Thermal and Rheological Characterization of a Sorghum Composite Flour With Superior Breadmaking Quality

Abdulvahit Sayaslan[1] and Jie Hu[2]
[1]Gaziosmanpaşa Üniversitesi, Ziraat Fakültesi, Gıda Mühendisliği Bölümü, Tokat, TÜRKİYE
[2]Kansas State University, Department of Grain Science and Industry, Manhattan, Kansas, USA

ÖZET

En iyi kalitede ekmek yapıldığı rapor edilen bir sorgum katkılı buğday ununun termal ve reolojik özellikleri, buğday ve sorgum unları ve bu unlardan elde edilen nişasta ve proteinlerin özellikleri ile karşılaştırılarak; sorgum katkılı buğday unu bileşenleri arasındaki etkileşim araştırılmıştır. Sorgum katkılı buğday unu %50 sorgum unu, %39 buğday unu ve %11 gluten karışımı olup, karışımın protein miktarı, %14 nem esasına göre, %15'tir. Buğday ve sorgum unları ile bunlardan elde edilen nişasta ve proteinler, termal ve reolojik özellikleri bakımından farklılıklar göstermektedir. Ancak, sözü edilen sorgum katkılı buğday unu, kontrol buğday ununun reolojik özelliklerine yakın değerler vererek, daha önce bu karışımın en kaliteli ekmeklik sorgum katkılı buğday unu olduğu yönündeki sonucu desteklemektedir. Bu sonuçlar, tahıl bileşenlerinin termal ve reolojik özelliklerinin değişik tahıl unu katkılı ekmeklik unların hazırlanmasında yararlı olabileceğini göstermektedir.

ABSTRACT

Thermal and rheological properties of a specific sorghum composite flour, which was previously reported to be the best formulation for breadmaking, were compared with those of wheat and sorghum flours and of their isolated starches and proteins in order to predict possible interactions among the composite flour constituents. The composite flour was a mixture of 50% sorghum flour, 39% wheat flour, and 11% vital wheat gluten (15% composite final protein content at 14% moisture). The wheat and sorghum flours and their isolated starches and proteins differed in their pasting and gelatinization properties. However, this particular sorghum composite flour gave similar pasting properties to those of the control wheat flour, confirming the previous finding that this sorghum composite flour was the best blend for breadmaking. The results indicate that thermal and rheological studies of cereal components can provide invaluable information on the formulation of composite flours for breadmaking.

INTRODUCTION

The demand for cereals as food, feed, and industrial raw materials has been increasing in parallel to population increase in the world. Due to the population explosion in the world, particularly in the underdeveloped and developing countries, shortfalls in cereal production have been common problems in the human history. Currently, a shortage of cereals for food is being experienced by some underdeveloped nations. The total cereal production of the world was estimated to be about 2 million metric tons in 2002 (FAO 2002). Sorghum (Sorghum bicolor) production in the world, however, accounted for less than 4% (50-60 million metric tons) of total cereal production (FAO 2002). After wheat, rice, maize, and barley, sorghum is the fifth leading cereal produced in the world. The area planted to the four major cereals in the world can no longer be remarkably expanded due to the limitations in the availability of water and suitable temperature. Sorghum, however, can be grown in the semiarid regions of the world, such as certain parts of Africa and India, where wheat, rice, and corn cannot be planted. Furthermore, those semiarid regions of the world experience a higher rate of population growth. Therefore, sorghum will remain the staple of a large number of people in a vast area of semiarid regions (Dendy 1995, House et al 1995).

In addition to its large utilization as animal feed, sorghum has been traditionally used as food to prepare various kinds of porridges, breads, and beverages around the world (Murty and Kumar 1995). Substantial research in various countries on sorghum has directed at increasing yield, nutritional quality, and industrial utilization of sorghum. Recently, food-grade white sorghum varieties have been developed in the United States, which has a thin pericarp to improve milling properties and free from phenolics to eliminate undesirable flavor and color (Anonymous 1999).

Addition of sorghum flour to bread formulations has been studied since the 1960s (Bhatia et al 1968). In more recent years, blending sorghum flour with wheat flour, which is called sorghum composite flour, for breadmaking has gained widespread interest due to its certain advantages. The mixtures of several cereal flours can provide a greater variety of nutrients and thus improve nutritional quality of foods (Klopfenstein and Hoseney 1995). The use of sorghum composite flour in breadmaking provides an alternative to wheat flour for breadmaking in the regions of the world where wheat is not easily grown or available, thus reducing the dependency on wheat flour. Furthermore, due to the slow release of sugars from sorghum flour (lower glycemic index), sorghum composite flour may be better suited for consumption by people with diabetes (Toomey 1988). In addition, food products made from sorghum can be consumed by celiac patients since sorghum proteins, in contrast to the proteins of wheat, rye, and barley, are not harmful to those people with celiac disease (Connon 1999).

The properties of sorghum flour doughs and their breads and those of sorghum composite flours have been extensively studied (Pringle et al 1969, Subramanian et al 1983, Morad et al 1984, Ortega et al 1995, Rao and Rao 1997. In general, sorghum dough did not perform satisfactorily in breadmaking. Bread from sorghum dough was tougher in texture and lower in volume compared to bread from wheat dough. These inferior bread characteristics of sorghum dough were attributed to the lack of viscoelastic gluten properties in sorghum proteins. As the level of sorghum flour increased in a bread formulation, the dough quality decreased (Morad et al 1984, Foda et al 1987).

The addition of vital wheat gluten to wheat flours have been shown to improve dough rheology for breadmaking (Finney and Barmore 1948, Magnuson 1977, Stenvert et al 1981). However, Cubadda (1989) found that vital wheat gluten addition to sorghum flour did not markedly improve its breadmaking potential. Recently, Cheong (1998) studied the effects of vital wheat gluten addition to sorghum composite flours on breadmaking. It was found that bread from sorghum composite flour (50% sorghum flour, 39% wheat flour and 11% vital wheat gluten at a 15% final protein content on 14% moisture basis) gave a volume about 60% higher than that from a sorghum flour with only vital wheat gluten addition. It is obvious that interactions between proteins from wheat flour (endogenous proteins) and from vital wheat gluten (exogenous proteins) and their ratios are of great importance in breadmaking using sorghum composite flour. However, the nature of the interactions was not studied and largely unknown. Therefore, it is important to study those interactions by an appropriate experimental approach in order to better understand the underlying mechanisms. Knowledge of the thermal and rheological characteristics of major flour components and composites may help understand the mechanism of the interactions among sorghum flour, wheat flour, and vital wheat gluten during dough development and breadmaking. Differential scanning calorimeter (DSC) and rapid visco analyzer (RVA) have been widely used, respectively, for the thermal and rheological characterization of cereal-based products (Akingbala et al 1988, Walker et al 1988, Yuan and Thopson 1998, Whalen 1999).

Therefore, the objective of this study was to determine the thermal and rheological properties of individual flour components and of the aforementioned sorghum composite flour, which was previously found to be the best formulation for breadmaking, using DSC and RVA.

MATERIALS AND METHODS

Materials

Sorghum flour milled from decorticated whole-grain food-grade white sorghum was obtained from Jowar Foods, Inc., Hereford, TX. Hard wheat flour with 11.3% protein (14% mb) was purchased from ADM Milling Co., Shawnee Mission, KS. Vital wheat gluten and wheat starch were provided by Midwest Grain Products, Inc., Atchison, KS. The proximate analyses of the materials used in the study are given in Table I.

General Methods

Sorghum starch and protein were isolated from grain sorghum according to a small-scale wet-milling procedure devised by Yang and Seib (1995) and Xie and Seib (2000). Proximate analyses of the materials were carried out by the appropriate Approved Methods of the American Association of Cereal Chemists (AACC 2000).

Table I. Proximate analysis of materials[a]

Materia	MC %	Prot. %	Starch[b] %	Lipid %	Ash %	Fiber %
Sorghum Starch	6,9	1,0	91,7	0,1	0,16	<0,1
Sorghum Proteins	6,1	37,0	50,0	5,6	0,36	0,9
Sorghum Flour	11,4	9,8	73,9	2,7	1,27	0,9
Sorghum Starch	10,3	0,3	n/d	n/d	n/d	n/d
Sorghum Gluten	8,3	75,0	15,3	0,2	0,20	1,0
Sorghum Flour	11,2	11,7	75,4	0,9	0,58	0,2

[a]As is basis
[b]% starch calculated by [100 - (%MC + %Protein + %Lipids + %Ash + %Fiber)]
[c]Not determined

Determination of Pasting Properties

Pasting properties of the individual flour components and composite flour were studied using an RVA instrument equipped with a Thermocline software (Foss North America, Inc, Eden Prairie, MN) by AACC Method 76-21 (AACC 1995) with slight modification. Starch or protein (3.0 g, 14% mb) or flour samples (3.5 g, 14% mb) were weighed into the RVA canisters and calculated amount of distilled water (a final sample plus water weight of 28.0 g) added. The samples in the canister were submerged in the water and wetted by gentle stirring with the canister paddles prior to mounting the sample canister on the RVA instrument, which was warmed up at 50C for 30 min. The temperature profile was as follows: Sample heating at 50C/1min; heating up to 95C/3.4 min; holding at 95C/2.7 min; cooling down to 50C/3.9 min; and holding at 50C/2 min. A total of 13 min was required for a given sample run. Each sample was run in duplicate and the data were analyzed using the Thermocline software from the instrument supplier.

Determination of Thermal Properties

Phase transitions of the individual flour components and composite flour were studied using a DSC instrument equipped with a Thermal Analysis software (Perkin-Elmer Corp., Norwalk, CT). Aluminum DSC sample pans were also obtained from the instrument supplier. Samples (2.75 mg, as is) were weighed into the sample pans and distilled water added until reaching sample final moisture content of 75%. The sample pans were then hermetically sealed and rested for 3 hr. The sample pans were heated from 30 to 130C at a scanning rate of 10C/min. An empty DSC pan was used as the reference. The data were analyzed using the Thermal Analysis software from the instrument supplier.

RESULTS AND DISCUSSION

RVA Pasting Properties

In a short period of run time (about 13 min) with a small sample amount (3.0-3.5 g), RVA pasting measurements of the wheat and sorghum starches, wheat and sorghum proteins, and wheat and sorghum composite flours provided some information on the rheological properties of those materials (Figs. 1 - 3). All samples except sorghum composite flour gave reproducible RVA pasting curves under these experimental conditions. Sorghum composite flour produced RVA pasting curves (Fig. 3) slightly different from one another probably because of the separation of the wheat and sorghum flours and vital wheat gluten. Another reason for the reduced repeatability of the RVA pasting measurements with the sorghum composite flour may arise from the heterogeneous nature of the composite.

The pasting properties of the starches from wheat and sorghum (Fig. 1) differed noticeably. The RVA curves of wheat and sorghum flours were also different; they closely resembled the RVA curves of their starches (data not shown). Sorghum starch gave a higher peak, trough, and final viscosity and a lower breakdown and setback viscosity compared to the pasting data from the wheat starch (Fig. 1). In terms of pasting time and temperature, the sorghum starch gave a higher pasting time and a slightly higher pasting temperature (Fig. 1). Pasting time and temperature of a starch are of great importance in cereal-based food products (Maningat and Seib 1997); a slight difference in the pasting time and temperature of a starch strongly influences the breadmaking quality of its flour.

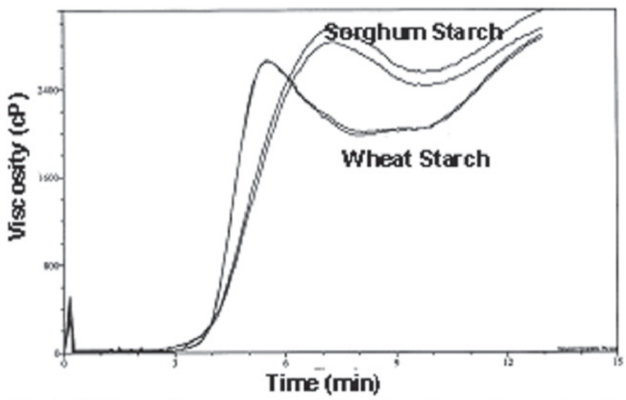

Fig 1. RVA pasting curves of wheat and sorghum starches

No published data are available on the application of RVA to proteins. Indeed, RVA was developed and has been used to study the thermal/rheological properties of cereal products with starchy materials (Walker et al 1988). As expected, wheat gluten did not give any response to RVA pasting measurements as opposed to sorghum proteins (Fig. 2). The curve given by the sorghum proteins in this study was probably an artifact of the high level of starch (50%) present in sorghum proteins (Table I). Therefore, the RVA data from the proteins of those cereals are of limited significance.

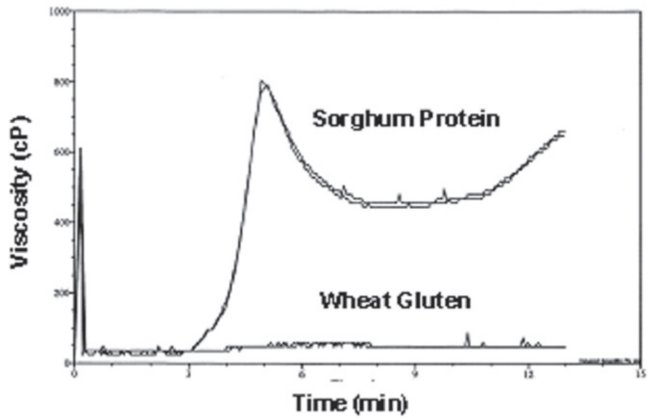

Fig 2. RVA pasting curves of wheat gluten and sorghum proteins

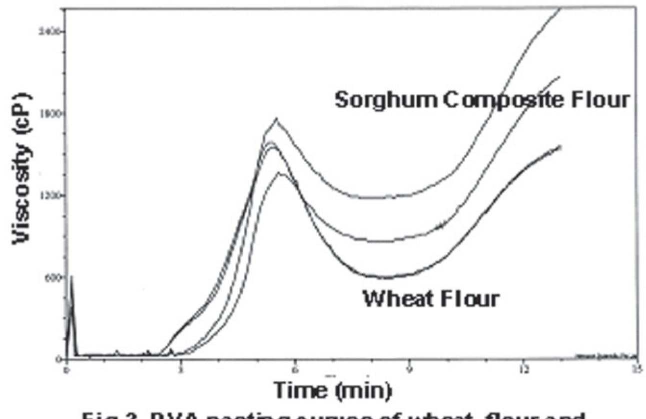

Fig 3. RVA pasting curves of wheat flour and sorghum composite flour

The RVA pasting curves of the wheat flour and sorghum composite flour, which was a mixture of 50% sorghum flour, 39% wheat flour, and 11% vital wheat gluten, are shown in Fig. 3. This particular sorghum composite flour preparation used in this study was reported to be the best blend for breadmaking and produced bread with 60% higher loaf volume than the bread from a blend of sorghum flour and vital wheat gluten without the addition of wheat flour (Cheong 1998). The RVA data obtained in this study in a sense confirmed the findings of Cheong (1998). Although, individual components of the wheat and sorghum flours (starch and proteins) were quite different in RVA pasting properties (Figs.1 and 2), the RVA pasting properties of this particular sorghum composite flour was fairly similar to those of wheat flour (Fig. 3). Sorghum composite flour gave a similar peak and final viscosity and pasting time to those from wheat flour. This clearly shows the positive influence of the ingredients in such a composite flour system on narrowing down the gap between the pasting properties of wheat and sorghum flours. When the results from the aforementioned researches and from this particular research are combined, it can be concluded that the pasting properties of the mixture of the sorghum flour, wheat endogenous and exogenous glutens are quite similar to the pasting properties of the wheat flour, implying positive interactions among the ingredients and their contribution to dough rheology and breadmaking performance.

DSC Phase Transition Properties

The quality of cooked sorghum foods may be associated with the thermal phase transition properties of sorghum flour, particularly its starch (Akingbala et al 1988). Thus, DSC may provide a valuable insight into understanding the interactions among the major flour components in a composite flour system. Fig. 4 shows the DSC endotherms for the starches from wheat and sorghum. The starches differ remarkably in their gelatinization temperatures and enthalpies. Wheat starch gave a lower peak gelatinization temperature and enthalpy than did sorghum starch. This DSC result is consistent with the RVA pasting results in that the two starches have different thermal and rheological properties, which may partly explain the difference in the breadmaking properties of wheat and sorghum flours. However, the major difference that is substantially effective on breadmaking quality of those flours has been found to be the lack of viscoelastic properties in sorghum proteins as compared to wheat gluten (Morad et al 1984, Foda et al 1987).

The DSC measurements of wheat gluten and sorghum proteins are given in Fig. 5. As expected, wheat gluten did not give any DSC denaturation peak. Sorghum proteins, however, gave a first-order phase transition peak, which is probably due to the high level of starch contamination in the sorghum proteins (Table I) as discussed earlier. The peak gelatinization temperatures of sorghum starch (68.6C) and sorghum proteins (71.5C) are close enough to support the idea that the DSC transition curve for the sorghum proteins (Fig. 5) was an artifact of contaminating sorghum starch. The DSC gelatinization curves for the wheat and sorghum composite flours are shown in Fig. 6. The peak gelatinization temperature for wheat flour (62.8C) is very close to that of wheat starch (62.0C). However, when wheat flour, sorghum flour and vital wheat gluten were blended (sorghum composite flour), two peaks of phase transition were obtained (Fig. 6), which represent mainly the wheat starch and sorghum starch gelatinization endotherms. It is important that a slight deviation in the gelatinization temperatures of the flours from the gelatinization temperatures of their individual starches in the composite system was observed. This change is more likely a result of the interactions among the starch and protein constituents of the sorghum composite flour.

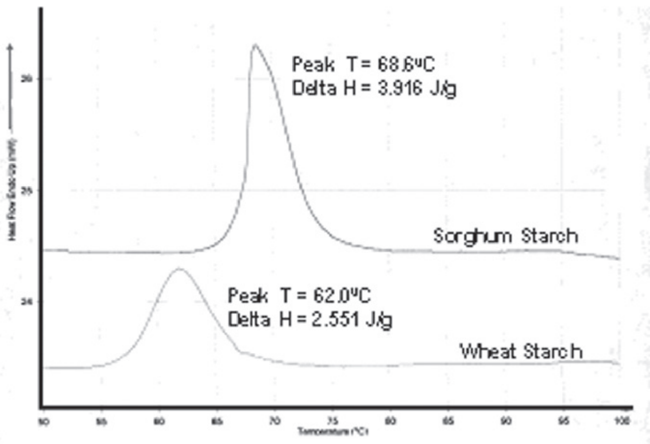

Fig 4. DSC curves of wheat and sorghum starches

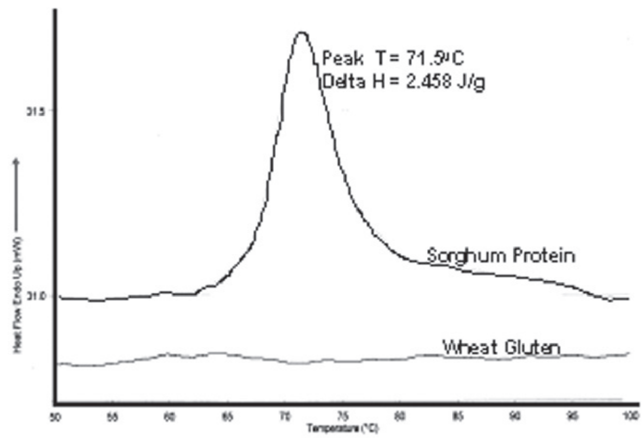

Fig 5. DSC curves of wheat gluten and sorghum proteins

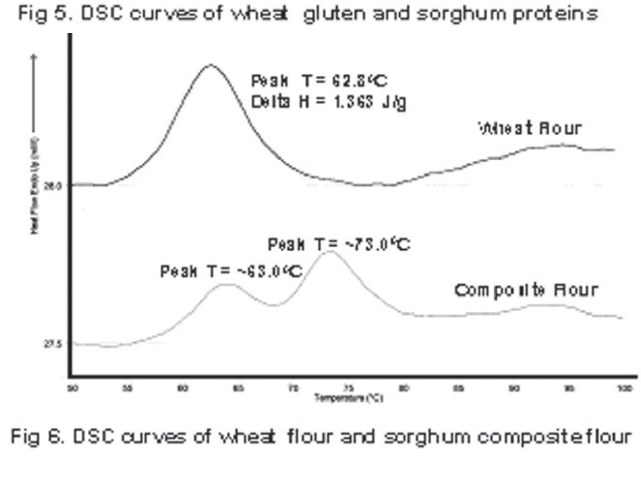

Fig 6. DSC curves of wheat flour and sorghum composite flour

CONCLUSIONS

Based on the findings obtained through this study, the thermal and rheological characterization of flours, their major components, and composite flour provided useful information on the interactions among the flour components in a composite flour system and their relation to final product quality. Thus, DSC and RVA can be successfully used for such purposes. A further detailed and comprehensive experimental approach that will include flours, major flour components (starch, protein), and composite flours with various ratios of wheat flour, sorghum flour, and vital wheat gluten is required to better understand the underlying mechanisms for developing a suitable sorghum composite flour system with improved breadmaking potential.

LITERATURE

AACC. 2000. Approved Methods of the American Association of Cereal Chemists. The Association: St. Paul, MN.

Akingbala, J.O., Gomez, M.H., Rooney, L.W., and Sweat, V.E. 1988. Thermal properties of sorghum starch. Starch/Stärke. 40:375-378.

Anonymous. 1999. Jowar Foods. http://www.jowar.com.

Bhaita, B.S., Chakrabarty, T.K., Mathur, V.K., Siddish, C.H., and Raghavan, P.K.U. 1968. Use of maize and milo flours in the preparation of bread. Indian Food Packaging. 22:33-37.

Cheong, M.L. 1998. Bread making potential of sorghum-based composite flour. MS Thesis. Kansas State University: Manhattan, KS.

Connon, J.J. 1999. Celiac disease. Pages 1163-1168 in: Modern Nutrition in Health and Disease. Williams & Wilkings, Co.: Baltimore, MD.

Cubadda, R. 1989. Development of new technologies for the utilization in developing countries of flours obtained from local materials. Industrie Alimentari. 25:681.

Dendy, D.A.V. 1995. Sorghum and millets: Production and importance. Pages 11-25 in: Sorghum and Millets: Chemistry and Technology. D.A.V. Dendy, ed., American Association of Cereal Chemists: St. Paul, MN.

FAO. 2002. Food and Agriculture Organization of the United Nations. http://www.fao.org.

Finney, K.F. and Barmore, M.A. 1948. Loaf volume and protein content of hard winter and spring wheats. Cereal Chem. 25-291-298.

Foda, Y.H., Ramy, A., Rasmy, N.M., Abu-Salem, F.M., and Yassen, A.E. 1987. Rheological and sensory characteristics of doughs and balady bread based on wheat, sorghum, millet, and defatted soy flour. Annals of Agric. Sci. Al-Shams University: 32:381-395.

House, L.R., Osmanzai, M., Gomez, M.I., Monyo, E.S., and Gupta, S.C. 1995. Agronomic principles. Pages 27-67 in: Sorghum and Millets: Chemistry and Technology. D.A.V. Dendy, ed., American Association of Cereal Chemists: St. Paul, MN.

Klopfenstein, C.F. and Hoseney, R.C. 1995. Nutritional properties of sorghum and millets. Pages 125-168 in: Sorghum and Millets: Chemistry and Technology. D.A.V. Dendy, ed., American Association of Cereal Chemists: St. Paul, MN.

Magnuson, K. 1977. Vital wheat gluten update 1977. Bakers Digest. 51:108-110.

Maningat, C. and Seib, P.A. 1997. Update on wheat starch and its use. Pages 261-284 in: Proceedings of International Wheat Quality Conference. J. L. Steele and O.K. Chung, eds. Grain Industry Alliance: Manhattan, KS.

Morad, M.M., Doherty, C.A., and Rooney, L.W. 1984. Effect of sorghum variety on baking properties of U.S. conventional bread, Egyptian pita "balady" bread, and cookies. J.Food Sci. 49:1070-1074.

Murty, D.S. and Kumar, K.A. 1995. Traditional uses of sorghum and millets. Pages 185-221 in: Sorghum and Millets: Chemistry and Technology. D.A.V. Dendy, ed., American Association of Cereal Chemists: St. Paul, MN.

Ortega, R.R., Siqueiros, M.G., Hernandez, R., and Ramirez, W. B. 1995. Evaluation of rheological and bread making properties of composite wheat and decorticated sorghum flours. Institute of Food Technologist' Poster No. 294.

Pringle, W., Williams, A.A., and Hulse, J.H. 1969. Mechanical developed doughs from composite flours. Cereal Science Today. 14:114-129.

Rao, J.S. and Rao, V.G. 1997. Effect of incorporation of sorghum flour to wheat flour on chemical, rheological, and bread characteristics. J. Food Sci. Tech. India. 34:251-254.

Stenvert, N.L., Moss, R., and Murray, L. 1981. The role of vital wheat gluten in breadmaking. Part I. Quality assessment and mixer interaction. Baker Digest. 55:125-128.

Subramanian, V., Jambunathan, R., and Sambasiva, R.N. 1983. Textural properties of sorghum dough. J. Food Sci. 48:1650-1673.

Toomey, G. 1988. Sorghum as substitute: Food enterprises for Indian woman. IDRC Reports. 17:20-21.

Walker, C.E., Ross, A.S., Wrigley, C.W., and McMaster, G.J. 1988. Accelerated starch paste characterization with the Rapid Visco Analyzer. Cereal Foods World. 33:491-493.

Whalen, P.J. 1999. Detecting differences in snack ingredient quality by rapid viscoanalyzer. Cereal Foods World. 44:24-26.

Xie, X.J. and Seib, P.A. 2000. Laboratory precedure to wet-mill 100 g of grain sorghum into six fractions. Cereal Chem. 77:392-395.

Yang, P. and Seib, P.A. Low-input wet-milling of grain sorghum for readily accessible starch and animal feed. Cereal Chem. 72:498-503.

Yuan, R.C. and Thompson, D.B. 1998. Rheological and thermal properties of aged starch pastes from three waxy maize genotypes. Cereal Chem. 75:117-123.