency (peak time). A 150g sample of prepared dough is placed on the extensograph rounder and shaped into a ball. The ball of dough was removed from the rounder and shaped into a cylinder. The dough cylinder was placed into the extensograph dough cradle, secured with pins, and rested for 45 minutes in a controlled environment. The extensograph recorded a curve on graph paper as the test was run. The same dough was shaped and stretched two more times, at 90 minutes and at 135 minutes.

The extensograph test measures and records:

1. Resistance to Extension: is the R value and is indicated by the height of the curve 5 minutes after the beginning of the diagram. It is expressed in centimeters (cc), Brabender unit (BU), or Extensograph units (EU).

2. Extensibility: is the E value and is indicated by the length of the curve. It is expressed in millimeters (mm) or centimeters (cm).

3. Area under the curve is a combination of resistance and extensibility. It is expressed in square centimeters (cm²).

4. R/E Ratio indicates the balance between dough strength (resistance to extension) and the extent to which the dough can be stretched before breaking (extensibility) (WMC, 2004).
3.2.5. Bread evaluation

3.2.5.1. Physical evaluation

3.2.5.1.1. Bread specific volume

The specific volume of bread was calculated according to the AACC method (2000) by dividing volume (cc) by weight (gm). Loaves volume was measured by rapeseed displacement immediately after removing from the oven and weighing. Loaf was placed in a container of known volume into which rapeseeds were run until the container was full. The volume of seeds displaced by the volume was considered as the loaf volume.

Bread specific volume (B.S.V.) was calculated according to the equation:

\[
B.S.V. = \frac{\text{Loaf volume (cc)}}{\text{Loaf weight (gm)}} = \frac{cc}{gm}
\]

3.2.5.1.2. Pan Bread crumb color

Minolta Spectrophotometer (CM- 508d, Japan) was used to determine bread color. The Minolta Chroma Meter was attached to the bread crumb and measurements were taken. Three readings were taken and an average \( L, a, \) and \( b \) values were recorded.

Bread color results were reported in terms of 3-dimensional color values based on the following rating scale:

<table>
<thead>
<tr>
<th>( L )- value</th>
<th>Whiteness</th>
<th>100 white</th>
<th>0 black</th>
</tr>
</thead>
<tbody>
<tr>
<td>( a )- value</td>
<td>Positive values</td>
<td>(+) red color</td>
<td>(-) green color</td>
</tr>
<tr>
<td>Negative values</td>
<td>(-) blue color</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( b )- value</td>
<td>Positive values</td>
<td>(+) yellow color</td>
<td></td>
</tr>
<tr>
<td>Negative values</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.2.5.1.3. Texture analysis for pan bread

Texture of breads (hardness, springiness, cohesiveness, chewiness, gumminess and resilience) was determined by Texture Profiles Analysis (TPA).
Breads were sliced transversely using an electric knife to obtain uniform slices of 2 cm thickness. Bread slices taken from the center of each loaf were used to evaluate the crumb texture. By using the specified cork corer, a sample of 2 cm height was taken. Texture profile analysis (TPA) was performed using the Sintech universal testing machine (TA.HD plus). The computer was set for Test works software and an appropriate test was selected for the TPA analysis. Sample was taken and then kept in between the two load cell (2000 lb) plates of the machine, and the load cell was slowly brought to a lower level, so that it touches the sample. The parameters like length, diameter, speed, the percent compression, and number of cycles (two) were given as input data to the computer before starting the compression of the sample. Then the load cell starts slowly moving downwards, compressing the sample, and wait between first and second compression cycle for 5 seconds. After two cycles the compression of the sample will automatically stop. The graph and data were recorded in the computer. TPA was done with 9 loaves at the same day after baking.

The example of the shape of a texture profile (TPA) curve is given in the figure below:

![Figure I. Texture profile analysis](image-url)
The parameters are listed below together with a brief definition of each:

**Hardness**: the force required to compress the material by a given amount. It is defined as the peak force during the first compression cycle (First bite).

**Cohesiveness**: the strength of the internal bonds in the sample. It is defined as the ratio of the positive force area during the second compression to that during the first compression.

**Springiness**: the elastic recovery that occurs when the compressive force is removed. It is defined as the height that food recovers during the time that elapses between the end of the first bite and the start of the second bite. It is calculated by \( \frac{\text{Length}_2}{\text{Length}_1} \) (mm/mm).

**Gumminess**: the energy required to break down a semi-solid food ready for swallowing.

**Chewiness**: the energy required to chew a solid food into a state for swallowing.

**Resilience**: It is how well a product “fight to regain its original position”. It is calculated by \( \frac{\text{Area}_5}{\text{Area}_4} \) (Nmm/Nmm).

### 3.2.5.1.4. Determination of circumference of balady bread

Circumference of 9 samples was measured from triplicate baking of balady bread. The determinations were carried out directly after baking and allowing the loaves to cool for 1 hour for sensory evaluation.

### 3.2.5.2. Sensory evaluation

Semi trained panelists were given a hedonic scale questionnaire to evaluate the bread. Pan bread was evaluated through general appearance, crumb grain, odor, softness, taste, mouth feel and overall acceptability. Balady bread was evaluated based on general appearance, softness, aroma, taste, crumb color, mouth feel and overall acceptability measures. They were scored on a scale of 9 points, in which (1- extremely dislike, 2- dislike very much, 3- dislike moderately, 4- dislike slightly, 5- neither like nor dislike, 6- like slightly, 7- like moderately, 8- like very much, and 9 – extremely like).
During sensory evaluation, panelists were instructed to drink water or wash mouth after each evaluation. Sensory evaluation was done on the day in which breads were prepared.

3.3. Statistical analysis

The analysis of variance (ANOVA) was performed to examine the significant level in all parameters measured. Least significant difference (LSD) test was used to separate between the means. All analyses were performed in triplicate (n = 3). The level of significance was 0.001 (Gomez and Gomez, 1984).
CHAPTER FOUR

4. RESULTS and DISCUSSION

4.1. Chemical composition of wheat and sorghum flours

The results of moisture, ash, crude protein, fat, carbohydrates, and some minerals contents of wheat and sorghum flours are illustrated in Table 1.

4.1.1. Proximate composition of wheat flour

4.1.1.1. Moisture content

As shown in Table 1 the moisture content of wheat flour was 11.44%. This result was higher than Carson and Sun (2000) results, who reported that the moisture content of hard wheat flour was 9.9%. Moreover, Abdalla (2003) studied the moisture content of Australian wheat flour (72-75% extraction) and Indian wheat flour (82% extraction). He reported that the moisture contents were 13.45 and 10.67% respectively.

4.1.1.2. Ash content

The ash content of extracted wheat flour, as shown in Table 1, was 0.52%. This result agreed with the previous findings 0.31- 0.62% reported by Pareds-Lopez et al., (1978) and higher than 0.45% reported by Egan et al. (1981). However it is lower than that reported by Coskuner and Karababa (2005) which was found it to be 0.6%. The ash content of Australian wheat flour (72-75% extraction) was 0.52% as reported by Abdalla (2003). On the other hand, Idowu, (1996) reported that the ash content of wheat flour was 1.3%.

4.1.1.3. Fat content

The results showed that the fat content of wheat flour was 1.05% (Table 1). This value is similar to that obtained by Abdel-Kader (2000), who reported that the fat content of soft wheat flour (82% extraction) milled from white Australian wheat...
Table 1: Chemical composition (%) of wheat, whole and decorticated sorghum flours.

<table>
<thead>
<tr>
<th>Type of Flour</th>
<th>Moisture</th>
<th>Ash</th>
<th>Crude Fat</th>
<th>Crude protein</th>
<th>Carbohydrate</th>
<th>Ca</th>
<th>Fe</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole Sorghum Flour</td>
<td>8.16&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.76&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.87&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10.85&lt;sup&gt;a&lt;/sup&gt;</td>
<td>76.36</td>
<td>0.016</td>
<td>0.013</td>
<td>0.281</td>
</tr>
<tr>
<td>Decorticated Sorghum Flour</td>
<td>7.89&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.32&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.03&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.62&lt;sup&gt;a&lt;/sup&gt;</td>
<td>78.14</td>
<td>0.017</td>
<td>0.0078</td>
<td>0.216</td>
</tr>
<tr>
<td>Extracted Wheat Flour</td>
<td>11.44</td>
<td>0.52</td>
<td>1.05</td>
<td>15.06</td>
<td>71.93</td>
<td>0.024</td>
<td>0.0023</td>
<td>0.105</td>
</tr>
</tbody>
</table>

Mean values having different superscript letter(s) in each column differ significantly ($p < 0.001$).
was 1.25%, and lower than the finding of Idowu (1996), who reported that fat content of wheat flour was 1.6%. Moreover, Abdalla (2003) studied the fat content of Australian wheat flour (72-75% extraction) and Indian wheat flour (82% extraction). He reported that the fat contents were 1.73 and 2.85% respectively.

4.1.1.4. Protein Content

The protein content of wheat flour, as shown in Table 1, was 15.06%. This result falls within the range of 8.5-16.1% reported by Chung et al., (2001) for wheat protein content study of hard winter wheat. However, it is higher than that obtained by Pomeranz et al (1977) who stated that the protein content of wheat flour was 12.3%; and that obtained by Abdalla (2003) who studied the protein content of Australian wheat flour (72-75% extraction) and Indian wheat flour (82 extraction). He reported that the protein content was 10.97 and 10.3% respectively.

4.1.1.5. Total carbohydrates

Table (1) shows the total carbohydrate content of wheat flour (71.93%) The result was lower than that reported by Abdalla (2003), who studied the total carbohydrate content of Australian wheat flour (72-75% extraction) and Indian wheat flour (82% extraction). He found that the total carbohydrate content was 73.33 and 75.39% respectively.

4.1.1.6. Minerals

As shown in Table 1, the calcium, iron and phosphorus content of wheat flour were 0.024%, 0.0023% and 0.105% respectively. Taha (2000) studied the minerals content of two Sudanese wheat cultivars (Condor 72%, Debeira 72%). He found that the amount of calcium, iron and phosphorus content were 0.51 and 0.54%; 102 and 82 µg/mg and 0.22 and 0.14% respectively.

4.1.2. Proximate composition of whole and decorticated sorghum flours:

4.1.2.1. Moisture content

The moisture content of the whole and decorticated sorghum flours (Tabat cultivar) were 8.16% and 7.89% respectively. This results were within the range of 5.7% to 10% reported by Yousif and Magboul (1972) for Sudanese sorghum cultivars, but higher than 6.3% as found by Elshewaya (2003). However, these values were below
the range of 8.89% to 9.88% reported by Arbab (1995). Elsayed (1999) who studied two Sudanese sorghum cultivars (Tabat and Feterita) found that the moisture content were 7.37 and 8.00% respectively.

4.1.2.2. Ash content

The ash content of whole and decorticated sorghum flours (Tabat cultivar) as shown in table 1 were 1.76% and 1.32% respectively. The results were in agreement with Purseglove (1972) who reported that the ash content of sorghum flour was 1.5-2%. These values were also found to be within the ranges of 1.1%- 2.7% reported by Shephered et al (1970) and 1.3% - 1.9% reported by Yousif and Magboul (1972), however, it is higher than that reported by Elshewaya (2003) who found that the ash content of the sorghum cultivar (Tabat) was 1.43%. Elsayed (1999), studied two Sudanese sorghum varieties (Tabat, Feterita), he concluded that the ash content were 1.5 and 1.8% respectively.

4.2.1.3. Fat content

The fat content of whole and decorticated sorghum flours were 2.87% and 2.03% respectively (Table1). These values were within the range of 2.5- 5.1% and 2.5-3.5% respectively as reported by Shephered (1970) and Eltinay et al (1979). Fat content value of whole sorghum was lower than 3.25% reported by Elshewaya (2003). As well as, Elsayed (1999), who found that fat content of two Sudanese sorghum cultivar (Tabat, Feterita), were 3.37% and 4.68% respectively.

4.2.1.4. Protein Content

The protein content of the whole and decorticated sorghum flours, as shown in Table 1, were 10.85% and 10.62% respectively. These values were within the range of 8.8-11.6% which was reported by Eltinay et al (1979). Protein content of whole sorghum cultivar (Tabat) was higher than the value reported by Elshewaya (2003) which was 8.74%. Elsayed (1999), studied two Sudanese sorghum cultivars (Tabat, Feterita); he found that the protein content were 6.64 and 12.71% respectively. However, Abdalla (2003) reported that the protein content of Sudanese sorghum variety (Fakimustahi) flour was 15.47%.
4.2.1.5. Total carbohydrates

Table 1 shows the total carbohydrates of whole and decorticated sorghum flours as 76.36% and 78.14% respectively. Similar result was obtained by Elshewaya (2003) which was 78.96%, and Elsayed (1999), who studied two Sudanese sorghum cultivars (Tabat and Feterita), and reported that the total carbohydrates were 78.78 and 71.33% respectively.

These results were higher than those reported by Eggum et al., (1983) who stated that the carbohydrates range from 71.0 to 73.4%. However Abdalla (2003) reported that the total carbohydrates of Sudanese sorghum cultivar (Fakimustahi) flour were 72.68%.

4.2.1.6. Minerals

As shown in Table 1, calcium, iron, and phosphorous content in the whole and decorticated sorghum flours were 0.016 % and 0.017%; 0.013% and 0.0078%; and 0.281% and 0.216% respectively.

FAO (1995) reported that iron content in sorghum was 4.2 (mg/100g) on dry basis. Taha (2000) studied the minerals content of three Sudanese sorghum cultivars, Dabar, Fakimustahi and Tetron, (100% extraction rate). He found that the amount of calcium was 0.62, 0.52 and 0.60%; phosphorous was 0.16, 0.12 and 0.12% and iron was 80, 65 and 72 µg/mg respectively.

4.2. Rheological properties of the dough prepared from composite flour of wheat and whole/ decorticated sorghum flours

4.2.1. Farinogram readings

The Farinogram parameters of the wheat flour with different levels of whole and decorticated sorghum flours are presented in Table 2. For both treatments, as the substitution level of sorghum flour increased, the water absorption values, as well as, dough development time of blends were decreased. Similar results were obtained by Carson and Sun (2000), who reported that at fixed gluten levels, as sorghum flour increased, water absorption decreased slightly. Moreover, the results indicated that the substitution with sorghum flour resulted in lower dough stability time at increasing levels. The decrease is more evident in the blends of 20% whole and decorticated sorghum flours.
Table 2: Farinogram readings of dough made from wheat flour with whole / decorticated sorghum flour.

<table>
<thead>
<tr>
<th>Farinogram Parameters</th>
<th>Control</th>
<th>Whole sorghum flour %</th>
<th>Decorticated sorghum flour %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5 10 15 20</td>
<td>5 10 15 20</td>
</tr>
<tr>
<td>Water absorption 14%</td>
<td>63</td>
<td>62.4 61.9 61.0 60.0</td>
<td>62.4 61.7 61.1 59.9</td>
</tr>
<tr>
<td>Development time (min)</td>
<td>10.1</td>
<td>8.4 7.4 7.8 7.8</td>
<td>8.8 8.5 8.1 7.2</td>
</tr>
<tr>
<td>Stability (min)</td>
<td>17.8</td>
<td>16.2 14.6 13.9 13.3</td>
<td>17.1 16.0 14.5 13.2</td>
</tr>
<tr>
<td>Mixing Tolerance Index MTI (FU)</td>
<td>11</td>
<td>17 21 23 25</td>
<td>20 23 26 28</td>
</tr>
<tr>
<td>Farinograph Quality Number (mm)</td>
<td>197</td>
<td>150 126 134 127</td>
<td>158 143 137 127</td>
</tr>
</tbody>
</table>
The results also showed that when the percentage of sorghum flours increased in the dough, the farinograph quality number values of blended flours decreased for both sorghum flour types. Mixing tolerance index (MTI) indicates the degree of softening during mixing. The results showed that, as the substitution level of sorghum flours increased, MTI increased. The highest MTI was observed in the sample of wheat 80% with 20% whole and decorticated sorghum flours than the control. This result is in agreement with that reported by Abdalla (2003), who stated that the degree of softening increased with increasing the amount of sorghum flour.

Generally, increasing the substitution with non-wheat cereal flour will have increasingly deleterious effects on rheological quality. Coskuner and Karababa (2005) reported that although stronger dough are preferred for loaf raised bread, commonly medium strength dough are preferred for flat bread-making. If the dough is too strong it will not react properly during the sheeting or flattening processes involved in the baking of flat breads.

4.2.2. Gluten content and gluten index

Table 3 shows the effect of substitution of wheat flour with whole and decorticated sorghum flour on gluten. The quantity and quality of gluten largely determine the dough rheological properties.

It is noticed that dry gluten decreased with increasing the amount of whole and decorticated sorghum flours. The dry gluten content of wheat flour was 13.7%. This result agrees with that reported by Kulkarni et al. (1987) who found that the dry gluten of hard red winter and hard red spring wheat ranged from 9.4- 15.1% and 11.7-15.3%, respectively. The values are higher than those reported by Huebner and Rothfus (1968) who concluded that dry gluten from different cultivars of hard wheat ranged between 9 and 11%. The decrease of dry gluten in composite flour may be due to the decrease in gluten content of the composite flour mixture due to increase in the sorghum contribution. This finding is in harmony with that obtained by Taha (2000), who reported that the dry gluten content of wheat flour (control) is higher than in composite flour (wheat/sorghum). Also, the wet gluten decreased as the amount of whole and decorticated sorghum flours increased. However, the decrease was more obvious beyond 10% sorghum flours substitution.
Table 3: Gluten quantity and quality of composite flour of wheat flour with whole/ decorticated sorghum flours.

<table>
<thead>
<tr>
<th>Quality Characteristics</th>
<th>Control</th>
<th>Whole sorghum flour %</th>
<th>Decorticated sorghum flour %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Dry gluten (%)</td>
<td>13.7</td>
<td>13.3</td>
<td>12.6</td>
</tr>
<tr>
<td>Wet gluten (%)</td>
<td>36.7</td>
<td>36.5</td>
<td>35.0</td>
</tr>
<tr>
<td>Gluten index%</td>
<td>96.6</td>
<td>96.5</td>
<td>96.0</td>
</tr>
</tbody>
</table>
This is due to the absence of gluten in sorghum flour. The wet gluten content of wheat flour was 36.7%. This finding is similar to that obtained by Mohamed (2000) who reported that wet gluten of white flour from Sudanese cultivars (season 1997/98) is in the range of 32.6 to 38.77%. Taha (2000) reported that, as the extraction rate of sorghum flours decreased, the wet and dry gluten decreased due to the increase of starch content of sorghum flour at lower extraction rate.

Furthermore, the gluten index decreased as the percentage of sorghum flours increased. The lowest gluten index 87.5% was obtained from 20% whole sorghum flour as compared with 96.6% for the control.

4.2.3. Extensogram readings

Table 4 and Figures (2-10) summarize the data obtained from the extensogram. The results showed that, in general, increasing the substitution of sorghum flours reduced the energy, the resistance to extension, extensibility, and maximum resistance of the dough to extension; while the ratio number between resistance and extensibility was increased. The decrease in energy meant that less work would be needed to stretch and break the dough as sorghum flour increased.

Similar findings were reported by Carson and Sun (2000) that at fixed gluten amounts, with increasing sorghum flour substitution percentage, dough strength and extensibility decreased significantly. The results also indicate that, generally, as the time increased, the energy, resistance to extension, maximum resistance and ratio number increased, while the extensibility decreased. This result agreed with that reported by Abdalla (2003), who found that, the resistance to extension, ratio number and energy increased with increasing the time from 45 to 135 min, while extensibility decreased. Moreover, Hamaker, (2001) reported that addition of sorghum flour to wheat flour produces marked negative effects on rheological properties of dough.

The decrease in the energy, resistance and extensibility of dough as affected by increasing the percentage of sorghum may be due to the reduction of gluten as the percentage of sorghum increased.
Table 4: Extensogram readings of dough made from wheat flour with different levels of whole/decorticated sorghum flours.

<table>
<thead>
<tr>
<th>Quality Characteristics</th>
<th>Control</th>
<th>Whole sorghum flour %</th>
<th>Decorticated sorghum flour %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0%</td>
<td>5%</td>
<td>10%</td>
</tr>
<tr>
<td></td>
<td>45 min</td>
<td>90 min</td>
<td>135 min</td>
</tr>
<tr>
<td>Energy (cm²)</td>
<td>88</td>
<td>129</td>
<td>141</td>
</tr>
<tr>
<td>Resistance to Extension (BU)</td>
<td>326</td>
<td>491</td>
<td>568</td>
</tr>
<tr>
<td>Extensibility (mm)</td>
<td>149</td>
<td>144</td>
<td>144</td>
</tr>
<tr>
<td>Maximum resistance (BU)</td>
<td>457</td>
<td>729</td>
<td>793</td>
</tr>
<tr>
<td>Ratio Number (R/E)</td>
<td>2.2</td>
<td>3.4</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Quality Characteristics</th>
<th>0%</th>
<th>5%</th>
<th>10%</th>
<th>15%</th>
<th>20%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>45 min</td>
<td>90 min</td>
<td>135 min</td>
<td>45 min</td>
<td>90 min</td>
</tr>
<tr>
<td>Energy (cm²)</td>
<td>88</td>
<td>129</td>
<td>141</td>
<td>81</td>
<td>145</td>
</tr>
<tr>
<td>Resistance to Extension (BU)</td>
<td>326</td>
<td>491</td>
<td>568</td>
<td>359</td>
<td>622</td>
</tr>
<tr>
<td>Extensibility (mm)</td>
<td>149</td>
<td>144</td>
<td>144</td>
<td>136</td>
<td>143</td>
</tr>
<tr>
<td>Maximum resistance (BU)</td>
<td>457</td>
<td>729</td>
<td>793</td>
<td>445</td>
<td>810</td>
</tr>
<tr>
<td>Ratio Number (R/E)</td>
<td>2.2</td>
<td>3.4</td>
<td>4</td>
<td>2.6</td>
<td>4.3</td>
</tr>
</tbody>
</table>
Figure 2: Extensogram of dough prepared from wheat flour (control).
Figure 3: Extensogram of dough prepared from composite flour with 5% whole sorghum flour.
Figure 4: Extensogram of dough prepared from composite flour with 10% whole sorghum flour.
Figure 5: Extensogram of dough prepared from composite flour with 15% whole sorghum flour.
Figure 6: Extensogram of dough prepared from composite flour with 20% whole sorghum flour.
Figure 7: Extensogram of dough prepared from composite flour with 5% decorticated sorghum flour.
Figure 8: Extensogram of dough prepared from composite flour with 10% decorticated sorghum flour.
Figure 9: Extensogram of dough prepared from composite flour with 15% decorticated sorghum flour.
Figure 10: Extensogram of dough prepared from composite flour with 20% decorticated sorghum flour.
4.3. Physical properties of pan and flat (balady) breads

4.3.1. Specific volume of pan bread

The effect of sorghum flours on specific volume of wheat pan bread is presented in Table 5. Bread specific volume decreased significantly with increasing sorghum substitution level. The volumes of bread made from composite flours, were less than those made from the control. The highest bread specific volume was 5.93 (cc/g) obtained with wheat flour (control), while flour containing 20% whole and decorticated sorghum flour resulted in the lowest bread specific volume of 5.04 and 5.27 (cc/g) respectively. This finding is in agreement with that reported by Aluko and Olugbemi’s (1989), who found that the volumes of bread made from composite flours were less than those made from wheat. This may be due to the greater level of sorghum in the composite mixture, the less the level of gluten network in the dough and consequently less ability to rise, due to the weak cell-wall structure. However the specific volumes of the 5, 10, and 15% levels of substitution were not significantly different from each other. This is in agreement with Morad, et al (1984) who concluded that the substitution of hard wheat flour with up to 20% sorghum flour significantly decreased the loaf volume of pan bread, and Perten et al. (1980) who reported that the addition of sorghum to wheat flour negatively influence the volume of bread. Nevertheless, acceptable bread could be made in the ratio of 70% wheat and 30% sorghum (Taha, 2000).

Abdel-Aal et al, (1993) reported that loaf volume and specific volume of pan breads prepared from composite flours were 25-60% less than that of the control bread but flat breads tolerated the protein supplements extremely well. On the other hand, Badi et al. (1976) reported that adding 10% millet-sorghum flour to the standard baking formula slightly increased loaf volume and improved crumb grain. Whereas adding sorghum flour (5-20%) to the standard formula decreased loaf volume; although the product was acceptable.
Table 5: Effect of whole / decorticated sorghum flours on specific volume of wheat flour pan bread.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Whole sorghum flour %</th>
<th>Decorticated sorghum flour%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Dough weight(g)</td>
<td>170</td>
<td>170</td>
<td>168</td>
</tr>
<tr>
<td>Loaf weight(g)</td>
<td>154</td>
<td>154</td>
<td>152</td>
</tr>
<tr>
<td>Loaf volume (cc)</td>
<td>913</td>
<td>866</td>
<td>836</td>
</tr>
<tr>
<td>Loaf specific volume (cc/gm)*</td>
<td>5.93(^a)</td>
<td>5.61(^b)</td>
<td>5.55(^bc)</td>
</tr>
</tbody>
</table>

Mean values having different superscript letter(s) in each column differ significantly ($p < 0.001$).

* \( \text{Loaf Specific Volume} = \frac{\text{Loaf volume (cc)}}{\text{Loaf weight (gm)}} \)
4.3.2. Crumb color of pan bread

The color values $L$ (light-dark), $a$ (red-green), and $b$ (yellow-blue) of the crumb of pan bread samples substituted with whole and decorticated sorghum flours are presented in Table 6. The results indicate that, as the percent of sorghum flours replacement increased, $L$ values shifted significantly from white to gray, $a$ values shifted from green to red, and $b$ values shifted from blue to yellow. In the whole sample, the $L$ values of the bread crumb samples substituted with sorghum flours decreased from 72.54 to 65.29, indicating a significant increase ($p<0.001$) in grayish color.

The highest $a$-value was that of bread made with 20% whole sorghum flour (-0.13); whereas, the lowest value belongs to bread made from control wheat flour (-0.75) which indicated more green color. The lowest result of $b$-value was that of bread made from the control wheat flour (9.51), whereas the highest value (12.67) was associated with bread made with 20% whole sorghum flour.

The effect of whole sorghum flour substitution on the color of the crumb of bread samples was more obvious than that of decorticated sorghum flour substitution, where bread samples substituted with whole sorghum flour gave lower $L$ values and higher $a$ and $b$ values when compared to the samples substituted with decorticated sorghum flour. In contrast, Torres, et al (1993) reported that the addition of decorticated sorghum flour did not significantly ($p<0.05$) affect the color of flour for tortillas. However, tortillas containing sorghum flour had undesirable black specks that affect their appearance. Also, Morad, et al (1984) studied the effect of sorghum variety on baking properties of U.S. conventional bread, balady bread and cookies. He found that the color values of pocket bread made from whole wheat flour was similar to those made from brown and yellow sorghum at 30% replacement, and white sorghum up to 40% replacement. Bread crumb color, especially of those made with brown sorghums could compete with bread from whole wheat. The results from this study indicate that sorghum seed-coat darkened crumb color. This may be due to the fact that the fibers and pigments reduced the green component in crumb color and shifted the color somewhat towards the gray-red, whereas sorghum coat imparted a yellowish tint on the crumb.
Table 6: Effect of adding whole / decorticated sorghum flours on wheat flour bread crumb color.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Whole sorghum flour %</th>
<th>Decorticated sorghum flour %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td><strong>L -value</strong></td>
<td>72.54&lt;sup&gt;a&lt;/sup&gt;</td>
<td>71.58&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>69.18&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>a - value</strong></td>
<td>-0.75&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-0.67&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-0.47&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>b -value</strong></td>
<td>9.51&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10.40&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>11.45&lt;sup&gt;cde&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Mean values having different superscript letter(s) in each column differ significantly ($p < 0.001$).
4.3.3. Texture characteristics of pan bread

Pan bread texture was determined as hardness, cohesiveness, springiness, gumminess, chewiness, and resilience using the TPA Texture Analyzer.

As shown in Table 7, it is evident that all TPA parameters of the experimental breads, except springiness and chewiness, are significantly different ($p < 0.001$). The results showed that, as the amount of sorghum flours increased, the hardness of the bread crumb increased. With up to 5% whole and decorticated sorghum flours, no significant difference ($p < 0.001$) was observed in hardness. The replacement of wheat flour with sorghum flours decreased cohesiveness, and resilience in bread samples; however, it increased gumminess. The results of springiness (which indicates the percentage recovery of bread), and resilience (which express the ability (speed) of material to return to its original shape after a stress) indicated that when the substitution level of sorghum flours increased, the bread required more time to recover its shape.

Gumminess and chewiness are secondary parameters. The chewiness is the most indicative characteristic of bread. It is calculated by multiplying gumminess, and springiness, whereas the determination of gumminess is calculated by multiply hardness and cohesiveness. The results showed that gumminess increased with an increased amount of sorghum flours in the blends. Regarding gumminess and chewiness, the results revealed that their values are highly dependant on hardness rather than on cohesiveness or springiness values.

It was reported that since wheat flours contain protein gluten which by suitable development gives the bread it’s unique and much desired texture; the inclusion of sorghum flours dilutes wheat gluten, and consequently weakens its strength. While the presence of starch in baking affects crumb characteristics (Taha, 2000).

4.3.4. Circumference of balady bread

The substitution effects of sorghum flour on balady bread quality are shown in Table 8. A slight decrease but significant in bread circumference has occurred with the inclusion of any amount of sorghum flour.
Table 7: Effect of adding whole / decorticated sorghum flours on wheat flour pan bread texture.

<table>
<thead>
<tr>
<th>Texture Characteristics</th>
<th>Control</th>
<th>Whole sorghum flour %</th>
<th>Decorticated sorghum flour %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Hardness (N)</td>
<td>11.48a</td>
<td>12.22a</td>
<td>16.70b</td>
</tr>
<tr>
<td>Cohesiveness</td>
<td>0.71a</td>
<td>0.69a</td>
<td>0.70a</td>
</tr>
<tr>
<td>Gumminess (N)</td>
<td>8.19a</td>
<td>8.48a</td>
<td>11.65bc</td>
</tr>
<tr>
<td>Springiness</td>
<td>0.90a</td>
<td>0.75a</td>
<td>0.82a</td>
</tr>
<tr>
<td>Chewiness (N)</td>
<td>7.41a</td>
<td>6.35a</td>
<td>9.61a</td>
</tr>
<tr>
<td>Resilience</td>
<td>0.37a</td>
<td>0.33ab</td>
<td>0.32b</td>
</tr>
</tbody>
</table>

Mean values having different superscript letter(s) in each column differ significantly ($p < 0.001$).
Table 8: Physical properties of balady bread

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>Control</th>
<th>Whole sorghum flour %</th>
<th>Decorticated sorghum flour %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Bread circumference</td>
<td>36.97&lt;sup&gt;a&lt;/sup&gt;</td>
<td>35.43&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>34.60&lt;sup&gt;cd&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Mean values having different superscript letter(s) in each column differ significantly (*p* < 0.001).
4.4. Sensory evaluation of breads

Sensory scores of pan and flat bread samples made with substitution with sorghum flours are presented in Table 9 and 10 respectively. The Analysis of variance (ANOVA) of the data showed that the effect of wheat and sorghum blends on sensory properties was statistically significant ($p < 0.001$) for all types of breads evaluated in this study.

4.4.1. Pan Bread

The sensory properties of pan breads made from blends of wheat and whole /decorticated sorghum flours as well as the control bread are presented in Table 9. All sensory scores general appearance, crumb grain, taste, softness, mouth feel, and overall acceptability were significantly different among blend samples, except odor. All breads were rated as acceptable by the panel except mouth feel attribute of the samples with 20% whole and decorticated sorghum flour. But the preference was decreased as the substitution of sorghum level increased. According to the results in Table 9 bread made from 100% wheat flour (control) showed excellent attributes in comparison with other types of bread. Generally, individual sensory scores of pan bread made with whole sorghum flour were slightly lower than those of blends of decorticated sorghum flour.

This result may be explained by the characteristics of the grain coat in the flour. The results showed that the level of preference declined with decreasing the level of wheat flour substitution in the bread.

However, Anglani, 1998; Carson et al., 2000; Hugo et al., 2000, 2003a, reported that addition of 20 to 50% sorghum flour to wheat flour produce excellent bread. While, Summer and Nielson (1976a) produced acceptable Nigerian bread using an 80/20 wheat/ sorghum composite flour blend. Moreover, Perten (1977) reported that the satisfactory production of French-type bread from composites of 85% (87% extraction) and 15% sorghum flour. Composite bread produced from composite flours at the ratios 90/10, 80/20 and 70/30 wheat/sorghum were found to give acceptable bread quality (Taha, 2000).
Table 9: Sensory evaluation of pan bread from composite flour of wheat flour with whole/ decorticated sorghum flours.

<table>
<thead>
<tr>
<th>Sensory attributes</th>
<th>Control</th>
<th>Whole sorghum flour %</th>
<th>Decorticated sorghum flour %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>General appearance</td>
<td>8.44&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.11&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.11&lt;sup&gt;bcd&lt;/sup&gt;</td>
</tr>
<tr>
<td>Crumb grain</td>
<td>8.22&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.99&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>7.13&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mouth feel</td>
<td>8.22&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.59&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>7.11&lt;sup&gt;abc&lt;/sup&gt;</td>
</tr>
<tr>
<td>Odor</td>
<td>7.75&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.94&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.25&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Taste</td>
<td>8.44&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.22&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.74&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Softness</td>
<td>8.67&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.67&lt;sup&gt;b&lt;/sup&gt;</td>
<td>7.56&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Overall acceptability</td>
<td>8.29</td>
<td>7.59</td>
<td>6.98</td>
</tr>
</tbody>
</table>

Mean values having different superscript letter(s) in each column differ significantly ($p < 0.001$).
4.4.2. Balady Bread

With respect to the organoliptic evaluation of the bread produced, the overall quality correlates with the ratio of the sorghum flour are shown in Table 10. The general appearance of balady bread was significantly ($p < 0.001$) different with increasing levels of sorghum flours (whole/ decorticated). The crumb color of the breads substituted with 5% and 10% decorticated sorghum flour was significantly comparable to the control; whereas at higher levels of substitution, samples were significantly darker ($p < 0.001$). These results are in agreement with those reported by Sumner and Nielsen (1976b), who concluded that incorporation of 20% sorghum flour in bread formulation darkens the internal and external loaf color.

Taste scores decreased significantly as the level of sorghum flour increased. A slight bitter taste at a 10% or greater replacement level of whole sorghum flour may be due to the phenolic compound and tannins found in the seed- coat.

When the proportion of sorghum flours increased in breads, the softness and mouth feel of bread scores decreased significantly. These results were apparently found in the samples with whole sorghum flour levels rather than those with decorticated sorghum flour. Generally, it is observed that both the control bread and that bread made with up to 20% sorghum flours did not vary significantly ($p< 0.001$) in aroma characteristic. However, there was a variation in general acceptability among sorghum flours substitution levels. The control had a higher acceptability score compared to all sorghum flours substitution.

Generally the bread was accepted with at its different levels of whole and decorticated sorghum flours substitution levels. However, the preference was reduced with increasing levels of substitution. These results are in agreement with those reported by Kyomugisha (2002). On the other hand, there was a steady deterioration of bread quality as the percentage of non-wheat flour was increased, and the additions of sorghum flours to the wheat flour blend did not improve the sensory properties of the flat breads.

It should be realized that the preference, according to taste, differs from one region in the Sudan to another. It is expected that composite flour bread assumes a higher degree of preference in rural areas where the people are more accustomed to the taste of products made from sorghum alone. Accordingly composite flour bread should be tested in rural areas first.
Table 10: Sensory evaluation of balady bread supplemented with whole/decorticated sorghum flours.

<table>
<thead>
<tr>
<th>Sensory attributes</th>
<th>Control</th>
<th>Whole sorghum flour %</th>
<th>Decorticated Sorghum flour %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5  10  15  20</td>
<td>5  10  15  20</td>
</tr>
<tr>
<td>General appearance</td>
<td>8.33\textsuperscript{a}</td>
<td>7.00\textsuperscript{b} 6.96\textsuperscript{b} 5.83\textsuperscript{e} 5.83\textsuperscript{c}</td>
<td>7.33\textsuperscript{b} 7.33\textsuperscript{b} 7.44\textsuperscript{b} 7.56\textsuperscript{ab}</td>
</tr>
<tr>
<td>Crumb color</td>
<td>8.56\textsuperscript{a}</td>
<td>7.44\textsuperscript{bcd} 6.89\textsuperscript{de} 6.22\textsuperscript{ef} 5.89\textsuperscript{f}</td>
<td>8.02\textsuperscript{ab} 7.78\textsuperscript{abc} 7.11\textsuperscript{cde} 6.78\textsuperscript{de}</td>
</tr>
<tr>
<td>Softness</td>
<td>8.28\textsuperscript{a}</td>
<td>6.56\textsuperscript{cd} 6.60\textsuperscript{cd} 6.11\textsuperscript{de} 5.44\textsuperscript{e}</td>
<td>7.67\textsuperscript{ab} 7.33\textsuperscript{bc} 7.32\textsuperscript{bc} 6.78\textsuperscript{bcd}</td>
</tr>
<tr>
<td>Aroma</td>
<td>7.93\textsuperscript{a}</td>
<td>7.87\textsuperscript{a} 6.56\textsuperscript{bc} 6.56\textsuperscript{bc} 6.33\textsuperscript{c}</td>
<td>7.22\textsuperscript{ab} 7.85\textsuperscript{a} 7.22\textsuperscript{ab} 7.67\textsuperscript{a}</td>
</tr>
<tr>
<td>Taste</td>
<td>8.29\textsuperscript{a}</td>
<td>7.15\textsuperscript{bc} 6.46\textsuperscript{cd} 5.88\textsuperscript{de} 5.66\textsuperscript{e}</td>
<td>7.33\textsuperscript{b} 7.10\textsuperscript{bc} 6.90\textsuperscript{bc} 6.87\textsuperscript{bc}</td>
</tr>
<tr>
<td>Mouth feel</td>
<td>8.00\textsuperscript{a}</td>
<td>8.12\textsuperscript{a} 6.67\textsuperscript{cd} 6.44\textsuperscript{cd} 6.11\textsuperscript{d}</td>
<td>7.74\textsuperscript{ab} 7.00\textsuperscript{bcd} 7.33\textsuperscript{abc} 6.78\textsuperscript{cd}</td>
</tr>
<tr>
<td>General acceptability</td>
<td>8.23</td>
<td>7.36  6.69  6.17  5.88</td>
<td>7.55  7.40  7.22  7.07</td>
</tr>
</tbody>
</table>

Mean values having different superscript letter(s) in each column differ significantly ($p < 0.001$).
Plate 1: Pan Bread made from composite flour (whole sorghum-wheat).

WF: Wheat flour 100%
WSF 5%: Whole Sorghum Flour 5%.
WSF 10%: Whole Sorghum Flour 10%.
WSF 15%: Whole Sorghum Flour 15%.
WSF 20%: Whole Sorghum Flour 20%.
Plate 2: Pan Bread made from composite flour (decorticated sorghum-wheat).

WF: Wheat flour 100%
DSF 5%: Decorticated Sorghum Flour 5%.
DSF 10%: Decorticated Sorghum Flour 10%.
DSF 15%: Decorticated Sorghum Flour 15%.
DSF 20%: Decorticated Sorghum Flour 20%.
Plate 3: Balady Bread made from composite flour (whole sorghum-wheat).

1- Wheat flour 100%
2- Whole Sorghum Flour 5%.
3- Whole Sorghum Flour 10%.
4- Whole Sorghum Flour 15%.
5- Whole Sorghum Flour 20%.
Plate 4: Balady Bread made from composite flour (de corticated sorghum- wheat).

1- Wheat flour 100%
6- Decorticated Sorghum Flour 5%.
7- Decorticated Sorghum Flour 10%.
8- Decorticated Sorghum Flour 15%.
9- Decorticated Sorghum Flour 20%.
Plate 5: Effect of adding sorghum flour (whole/ decorticated) on pan bread made from hard white winter wheat flour.

WF: Wheat flour 100%
WSF  5%: Whole Sorghum Flour 5%.      DSF  5%: Decorticated Sorghum Flour 5%.
WSF 10%: Whole Sorghum Flour 10%.    DSF 10%: Decorticated Sorghum Flour 10%.
WSF 15%: Whole Sorghum Flour 15%.    DSF 15%: Decorticated Sorghum Flour 15%.
WSF 20%: Whole Sorghum Flour 20%.    DSF 20%: Decorticated Sorghum Flour 20%.
Plate 6: Effect of adding sorghum flour (whole/ decorticated) on balady bread made from hard white winter wheat flour.

1- Wheat flour 100%
2- Whole Sorghum Flour 5%.
3- Whole Sorghum Flour 10%.
4- Whole Sorghum Flour 15%.
5- Whole Sorghum Flour 20%.
6- Decorticated Sorghum Flour 5%.
7- Decorticated Sorghum Flour 10%.
8- Decorticated Sorghum Flour 15%.
9- Decorticated Sorghum Flour 20%.
CHAPTER FIVE

5. CONCLUSIONS and RECOMMENDATIONS

5.1. Conclusions

The following conclusions could be considered from the preceding work:

- Wheat flour had higher protein, moisture, and calcium values, and lower fat, ash, carbohydrates, iron, and phosphorous values compared to whole and decorticated sorghum flours.
- The decortication of sorghum grains decreased moisture, ash, fat, crude protein, iron and phosphorous content. However, carbohydrate content was increased.
- The water absorption, development time, stability time and quality number of the dough decreased with increasing levels of sorghum flour in both whole and decorticated blends, while the mixing tolerance index of the dough increased.
- The high quantity and strong quality of gluten in composite flour samples decreased as the amount of sorghum flours substitution increased.
- Increasing the substitution of sorghum flours reduced the energy, the resistance to extension, extensibility, and maximum resistance of the dough to extension. While the ratio number between resistance and extensibility was increased i.e. the dough tended to be short.
- As the time of Extensogram increased, the energy, resistance to extension, maximum resistance and ratio number of the dough increased, while the extensibility decreased.
- The higher the level of substitution of wheat flour with (whole and decorticated) sorghum flours, the lower the scores of the circumference of balady bread and specific volume of pan bread.
- The whole sorghum flour blends gave less loaf scores than decorticated sorghum flour blends.
- Although slight color changes were observed in $L$, $a$, and $b$ values, there were significant differences among the different levels of substitution. However, crumb color was directly related to sorghum extraction rate and the level of substitution.
- Increasing the level of sorghum flours decreased cohesiveness, springiness and resilience of pan bread made of whole/ decorticated sorghum-wheat composite flour, while, hardness, gumminess and chewiness increased.
• Acceptable pan and balady bread could be made with adding up to 20% whole or decorticated sorghum flours.
5.2. Recommendations

Based on these conclusions, the following recommendations were made:

- Wheat - sorghum composite flour is a viable alternative to 100% wheat flour at levels up to 20% substitution.
- Whole and decorticated sorghum flours can be successfully incorporated into pan and balady bread formulations. Hence, the research on flat breads might provide an opportunity to broaden the base of composite-flour products in the market.
- Large scale production of wheat - sorghum composite flour, should be adopted by large milling companies so as to reduce the dependence on imported wheat for the preparation of products which are very popular in the country.
- To explore consumer acceptability of the bread in the different regions, pilot bakeries need to be established to prepare the market for sorghum-wheat bread.
- Further work should be conducted for wheat- sorghum composite flour with addition of improvers such as Gum Arabic.
- Chemical analyses and shelf life of the final product should be studied.
- In evaluating the preference of different types of bread, the bread taste at different regions and society groups of the Sudan should be taken into consideration.
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