UTILIZATION OF SORGHUM IN EL SALVADOR: GRAIN, FLOUR AND END-PRODUCT QUALITY

A Thesis

by

LUZ ELIANA PINILLA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2010

Major Subject: Food Science and Technology

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Approved by:

Chair of Committee,	Lloyd W. Rooney
Committee Members,	Joseph Awika
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ABSTRACT

Utilization of Sorghum in El Salvador: Grain, Flour and End-Product Quality.

(December 2010)

Luz Eliana Pinilla, B.S., Purdue University

Chair of Advisory Committee: Dr. Lloyd W. Rooney

There is limited information on the utilization of sorghum for human consumption in El Salvador. Increased wheat prices have driven the baking industry to seek alternative cereals for manufacturing of their products. The white color and bland taste characteristics of Salvadorian sorghum is ideal for use as a partial substitute of wheat (up to 50%) or alone in baked goods and a wide variety of foods. Further information on the grain quality, milling characteristics and impact on end-product was assessed to make better use of the available grain.

Three different varieties of improved and local cultivars (RCV, Native and ZAM 912) were evaluated for their grain, flour and end-product quality. Grain hardness, color and composition of the grains varied from hard to intermediate to soft. Burr, hammer and roller milling were used for sorghum flour production. Impact of grain characteristics and milling quality was evaluated through the flours produced and their end-product quality.

Grain hardness significantly affects flour and final product characteristics. Harder grain, RCV, produced flours more difficult to cook and with a grittier texture than those produced from Native cultivars (floury endosperm). Cupcakes produced from harder grain flours had lower volume and harder texture than cupcakes made from the Native varieties. ZAM 912 was an intermediate hard sorghum variety and produced the darkest flour and darkest cupcakes due to its pericarp hue. Appropriate use of this grain's flour can be used in baked products with a darker hue (e.g. chocolate pastries). Harder grain flours can be utilized in coarse crumb products (e.g. cookies, *horchata,* and *atole*).

Hammer mills produced the coarsest particles for all the varieties evaluated. Burr mills produced flour with similar cooking and end-product texture qualities as the roller mill. However, burr mills are not suitable for production of large quantities of whole sorghum flour. Nevertheless, they are more affordable for small entrepreneurs.

Cultivars analyzed produce quality flour that can be used in an array of baked foods, i.e. ethnic beverages, porridges, cookies, flour mixes, *tortillas*, sweet breads. Whole sorghum flour substitution as low as 25% in wheat-based foods can represent significant cost savings for its users.

DEDICATION

To the hard working, kind-hearted artisan bakers of El Salvador: your humanity, tenacity, and drive to keep bread on the tables of Salvadorian families are an inspiration.

ACKNOWLEDGEMENTS

I would like to give exceptional recognition to Dr. Lloyd Rooney; thank you so much for your patience and for believing in my abilities to conclude this thesis project successfully. Sincere thanks to Dr. Joseph Awika and Dr. Nancy Turner for your patience and your support while serving on my committee.

I am especially grateful to Vilma R. Calderon, M.S. and the CENTA food processing lab members; thank you for all of your support, encouragement and friendship throughout this process. I could not have done this without you.

Sincere thanks to Compatible Technology International (CTI) for their great work in improving lives through the development of practical and affordable technology, like the Omega and Ewing mills.

Winrock International– Arlen Garza and Mr. Ricardo Auerbach: thank you for the travel logistics support and for being such great hosts during my first trip to El Salvador.

Friends and CQL colleagues and staff: thank you so much for making my time at Texas A&M University a great experience.

Dear thanks to my mother, my father and my sisters for their encouragement and consistent support in my pursuit of higher education. Finally, thanks to that greater spiritual force we all believe in one way or another: God. You were gave me the strength, faith and grace to accomplish this extraordinary aspiration.

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INTRODUCTION

Sorghum bicolor (L.) Moench originated between 4500 and 1000 BC in parts of Central Africa, subsequently spreading to Asia and India (Schober and Bean 2008). Although the majority is grown in these areas (~55%), the U.S. produces 25-30% of world production. Between 15 to 20% is grown in Latin America. S. bicolor varieties are white, red, black, yellow, brown and many shades of color depending on genetics and environmental conditions. In addition, glumes vary from tan to dark purple (Smith 2000). Sorghum is an important food staple especially in hot, dry areas where other crops like maize fails or become contaminated with mycotoxins (Chandrashekar and Satyanarayana 2006; Smith 2000).

This grain is used for food in India and much of sub-Saharan Africa. In the U.S., it is used as livestock feeds. It has been utilized for human consumption in porridges, beer, unleavened bread, couscous composite blends, and ethnic beverages (Taylor et al. 2006; Waniska et al. 2004). Utilization of sorghum in Central America is common among many rural communities that do not have access to enough cereals (i.e. corn). It is planted with maize and after the maize is harvested, the sorghum produces grain that is used in blends with maize or alone depending upon economic status. It is used in ethnic beverages (i.e. *horchata*, *atole*) and *tortillas*. However, it has potential in other foodstuffs.

This thesis follows the style of Cereal Chemistry.

S. bicolor, along with corn, is among the most pervasive cereal grains grown in Central America specifically in El Salvador. Native sorghum varieties are the most accessible to people in the rural areas. These varieties are characterized by a cream color pericarp, dark purple glumes and have a softer endosperm texture than the improved varieties.

The improved varieties were developed by the Salvadorian Government agricultural research institution (CENTA) assisted by the International Sorghum, Millet and other grains collaborative research support program (INTSORMIL). These varieties produce harder grains with white pericarp, tan glumes and plant color. They are photoinsensitive, have improved grain yields and resistance to diseases (Zeledon 2007).

Increased wheat prices have stimulated use of alternative cereals in the production of Salvadorian baked goods (INTSORMIL 2008). The light color and bland taste makes sorghum a good cereal to substitute in wheat based products (Taylor et al. 2006). Currently, large and small food processors use sorghums alone or in blends with wheat flour in cookies, leavened breads, cakes and ethnic beverages (Brizuela-Sandoval 2005).

Efficient milling of sorghum is a major deficiency. There is little published data available regarding Salvadorian sorghum milling and product quality. The need for further development of sorghum utilization includes better understanding of sorghum grain, flour and end-product characteristics.

This research addressed these needs through the following objectives:

General Objective:

- Evaluate of milling characteristics of sorghums grown in El Salvador and their potential use in a wide variety of local foods. The specific objectives.

Specific Objectives:

- Determine grain characteristic of Salvadorian native and improved sorghum varieties.
- Determine effect of burr, hammer and roller mills on sorghum flour quality from native and improved varieties.
- Evaluate the effect of sorghum variety and milling method on final baked product characteristics using cupcakes as a model system.

LITERATURE REVIEW

Background

Domestication of sorghum is estimated to have occurred some 3,000 to 5,000 years ago (House 1995; Schober and Bean 2008). Sorghum is a tropical grass grown in semi arid regions of the world. West Africa, Uganda, Kenya, Tanzania, Rwanda, South Africa, Lesotho, Sudan, Ethiopia and Burundi are countries were the grain is commonly grown. Its growth expanded to Asia, mainly India, central and northern China as well as to America. Significant production occurs in the drier areas of Argentina, northern Brazil, Venezuela and Colombia, southwestern United States and Central America. It is commonplace to find sorghum growing in areas that are too dry for corn to grow (House 1995; Rooney 1991).

Utilization

Sorghum has been utilized for livestock feeding and in traditional foods for human consumption (Murty 1995; Waniska et al. 2004). The use of this grain is widespread in the production of fermented foods: industrial production of sorghum beer in African countries and breads such as *injera*, *kisra* and *dosa*. It is also used in porridges (i.e. *ogi* and *ugali*), couscous, unfermented breads such as *tortillas* and *roti*, and rice-like products (i.e. *horchata*) (Murty 1995; Rooney 1991). Information on sorghum use in composite flours for bread has been found on literature regarding production of wheat (gluten) free breads (Taylor and

Dewar 2001). Sorghum bread recipes with different gums, enzymes, starches, emulsifiers have been produced. Successful production of cakes and cookies using sorghum flour has been reported (Oyidi 1976). Cake recipes have been developed using a flour blend of sorghum or maize with cassava starch (Olatunji 1992a). Production of 100% sorghum flour cookies has also been reported (Hoseney 1994).

Sorghum crops have played a key role in food security due to its drought tolerance, resistance to plagues, and reduced level of mycotoxins (Chandrashekar and Satyanarayana 2006; Waniska 2000). Sorghum is the major source of energy and protein for many; it represents 70% of the cereals grown in West Africa (Taylor and Dewar 2001). Nutrient content and value of sorghum has been under reported in the past. However, it is clear from recent data on the grain (Table A-3) that its current macro and micro nutrient bioavailability becomes significant in the diets of populations where food security is an issue. Sorghum is a rich source of complex carbohydrates that contributes to satiety and contains more fat than wheat, rice and cassava.

In terms of micronutrients, sorghum bioavailability of dietary manganese and copper contents are important because these play an important role in the prevention of anemia in developing countries. In 1998, The Committee for Micronutrient deficiencies identified Iron and Zinc dietary availability to be limited in developing countries. Sorghum has 10% bioavailability of Iron and moderate bioavailability for Zinc, making this grain a good source for these nutrients in developing countries (USCP 2010). Positive results have been reported on nutrient bioavailability of fermented breads (i.e. injera) (Mohammed 2009). Fermentation may increase mineral availability and could be useful in countries where fermented foods are eaten, i.e. Sudan, Ethiopia. In El Salvador, non-governmental organizations have been using 100% whole grain sorghum products (i.e. ethnic beverages – *atole* and cookies) to address malnutrition issues in rural areas (CTI 2008a; FIMRC 2010).

Ghana, Mexico and Nicaragua have experienced a positive impact in their economy and food baskets (DeWalt et al. 1990; Hawkins et al. 1986; Kudadjie et al. 2004; Trouche et al. 2009). In Nicaragua, sorghum is cultivated in dry marginal areas where corn production is uncertain due to unpredictable droughts. In Mexico, sorghum has become one of the top crops along with corn and beans since the 1960's. Increase of this crop production at the time was to meet increased internal demand from the livestock industry. However, it eventually developed as a crop used by rural communities when maize failed to produce sufficient, quality product for human consumption (DeWalt et al. 1990). Threat of environmental phenomena, such as 'El Nino' could eventually shift the use of sorghum as an alternative cereal crop (Taylor and Dewar 2001).

Sorghum Uses in Central America

Uses of sorghum in Central America have been limited to *tortillas* and ethnic beverages (House 1995; Murty 1995). Most of the sorghum grown particularly in El Salvador can be used to produce flours with a bland, neutral taste as well as a light color that can be used up to 100% or as a wheat flour extender in baked products (Zeledon 2007). Native and improved varieties can be used for this purpose. Native varieties usually have a soft endosperm texture, white pericarp and the majority contains dark, purple glumes. When using this grain, pericarp removal must be done when flour with a light hue is desired. Native varieties are more susceptible to molds and diseases, decreasing grain yield. Improved sorghum varieties generated by CENTA and INTSORMIL have potential for production of flour since they have similar characteristics. These varieties have more vitreous endosperm texture, tan glume color versus dark purple and are perceived to have better grain yields than native varieties (Calderon 2008; Hernandez 2009). Similar improved yields and grain quality has occurred in other Central American Countries (Trouche et al. 2009). Knowledge beyond physical appearance and agronomic characteristics of these grains is limited; further development of data to determine optimum sorghum varieties for food production (namely flour) is needed.

Grain Quality

Different kinds of methods have been used in the past to observe different cereal grain quality characteristics (Bean et al. 2006; Chang 1988; Griffey et al. 2010; López-Bellido et al. 1998; Oomah 1981; Wu and Shi 2004). The characteristics of the grain determine food processing applications (i.e. harder grains in dry milling process). Grain physical and chemical properties have been described from the results obtained from these tests (Cagampang

1984; Campbell et al. 2007; Chandrashekar and Mazhar 1999). Chemical composition (starch and protein quality) varies from grain to grain. An example of this is the presence of gluten forming proteins only found in wheat (Schober and Bean 2008).

Sorghum physical properties have been previously characterized; kernels vary in appearance (size and shape) with 1000-kernel weight varying between 30 to 80g. Its anatomical structure is composed of pericarp, endosperm and germ (Bean et al. 2006; Rooney 1991; Waniska 2000). Like maize, sorghum has a proportionally larger germ in relation to endosperm size. Hence, higher oil content is observed in sorghum (3.4%) than in wheat (2.2%) (Taylor and Dewar 2001). The endosperm has a floury and corneous texture; proportions of these vary from cultivar to cultivar due to genetic characteristics of the variety and environmental effects. The outer portion of the endosperm is corneous and is composed of protein bodies covered with a continuous protein matrix. The inner portion of the endosperm is floury and consists of starch granules loosely packed in a discontinuous protein matrix. Polyphenolic composition depends on the sorghum pigmentation: pericarp color derives from the presence of these compounds. Presences of such chemicals are favorable in products like beer, but unfavorable in flours and baked goods (Hoseney 1994; Rooney 1991; Schober and Bean 2008).

Currently, there are no publications about milling behavior or product quality from Salvadorian milled grains. Therefore, increasing knowledge of physical grain characteristics of Salvadorian sorghums is important in the evaluation of sorghum milling processes and end-product quality.

Milling of Cereal Grains

One of the most important characteristics of grain processing is kernel hardness, especially in milling (Bettge and Morris 2000; Cagampang 1984). Most of the tests used in sorghum kernel quality include the study of this characteristic: physical (corneous endosperm proportion) and chemical (protein content and quality) composition has been related to hardness in the past (Blumenthal et al. 2008; Mazhar and Chandrashekar 1995; Wallace 1990). The tangential abrasive dehulling device (Oomah 1981), test weight, endosperm texture evaluation (Smith 2004), and Rapid Visco™ Analyzer (Almeida-Dominguez et al. 1997a; Almeida-Dominguez et al. 1997b) have been used to learn more about grain processing behavior in relation to grain hardness.

Milling of different cereal grains, i.e. rye (Heiniö et al. 2003), barley (Izydorczyk and Dexter 2004; Sharma and Gujral 2010), corn (Sandhu et al. 2007), wheat (Mattern 1991) was developed to increase utilization of the grain in food products (Hoseney 1994). The main objective of grain milling other than reducing grain to fine particles, is to separate its anatomical parts to achieve the highest amount of endosperm material in the final product. This is to prevent pericarp pigments from transferring into flour, and oil contamination as this can reduce keeping quality of the product (i.e. rancidity of germ oils).

Sorghum Milling

Inherent anatomical structure of sorghum prevents achieving effective separation of grain germ and bran from the endosperm. Pericarp is unique among cereals as it contains starchy fractions that make it more susceptible to disintegration during milling. In addition, sorghum lacks a kernel crease, which affects its removal. In addition, sorghum endosperm, unlike soft wheat endosperm, comprises starch fractions in the floury and corneous sections (Taylor and Dewar 2001). Because of these characteristics, sorghum endosperm composition with higher proportions of corneous fraction is preferred for milling because they give higher amounts of endosperm flour and better separation of the pericarp and germ (Maxson 1971; Taylor and Dewar 2001).

Limited literature has been found regarding existing methods for sorghum milling. Hulse in the 1980’s along with Munck in the 1990’s have done the most extensive documentation of these. Milling of sorghum ranges from the traditional mortar and pestle to the small scale abrasive and attrition equipment adapted from milling machines used to decorticate/dehull other cereal grains, i.e. rice and barley. In Africa the majority of the sorghum is processed by hand, however stone and hammer mills are commonly used in communities to process the grain as well (Munck 1995; Schober and Bean 2008; Taylor and Dewar 2001).

Two basic principles are used in the milling of sorghum: impact and attrition. Impact is done by accelerating grain against a hard surface (i.e. wood or metal) to reduce its particle size. Attrition uses shearing forces in rollers, rotating disks or pressurized cylinders, where, for the latter, the effect of metal to seed is compounded by seed surfaces rubbing against each other. In practice, more than one of these principals comes in to play depending on the final product that is wanted.

Use of decorticating equipment (abrasion and attrition machines) in processing of sorghum for food use has been beneficial for rural African communities in the production of traditional food stuffs (i.e. porridges). Main differences between the two types of decorticating equipment is that attrition mills produce finer particles than the abrasion equipment (Munck 1995). Drawbacks of kernel breakage and partial removal of germ during abrasion process were addressed by parboiling (boil-soak-boil process) grain previous to dehulling (Young et al. 1990) (Munck 1995). Sorghum abrasive decortication is done sometimes before hammer milling. This is especially beneficial in the abrasion of sorghums with high tannin testa (Taylor and Dewar 2001). Roller mill equipment used in wheat flour production is an impractical and expensive process but has been used for sorghum milling.

Sorghum Milling in El Salvador

Use of disc (plate) mills in El Salvador has become economically viable for the processing of whole sorghum flours. Community mills (i.e. nixtamal mills) are the most typically used equipment in the rural communities for sorghum milling. This equipment is not effective for sorghum milling purposes. Mill owners do not want bakers to use the equipment for other than masa production. This limits sorghum flour production. More recently, several rural baking associations produce whole sorghum flour using an improved burr mill from Compatible Technology International (CTI).

Two kinds of burr mills have been used in El Salvador: Omega VI and Ewing III. Main differences between the two mills are the assembly materials and operation mechanisms to tighten the discs. Mechanical action involves increased abrasion intensity by manipulating plate gap with the objective to decrease particle size after multiple passes of the material through the mill. These have a thin feeding auger, motor of about 1.5 HP, which results in a milling output of 7 kg per hour to produce flour for bakery products.

As in the African countries and other rural locations worldwide that consume sorghum, the hammer Mill (Model: JF-3) is used in El Salvador for sorghum milling. This equipment uses 16 hammers at a rotating speed of 4300 rpm to force grains through a 0.8 mm mesh. The milling output (15-20 kg/hour) is considerably higher than that of burr mills, however this machine produces a larger particle size which requires sieving of the flour for use in baked goods and beverages (Calderon 2010).

Roller milling is a recent approach to process sorghum into flour in El Salvador. Proinsa, a commodity grain seller in El Salvador, has performed tests with Henan Double Elephants Machinery/ 6MF-60. The milling output of this mill is significantly higher than the previous mentioned equipment: ~300 kg per hour. The majority of the flour obtained through this process is less than 0.180

micrometers. It can separate sorghum bran from sorghum flour fractions to some extent. It is also able to grind the whole grain into very fine particle sizes.

The use of the Omega VI and Ewing disc mills had a positive economic impact in the production of sorghum flour (CTI 2008b; 2009) in El Salvador (CTI 2008a), Mali (CTI 2007), Haiti (Baran 2010) and Sudan (Wilson 2008) rural communities. However, the increased internal demand for sorghum flour in El Salvador calls for efficient ways to use this technology. Understanding of milling impact from this device on end-product quality is of importance to amplify benefits obtained from these mills.

Flour and Product Quality

Assessment of flour quality from a certain grain variety must be done in the framework of a particular end use. In general, there are quality traits that can be affected by external factors at different levels: high (i.e. frost damage, moisture content, protein content), intermediate (i.e. milling quality, seed size, baking quality) and low (i.e. seed color, starch composition, grain hardness) (Morris 2004). In the case of El Salvador, moisture content, seed and glume color, and grain hardness would be grain quality traits with the greatest impact on the production of Salvadorian sorghum flour.

Methods to Assess Sorghum Flour and End-Product Quality

Assessment of flour quality is done to predict its manufacturing performance; characteristics of the end-product are also used to perform quality evaluation, e.g. volume of bread loaf, diameter of cookies and the texture of cupcakes (Morris 2004). Component quality testing is also done when evaluating quality; the assumption is that one or more attributes of the flour can be used to predict its value in the end-product. For example, the value of low and high protein wheat flours: lower protein content is preferred in cake type products, versus high content in bread production (Morris 2004). Evaluation of flours involves testing starch and protein quality, particle size distribution, and color characteristics.

Recommended methods utilized for the evaluation of starch quality in wheat products involve the use of RVA or the Brabender Visco Amylograph. The RVA can be used for evaluation of cooking qualities of sorghum flour; methods to evaluate hydration rate and starch damage of cereal flours has been done in the past (Almeida-Dominguez et al. 1997b; McDonough et al. 2004; Whalen 1998; Zaidul et al. 2007). Analysis of protein, fat and dietary fiber provides more information on potential uses of the flour (Cauvain 2003; Hemery et al. 2007; Lebesi and Tzia 2009). Evaluation of color is important since it has an effect on the final product appearance and appeal (Lamberts et al. 2007;Mialon et al. 2002).

Sorghum in baked products in El Salvador has been focused specifically on sweet baked products: cookies, cakes/cupcakes and traditional sweet goods (i.e. *pepereche, semita*). Hence, the use of cupcakes as a reference product to evaluate sorghum flour quality from different varieties and processes is appropriate. The formulation utilized by CENTA for multi-grain cupcakes is used for wheat cupcakes but with differing percentage amounts for each ingredient, processing time and temperature (Cauvain 2003; DesRochers et al. 2003; DesRochers et al. 2004).

The utilization of whole grains in cupcakes improves nutritional value but may affect physical appearance and acceptability as noted in previous studies (Lebesi and Tzia 2009; Ragaee and Abdel-Aal 2006). Some of the methods used to assess quality in baked products includes texture analysis (Heenan et al. 2009; Lebesi and Tzia 2009) and color evaluation.

An array of sorghum food products have been produced around the world (e.g. sorghum porridges, unfermented and fermented breads, couscous, ethnic beverages, beer) and their physical and sensory characteristics have been evaluated (Belton and Taylor 2004; Cagampang 1984; Lebesi and Tzia 2009; Murty 1995; Smith 2000; Waniska et al. 2004). Conversely, there is limited information on the impact of Salvadorian sorghum flour quality and its effect on baked goods (Rodriguez 2009). Further exploration of this area is necessary to build deeper knowledge on impact of milling equipment (e.g. burr mills) in sorghum flour production and its end-product quality.

MATERIALS AND METHODS

Sorghum Varieties

RCV and ZAM 912 varieties harvested in 2009 were used (Fig. 1). Samples were obtained from CENTA's grain storage bank. These are improved varieties; RCV is a photoinsensitive variety that is used by Salvadorian sorghum farmers for animal feed and foods (Zeledon 2007). ZAM 912 is an improved, photosensitive native variety that CENTA is currently launching (Hernandez 2009). A native grain variety was provided by a large Salvadorian commodity grain seller (Proinsa). The improved varieties were grown in CENTA's nursery fields. Native variety location is unknown.

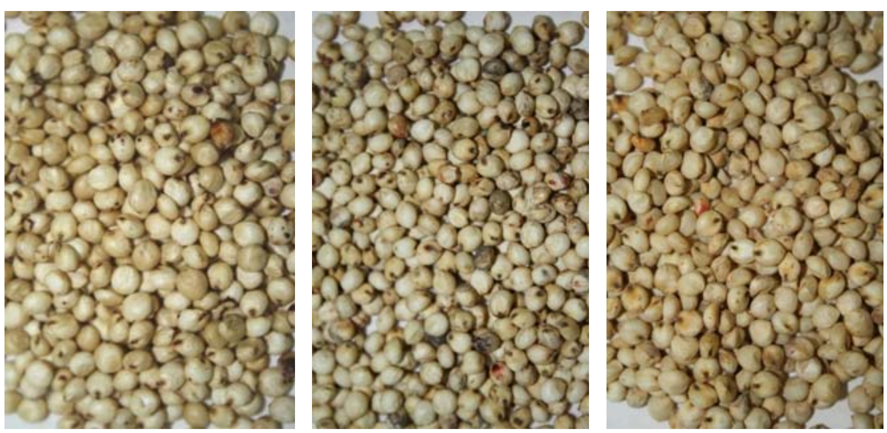

Fig. 1. Salvadorian sorghums: Native (left), ZAM 912(center), and RCV (right).

Sorghum Characterization

Hardness evaluation methods utilized include the Single Kernel Hardness Tester (SKHT, model SKCS 4100, Perten Instruments, Reno, NV). This method measured grain hardness Index, diameter (mm), and kernel weight (mg) (Bean et al. 2006).

RVA (Rapid Visco™ Analyzer, Newport Scientific v 2.2. Warriewood, Australia) was used to evaluate grain hardness. Methods developed to evaluate corn hardness (Almeida-Dominguez et al. 1997b) were utilized on sorghum samples. Sorghum grain was ground with a UDY mill using a 1 mm mesh screen. An 18% solids slurry was mixed and heated at 2.4 C/min for 25 minutes. Data collected from this method included RVU/min and Peak Viscosity (RVU units). Harder sorghums were expected to have delayed cooking curves versus softer grains.

Test Weight (kg/hL) of the three sorghum samples were measured using a small copper cup manufactured and utilized by Texas AgriLife Research Station in Vernon, TX. Density (g/cm^3) was measured by a nitrogen gas displacement method (Chang 1988) with a multipycnometer (Model MUP-1 S/N 232, Quantachrome Corp., Syosset, NY). T.A.D.D. (Tangential Abrasive Dehulling Device, Model 4E-115) was used to measure hardness (Abrasive Hardness Index) by percentage weight of sample retained after subjecting 20 grams of grain to 3.5 min of abrasion with a #104 Norton carborundum plate (Oomah 1981). A low T.A.D.D. percent translates to harder endosperm grain.

Thousand-Kernel weight (g) was determined by weighing 100 kernels and multiplying by ten. Endosperm texture is a subjective method that involves dissecting 10 kernels perpendicular to the position of the germ and evaluating dissected portion for presence of hard endosperm texture. Results for this method were presented in percent; number of identified hard kernels for every 10 grains evaluated. The higher this proportion is, the harder the grain is.

Each of the aforementioned tests was done in two separate days. Each day, three samples from each of the grains were used for each hardness method. The mean of six observations per variety, per test was collected.

Whole Sorghum Flour and Product Quality Evaluation

Grain Milling Equipment

The three sorghum varieties were subjected to different milling treatments. Grain was cleaned and dried prior to milling. No tempering or grain decortication was done on the grains, as it is not a common practice in El Salvador. All the grain samples were milled into whole grain flours. Burr, roller and hammer mills (Fig. 2) were used to process RCV, ZAM912 and the Native variety.

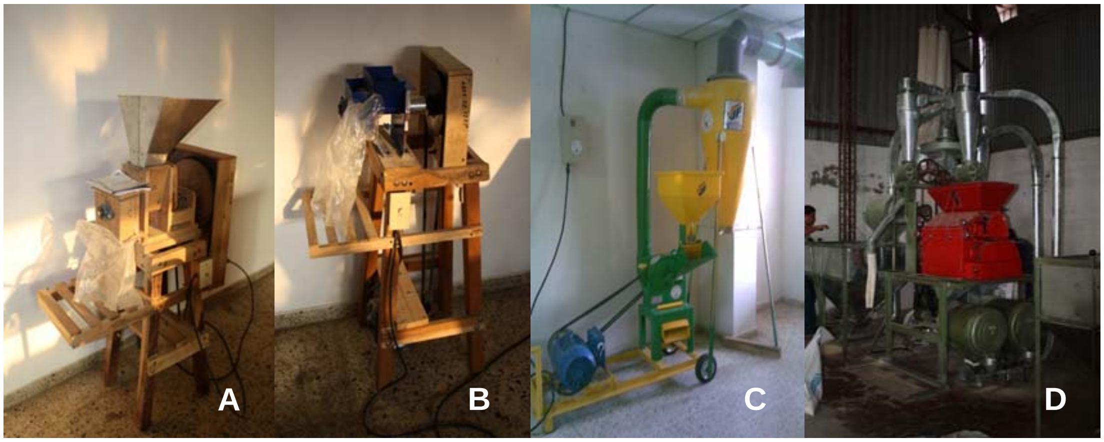

Fig. 2. Equipment currently used in Central America for sorghum milling: Omega VI (A), Ewing III (B), hammer mill (C) and roller mill (D).

Hammer and burr milling were performed in CENTA's Food processing lab. Roller milling took place at the manufacturing facilities of Proinsa. Burr mills (Omega VI and Ewing III, Compatible Technologies International, St. Paul, MN) were used to mill 1.36 kg of sorghum from each variety. To obtain flour for use in bakery products, the milled product was passed a minimum of 4 times through the Ewing III mill and 6 times through the Omega VI (wooden frame) mill. Plate gap was controlled through a screw mechanism (Fig. 3). Reference point used for starting burr gap was determined by turning the gap control screw clockwise to its maximum point (i.e. closest burr conformation) and then releasing screw 360° degrees counter clockwise from this conformation. Progressive decrease of gap between burrs occurred for each milling pass by tightening screw clockwise in increments of 60° toward the tightest burr conformation.

Fig. 3. Burr gap control screw: Ewing III mill (left), Omega VI mill (right).

Hammer (Model JF 3, Maquinas Agrícolas, Itapra SP, Brazil) and roller (Model 6MF-60, Henan Double Elephants Machinery, China) mill minimum milling amounts of 2.27 kg and 9.07 kg, respectively, were processed for each of the aforementioned grain varieties.

Particle size distribution of sorghum flour samples was measured using No. 20, 40, 60, 80 and 100 U.S. standard sieves. A modified method of determining and expressing fineness of feed materials by sieving, S319.4 (ASABE, 2008) was used to determine particle size distribution of the sorghum flours. Initial sample size was 50 g of sorghum flour. Samples were shaken for 7 minutes with a Rotap Testing sieve shaker (The W.S. Tyler Co., Cleveland, OH). Results for this test were expressed as percentage of the fractions from the weights left on the sieve. Mean of two observations was used to determine flour particle distribution for each variety/mill treatment of whole sorghum flours.

RVA 13 minute cooking profile was used to evaluate pasting temperature, peak viscosity, peak time, holding strength and final viscosity of sorghum flours and their blends with wheat flour (Zaidul et al. 2007). Breakdown and Setback were obtained by calculating the difference between peak viscosity and holding strength for the former and the difference between final viscosity and holding strength for the latter. Rapid Visco ™ Analyzer (RVA) equipment (Newport Scientific, version 2.2 Warriewood, NSW, Australia) was used to evaluate these on all 12 sorghum flour treatments. Means from three observations for each variety/mill treatment were used.

End-Product Evaluation

Cupcakes were the reference product used to evaluate sorghum flour quality in baked goods. CENTA's original formulation for 50% substitution of sorghum in wheat flour cupcakes was the base formula used to scale down to four cupcakes (Table I). Scale down was necessary due to sorghum-wheat flour blend limitation.

Cupcake ingredients were mixed using a Kitchen Aid 10 speed mixer. Flour blend and baking powder were premixed and sifted prior to starting blend of ingredients. Mixing was performed in three stages. During the first stage, butter and sugar were creamed for 1.5 minutes at speed 3. In second mixing stage, eggs were added slowly into the creamed butter for 2 minutes. The first minute, blend was mixed at speed 3 and second minute at speed 5. The third and last mixing stage involved the addition of milk, vanilla and flour blend. Flour pre-mix was stirred into the mix during 20 seconds and at speed 3 for 25 seconds, until batter looked smooth.

Forty-five grams of batter (± 0.3 g) were poured into the silicone cupcake liners (Easy Flex™ Silicone Baking Cups, Model No. 415-9400). A 12-well cupcake teflon pan was utilized. Wells located in the center of the pan were used to bake cakes for 25 minutes at 180ºC.

Table I. Cupcake ingredients and formulation

Ingredients	**Weight (g)**	**Ingredient Composition[1] (%)**	**Baker's Composition[2] (%)**
Flour Blend*	65.0	30	100
Sugar	43.3	20	67
Margarine	37.7	17	58
Eggs	50.0	23	77
Baking Powder	2.5	1	4
Non- Fat Milk	20.0	9	31
Vanilla	1.2	1	2

*Flour blend = 50/50 Sorghum and Wheat Flour. (Wheat flour characterization: Appendix C).
[1]Percentage of ingredient from total batch weight
[2]Percentage of ingredient based on flour blend weight

Texture analysis profile (TPA) (Bourne 2002) of cupcakes was done using TA.XT2 equipment (Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, UK). Preliminary tests indicated that 15 mm compression with a 10 cm diameter plate probe would have good repeatability when using a whole cupcake with standard height of 40 ml ± 3 ml. TPA was used to determine hardness and springiness of cupcakes. Results were given in Newtons (N) for hardness, and millimeters (mm) for springiness. Cupcake texture analysis took place one-hour after baking. Mean of six observations was collected per variety/mill treatment for hardness, and springiness parameters.

Three randomized baking replicates of four cupcakes per bake were done in three different days for each variety/mill flour treatment (12 cupcakes per variety/mill flour).

A modified version of the AACC Method 10-91.01 (Use of Layer Cake Measuring Template) was used to calculate a volume index for the cupcakes. Ohaus weight balance (Ohaus Voyager Pro VP6102CN NTEP Certified Balance, Pine Brook, NJ) was used to measure cupcake weight after baking. Six observations were collected for each variety/mill (sorghum-wheat blend) for volume index and weight.

Analytical Methods

Proximate analysis of whole sorghum flour crude fat and fiber followed method 920.39 (A) and 978.10 respectively, from the Official Methods of Analysis of the Association of Official Analytical Chemists (AOAC) (2006). Sorghum flour crude protein (% N x 6.25) & ash content was determined by high temperature combustion process following method 990.03 of the Official Methods of Analysis of AOAC (2006). Total dietary fiber content was done on sorghum flour from the three different varieties using method 985.29 from the Official Methods of Analysis of AOAC (2006).

Moisture content of grain was determined by SKHT (Model SKCS 4100, Perten Instruments, Reno, NV). Moisture measurement of flours (Sorghum and Blend with wheat flour) and cupcakes used the AACC Air Oven method 44.15.02 with a forced air oven (Model 16, Precision Scientific, Chicago, IL). Sorghum flour and sorghum-wheat flour blend moisture content was determined by the one–stage oven method (44.15.02). Cupcake moisture content was determined through the AIB recommended method for measurement of moisture in yellow layer cakes, which is a modified version of the two-stage procedure (44.15.02). Moisture content was calculated by percent weight lost. Mean of three observations was used to determine moisture content of flours and cupcakes. Means of six observations was done to determine moisture content of the grain.

A colorimeter (model CR-310, Minolta C0., LTD. Ramsey, NJ) was used to analyze grain, sorghum flour and cupcake color. Measurements were recorded using the CIE-L* a* b* uniform color space (CIE-Lab), where L* indicates lightness, a* indicates hue on a green (-) to red (+) axis, and b* indicates hue on a blue (-) to yellow (+) axis. Cupcake color evaluation was only performed for cupcake tops. Nine observations per variety/mill treatment were collected. Restricted amounts of sample prevented the evaluation of the crumb color. A scale from 1 to 6, 1 being lightest and 6 being the darkest hue was used to rate the crumb color of the cupcakes. The mean of six observations was used for L*a*b* determination of each grain variety. For the flours (whole grain sorghum flour and its blend with wheat flour), the L*a*b* values for each variety/mill treatment was determined from the mean of six observations.

Statistical Analysis

Analysis of variance (ANOVA) was done with SAS 9.2 for Windows using proc glm. Differences between means were analyzed utilizing Tukey's HSD (honest significant difference) with a 95% confidence level. Spearman correlations for grain hardness, flour cooking properties and end-product evaluations was done.

RESULTS AND DISCUSSION

Sorghum Grain Quality Evaluation

Physical Chemical Characterization

RCV, ZAM 912 and Native Salvadorian varieties were significantly different in grain hardness and physical characteristics. RCV was the hardest of the three varieties with the highest proportion of corneous endosperm texture, low T.A.D.D. percent, low RVA peak viscosity and high hardness index with the single kernel hardness tester. The Native variety had significantly softer grains while ZAM912 had intermediate grain hardness. Variability among grains was observed in thousand kernel weight (TKW), diameter and kernel weight evaluations (Table II).

All varieties had a cream, tan color pericarp. However, there was a significant difference among the three grains for the L value; the Native variety had a lighter color than ZAM 912 and RCV. ZAM 912 and the Native variety a* values were similar. The yellow hue was slightly more accentuated in the Native variety (18.2) than in ZAM 912(17.4) and RCV (17.2).

Grain characteristics are affected by their genetic composition. The environment plays a significant role in the development of the caryopsis characteristics. In Fig. 4, there is variation among kernels for softness, but RCV was clearly the hardest grain.

Table II. Physical properties of Native, ZAM 912 and RCV sorghums*

Properties	Varieties			Mean Separation
	Native	ZAM 912	RCV	Tukey HSD[1]
Density (g/cm^3)	1.351[b]	1.350[b]	1.386[a]	0.0047
T.A.D.D.[2](%)	65[a]	48[b]	17[c]	3
Endosperm Texture (%)	28[c]	67[b]	82[a]	12
Test Weight (kg/hL)	72.5[b]	73.6[b]	75.5[a]	1.2
TKW [3](g)	32.5[a]	25.9[c]	28.8[b]	0.6
Hardness Index	68.7[c]	78.5[b]	91.0[a]	1.7
Weight/kernel (mg)	30.6[a]	25.2[c]	28.1[b]	0.7
Diameter (mm)	2.78[a]	2.69[b]	2.55[c]	0.02
Moisture Content (%)	12.0[c]	12.6[b]	12.9[a]	0.1
L**	67.5[a]	64.4[b]	61.4[c]	0.3
a**	3.3[b]	3.6[a]	3.7[a]	0.2
b**	18.2[a]	17.4[b]	17.2[b]	0.3
Peak Viscosity (RVU)	1068.2[a]	947.2[b]	745.5[c]	15.2
Viscosity (RVU/min)	364.5[a]	255.2[b]	179.9[c]	15.7

* Values with same letter for each row are not significantly different, α= 0.05
[1] Tukey's Honest Significant Difference for means separation (P≤ 0.05)
[2] Tangential Abrasive Dehulling Device
[3] Thousand Kernel Weight
**L indicates lightness, a indicates hue on a green (-) to red (+) axis, and b indicates hue on a blue (-) to yellow (+) axis

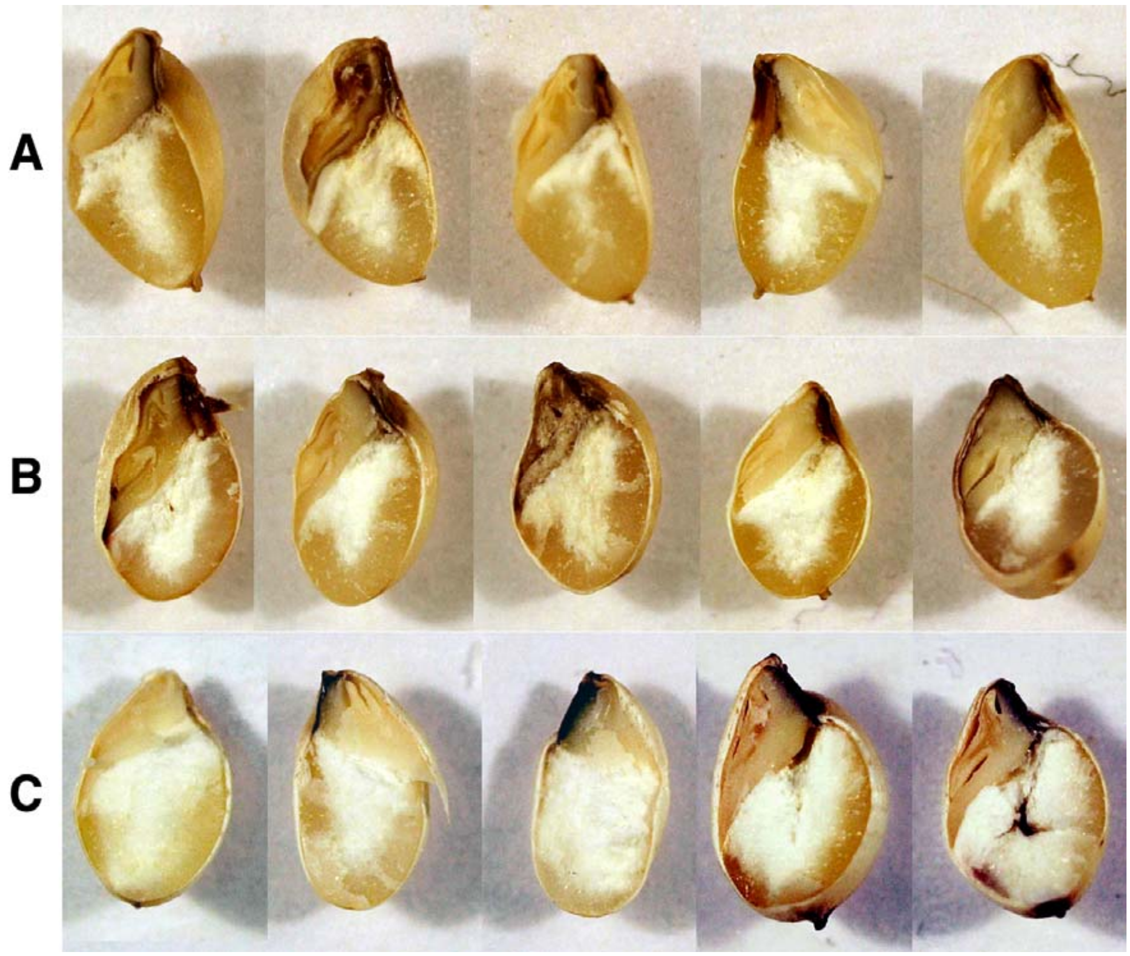

Fig 4. Cross section of Salvadorian sorghum varieties: (A) RCV, (B) ZAM 912 and (C) Native.

For composition, proximate analysis was done on these grains (Table III). Typical values for white sorghum (whole and decorticated sorghum flour) are shown in Table A-1 (Appendix A). Similar to physical characteristics of the grain, variability in chemical composition was detected and related to genetic and environmental effects.

Table III. Salvadorian (Native, ZAM912, and RCV) sorghum whole grain proximate analysis*

Variety	Crude Protein [1] (%N x 6.25)	Crude Fat [2] (%)	Crude Fiber [3] (%)	Ash[1] (%)	Total Dietary Fiber[4] (%)
Native	9.26	2.54	1.64	1.41	6.21
ZAM 912	11.49	2.37	1.60	1.48	5.24
RCV	12.14	2.02	1.89	1.59	6.28

* Results tabulated by independent laboratory.
[1] Combustion Analysis (LECO) AOAC Official Method 990.03, 2006
[2] By Ether Extraction, AOAC Official Method 920.39 (A), 2006
[3] AOAC Official Method 978.10, 2006
[4] AOAC Official Method 985.29, 2006

Grain hardness can be beneficial or detrimental depending on processing methods used. Hulse (1980) and Munck (1995) reported that ease in the separation of grain parts (bran and germ from endosperm), reduced ‘specky’ appearance, and higher flour extraction rates were achieved using grain with harder endosperm texture. This is most useful when dealing with grains that contain pigmented outer structures.

For milling Salvadorian sorghums, the selection of grains for sorghum flour was based on pericarp and glume color. White sorghums are the predominant type produced in El Salvador. Hence, they have excellent quality grain to process. The original concept to breed white, tan hard sorghums was based on decortication results obtained with the small attrition mills. When the use of small burr mills was promoted, the hard grain was no longer needed. Therefore, the softer endosperm varieties are more suitable for production of whole grain flours. Thus, sorghum flours from the hard, intermediate and soft endosperm varieties were evaluated to determine their quality and use in foods.

Whole Sorghum Flour Quality Evaluation

Physical Chemical Characterization

Sifting soft grain flour was difficult. The roller mill is known to produce small particle size flours, especially when soft grains are processed. However, expected results from milled Native varieties (i.e. high percent weight in mesh sieves #80, #100 and the pan) were not observed (Fig. 5). Instead, this high weight percentage was seen for the hardest grain milled in this equipment, RCV. The soft grain flours clogged sieves and gave misleading results. Pomeranz (1986) noted that small differences in moisture content in grain and drying conditions after harvest affect the flour particles obtained and cause clogging of mesh openings when sieving ground whole sorghum grain. Differences in sieves and equipment used can affect particle size separations.

A similar phenomenon is observed in other cereal grains (e.g. soft versus hard wheat flour). Studies on methods for particle size distribution with wheat flours that compared sieving with other available techniques found that flour from softer grains does not flow through sieve openings; it adheres and clogs the sieves. Conversely, harder grain flours are more easily sifted than soft grain flours (Hareland 1994).

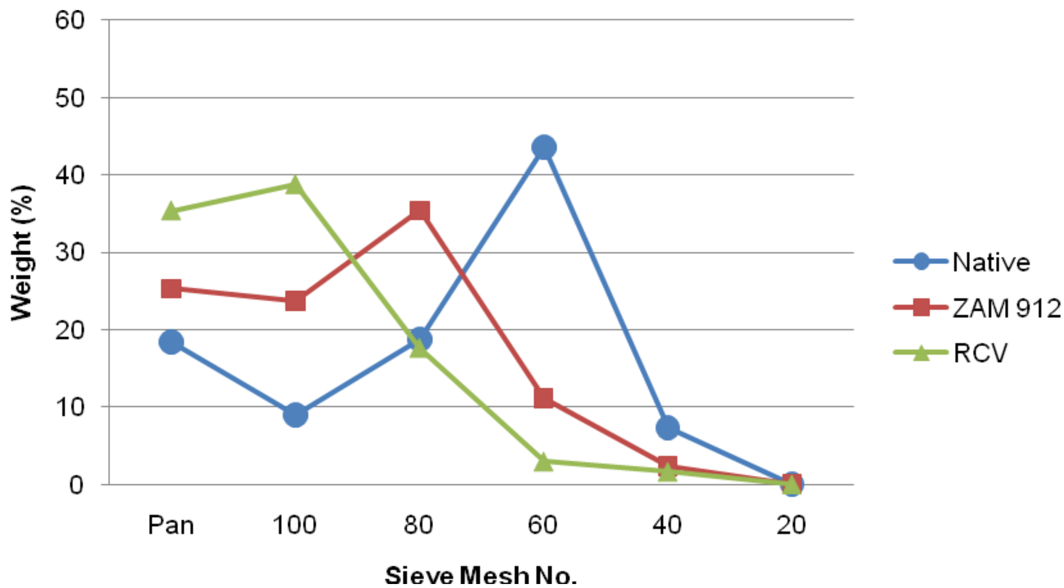

Fig. 5. Particle size distribution of flours from roller mill. Each line graph represents each Salvadorian variety evaluated: Native, ZAM 912 and RCV. Each point, for each line graph is the mean of two observations calculated as percent over for each sieve.

Particle size distribution of the coarse particles (total % weight of overs above sieve #60; % weight over #20 + % weight over #40 +% weight over #60) was used to assess quality of the three varieties when subjected to milling. In El Salvador, the flour milled from the hammer mill is usually passed through a #50 mesh: flour that passes mesh #50 is utilized in baked products. The overs of sieve #50 are characterized as coarse particles. Since sieve #50 was not used in the experiment, total percent weight of particles above sieve #60 was used as reference.

Therefore, the highest particle size distribution of coarse particles was produced by the Hammer mill. Moreover, the native variety produced the smallest proportion of these (53%) and RCV, the hard variety, produced the highest (62%) (Fig. 6, Table B-1). This agrees with previous studies of particle size distribution of hard flours (Bayram and Öner 2005; Chandrashekar and Mazhar 1999; Hareland 1994).

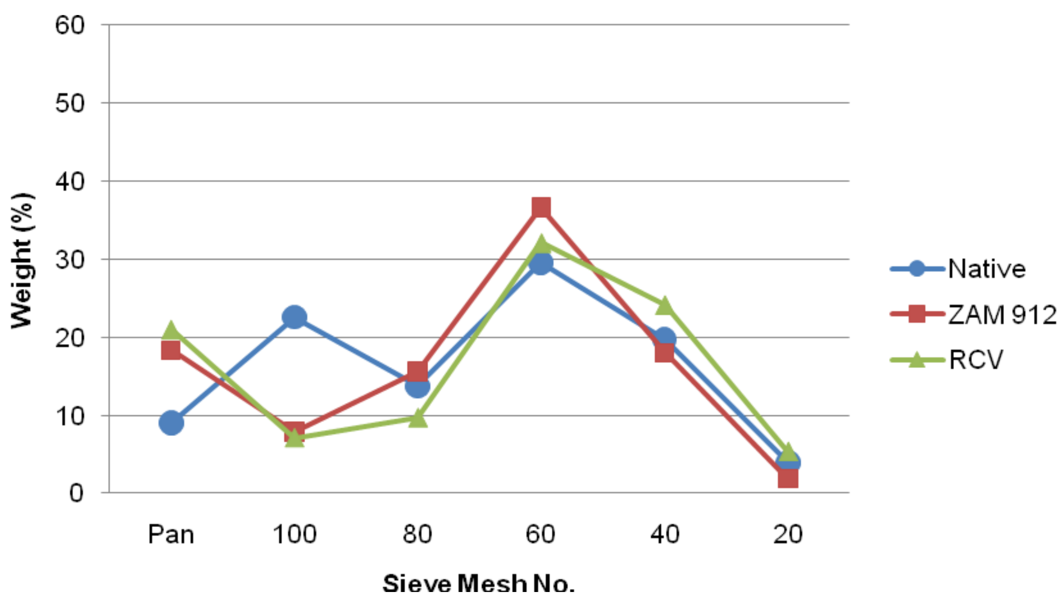

Fig. 6. Particle size distribution of flours from hammer mill. Each line graph represents each Salvadorian variety evaluated: Native, ZAM 912 and RCV. Each point, for each line graph is the mean of two observations calculated as percent over for each sieve.

Even though burr mills had very similar range of particle size distribution for the three varieties, softer grain flours (which produce smaller particles), behaved similar to that of the roller milled softer grain flours. This was especially true for the Omega VI (Fig. 7 and 8).

Nevertheless, unpublished data from the CENTA food processing lab on particle size distribution of softer Salvadorian sorghum grains reveal that the

Omega mill produces 60% of the milled flour with a particle size of 180 mm (>80 mesh) from native and improved variety sorghum grains (Calderon 2009).

For each of these milling systems, advantages and disadvantages can be identified. In general, for the burr mills (Omega VI and Ewing III) advantages include higher control on behalf of operator regarding the degree of granularity desired regardless of the variety used. Calderon and DuVille reported in 2009 longer milling time for harder grains. Burr mills are more effective small scale with discontinuous batch operation (2 kg in ~7 minutes) than the current nixtamal mills. However, milling of large volumes of grain can be difficult (+30 kg) since it will take time. Nevertheless, the use of these mills has been reported in the production of high volumes of flour. This has been achieved through its use in combination with the hammer mill. Burr mills are used as a secondary milling operation to reduce size of coarse particles from hammer milled flours.

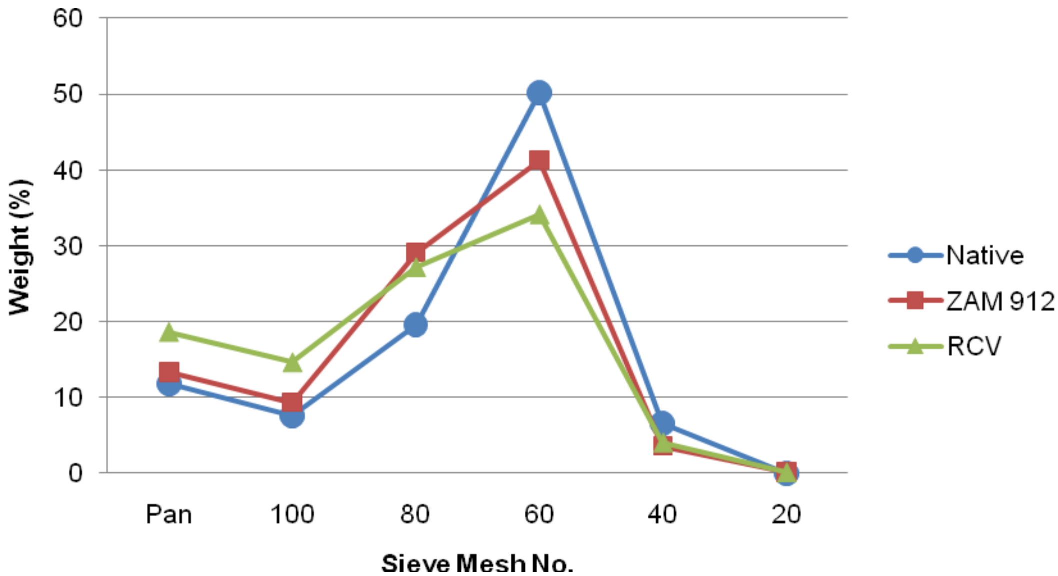

Fig. 7. Particle size distribution of flours from Omega VI mill. Each line graph represents each Salvadorian variety evaluated: Native, ZAM 912 and RCV. Each point, for each line graph is the mean of two observations calculated as percent over for each sieve.

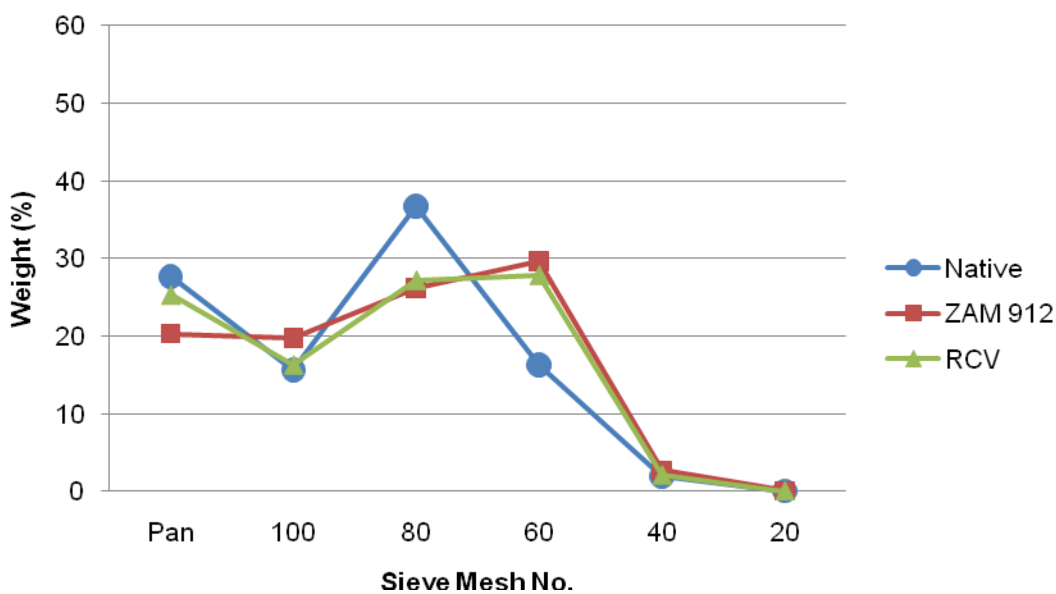

Fig. 8. Particle size distribution for flours from Ewing III mill. Each line graph represents each Salvadorian variety evaluated: Native, ZAM 912 and RCV. Each point, for each line graph is the mean of two observations calculated as percent over for each sieve.

Another advantage of these burr mills are their cost. For the quality of flour produced, these mills are affordable and practical for rural community millers and bakers. They are easier to maintain than roller and hammer mills. Moreover, CENTA food processing lab technicians are well trained in the use of this equipment, hence local technical assistance is available in the event any issues arise for burr mill users.

Conversely, the roller and hammer mill are advantageous from the volume and speed of production perspective. Large quantities of sorghum flour are produced in a shorter period than with burr mills. These large batch operation systems are more expensive to operate as they involve more energy costs to run. Maintenance of this equipment is expensive; if a malfunction occurs or a part needs to be replaced, cost will be higher than the cost to repair a malfunction with the burr mills. The particle size distribution is different for each of the flours derived from each variety for the hammer and roller mills (Figs. 5 and 6) compared to the burr mills (Figs. 7 and 8). Even so, Proinsa's experimental baking lab has been able to achieve a higher degree of wheat flour substitution with sorghum roller milled flours: up to 80% in muffins and cakes (Personal Communication, Anliker 2010).

Table IV. Whole sorghum flour crude protein (N% x 6.25) and ash (%) content for each variety/mill flour *

Variety	Mill	Crude Protein[1] (N % x 6.25)	Ash[1] (%)
Native	Omega	8.14	1.30
	Ewing	7.97	1.31
	Hammer	7.95	1.40
	Roller	8.20	1.08
ZAM 912	Omega	11.17	1.35
	Ewing	11.39	1.41
	Hammer	10.94	1.35
	Roller	10.96	1.52
RCV	Omega	11.58	1.49
	Ewing	11.77	1.61
	Hammer	11.37	1.46
	Roller	11.51	1.38

* Results tabulated by independent laboratory.
[1] Combustion Analysis (LECO) AOAC Official Method 990.03, 2006

The protein content was numerically higher in the harder grain flours (RCV) than in softer grain flours (Native) (Table IV). Improved varieties probably had higher nitrogen fertilization than native crops which increase grain protein content by 2-4 % (Smith 2000). Higher protein in whole grain flours of RCV and ZAM 912 was found because improved varieties are given higher rates of nitrates (Zeledon 2007).

Whole Sorghum Flour and Sorghum-Wheat Flour Blends

Cooking Characteristics

Table B-3 contains information on cooking behavior of sorghum flour obtained from different varieties and information on the 50/50 sorghum-wheat flour blends. The pasting temperature, peak viscosity, peak time and setback were the major characteristics observed for these flours. This data provides information on time and energy needed to cook product. These properties relate to acceptability of flour and its changes during baking.

In general, sorghum flours require more energy (higher temperature) to start gelatinization. The starch granules of sorghum take longer to hydrate due to their interaction with the surrounding protein (kafirins) and their hydrophobicity preventing faster absorption of water. In contrast, wheat proteins are more soluble and form gluten. The increase in pasting temperatures occurring from soft to hard grain endosperm occurs because the proportion of corneous endosperm in the grain increases, making it even more difficult for water to hydrate starch. Furthermore, large particle size flours are more difficult to hydrate.

Hard and soft (Fig.9) hammer milled grain cooking viscosity curves were lower than the flours obtained from the other three mills. These also took more time to reach peak viscosity.

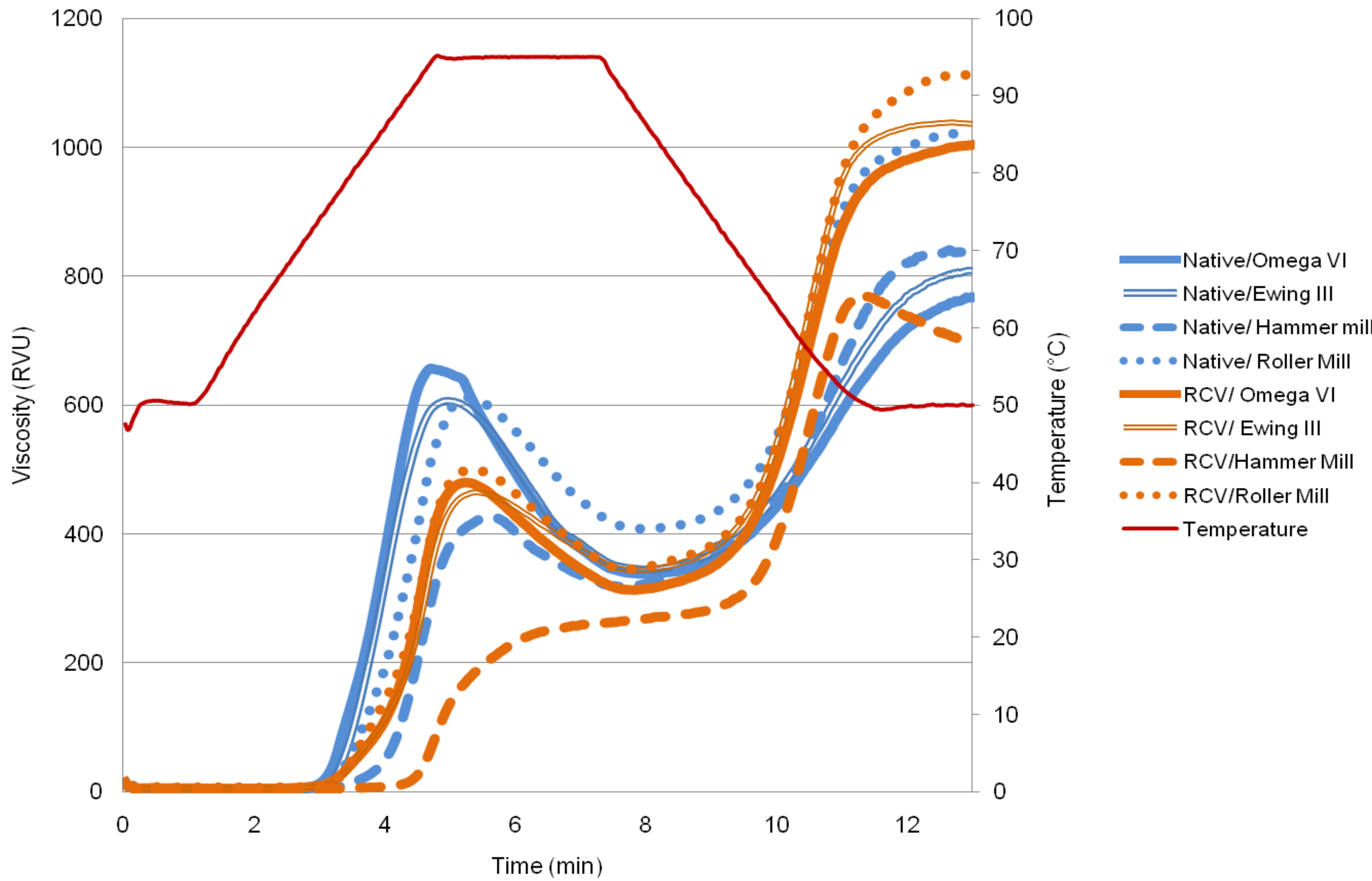

Fig. 9. RVA analysis (15% solids) of ground RCV and Native variety whole grain flour.

The highest final viscosities were observed for the roller milled flours from soft and hard grains. In general, harder grain flours were more difficult to cook than the softer grain flours. Blending wheat flour with the whole sorghum flour improved the cooking profile. Quicker pasting and reduction in retrogradation was observed (Figs. 10 and 11).

A correlation ($r=0.81$, $p<0.0001$) between sorghum and respective blends with wheat was found for the pasting temperature parameter (Fig.12). For each variety, higher pasting temperatures were seen for the hammer mill. This indicates that particle size has an effect on this factor, as previously noted; the largest particle size of the four mills was produced from the hammer mill. Therefore, the roller and burr mill flours from the Native grain exhibited lower pasting temperatures. Omega VI milled flour had the lowest pasting temperature (Figs. 9, 10 and 12). Similar trend was observed for 50/50 whole sorghum–wheat blend, but at lower pasting temperatures than those of sorghum alone (Fig. 11). The lower pasting temperature for the blends is due to the replacement of half of the sorghum with wheat flour. The increased availability of starch granules with higher swelling capacity, hydration and gelatinization rate could lead to decreased energy expenditure when processing products made from wheat-sorghum composite flours (Ragaee and Abdel-Aal 2006).

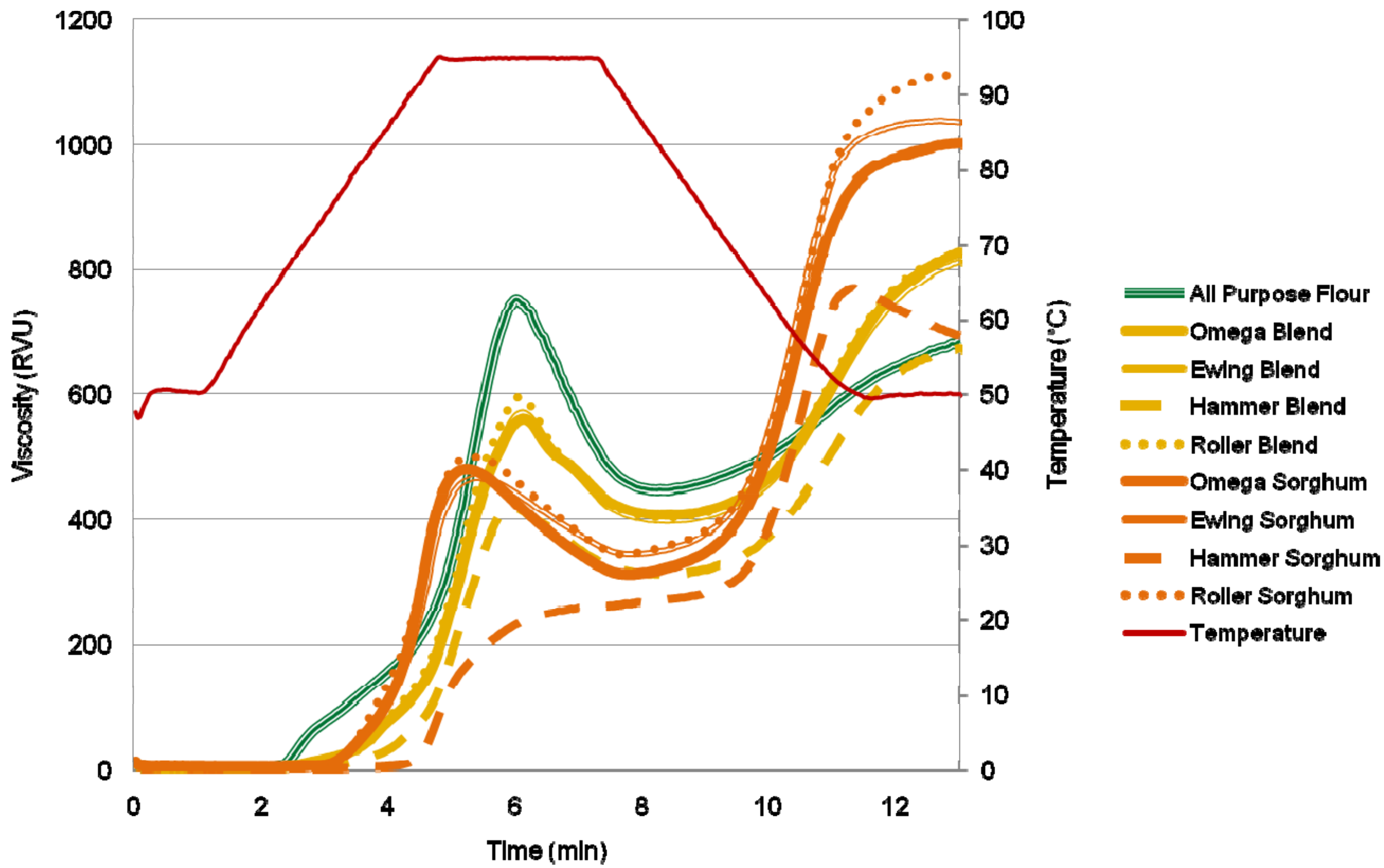

Fig. 10. RVA analysis (15% solids) for ground RCV sorghum and 50/50 whole sorghum-wheat flour blends.

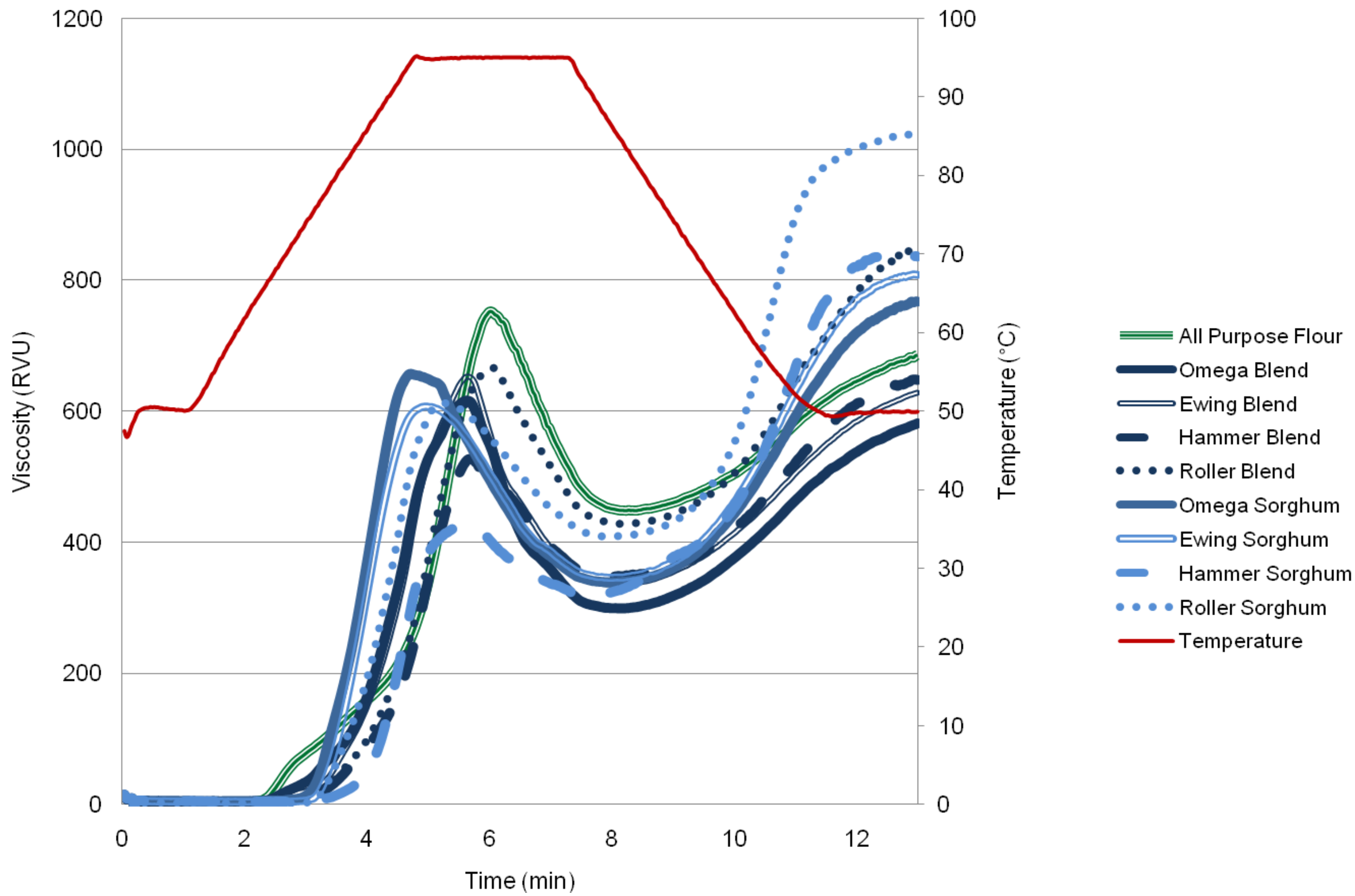

Fig. 11. RVA analysis (15% solids) for ground Native sorghum and 50/50 whole sorghum-wheat flour blends.

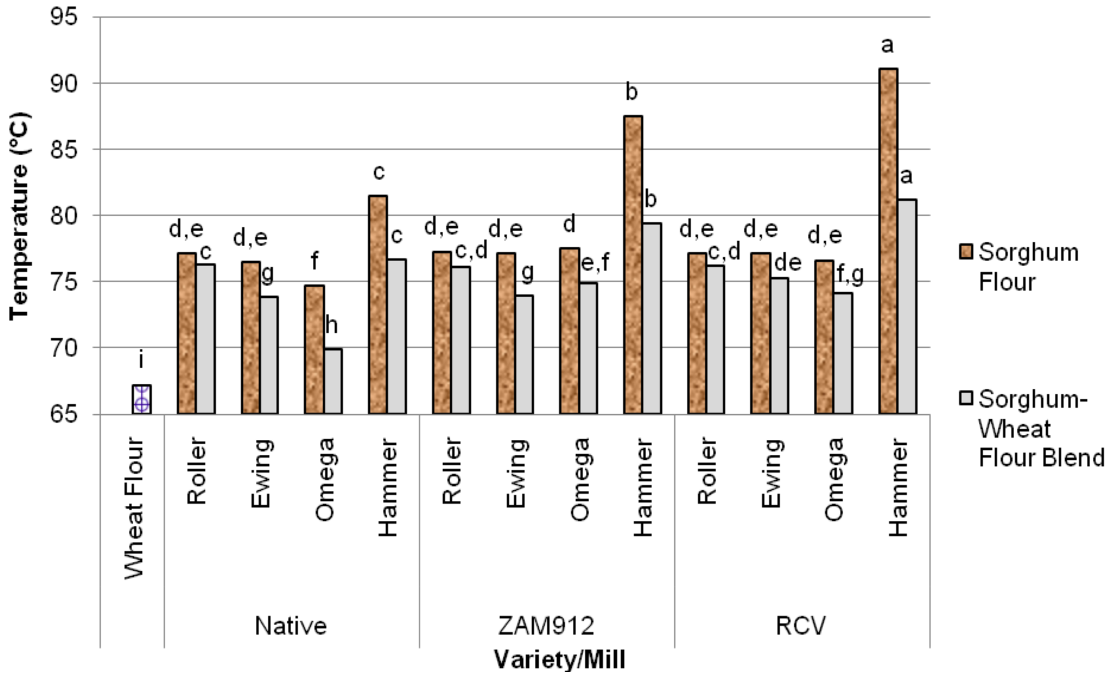

Fig.12. Pasting temperature among whole sorghum and whole sorghum-wheat blends for each variety/mill combination. Bars with same letters are not significantly different, α=0.05.

A similar trend to that of the pasting temperature was observed for hammer milled flours peak time (Fig. 13); longer time was required to reach peak viscosity for the harder grains than for the softer grains (Fig. 9). Ragaee et al. (2006) evaluated properties of whole grain sorghum flour finding it took higher pasting temperature and longer time to reach peak viscosity.

RCV hammer milled grain had the highest peak time (~ 8 minutes). Ewing and Omega milled sorghum flours were similar to each other within each variety: it took shorter time to reach peak viscosity than the hammer mill flour. In general, peak time increased as grain hardness and particle size increased.

More marked differences were noted between RCV and Native sorghum flours. The same trend follows for their respective blends with wheat; non-significant differences were observed among ZAM912 and RCV whole sorghum flour-wheat blends. Peak times for sorghum flours (except RCV/hammer mill flour) were lower than that of the sorghum blends. Same trend was observed in the sorghum-wheat flour blends.

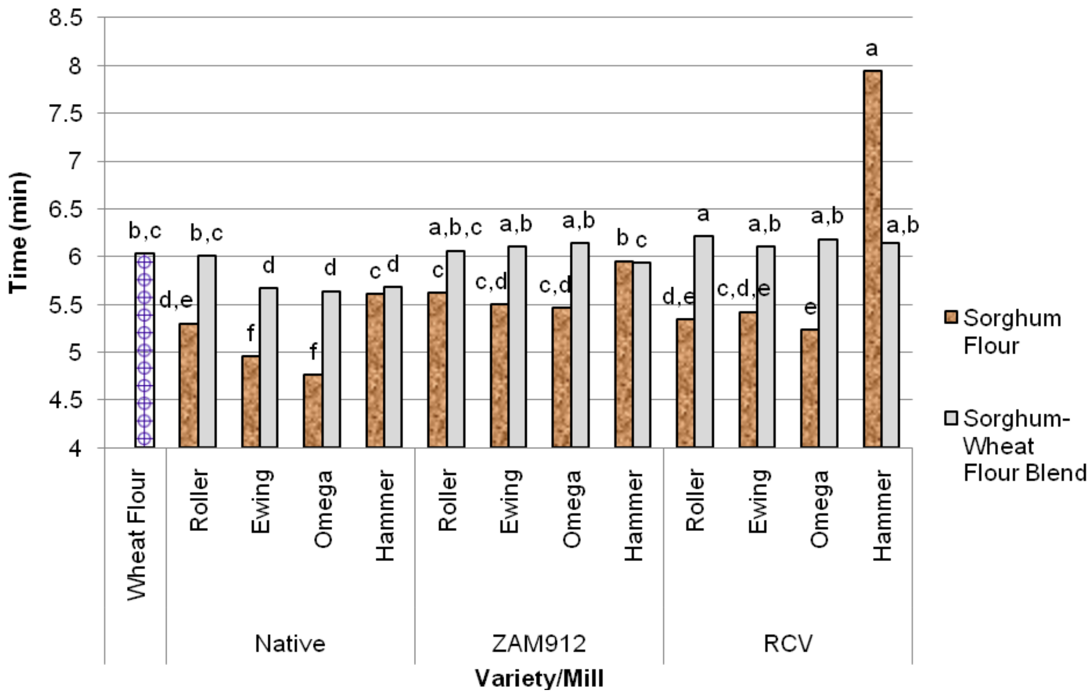

Fig.13. Peak viscosity time among whole sorghum and whole sorghum-wheat blends for each variety/mill combination. Bars with same letters are not significantly different, α=0.05.

Peak viscosity (Fig. 14) had an inverse trend to that of pasting temperature; lower peak viscosities were observed for harder grains and flours with more coarse particles (i.e. hammer mill). Starch availability and accessibility affects peak viscosity in RCV/hammer milled flour. The RVA slurry solids composition for the cooking profile may not have been enough for this sample to reach maximum viscosity. The peak viscosity determined for this flour was the highest point within the selected range to identify this value for all flours evaluated (between 0 and 8 minutes).

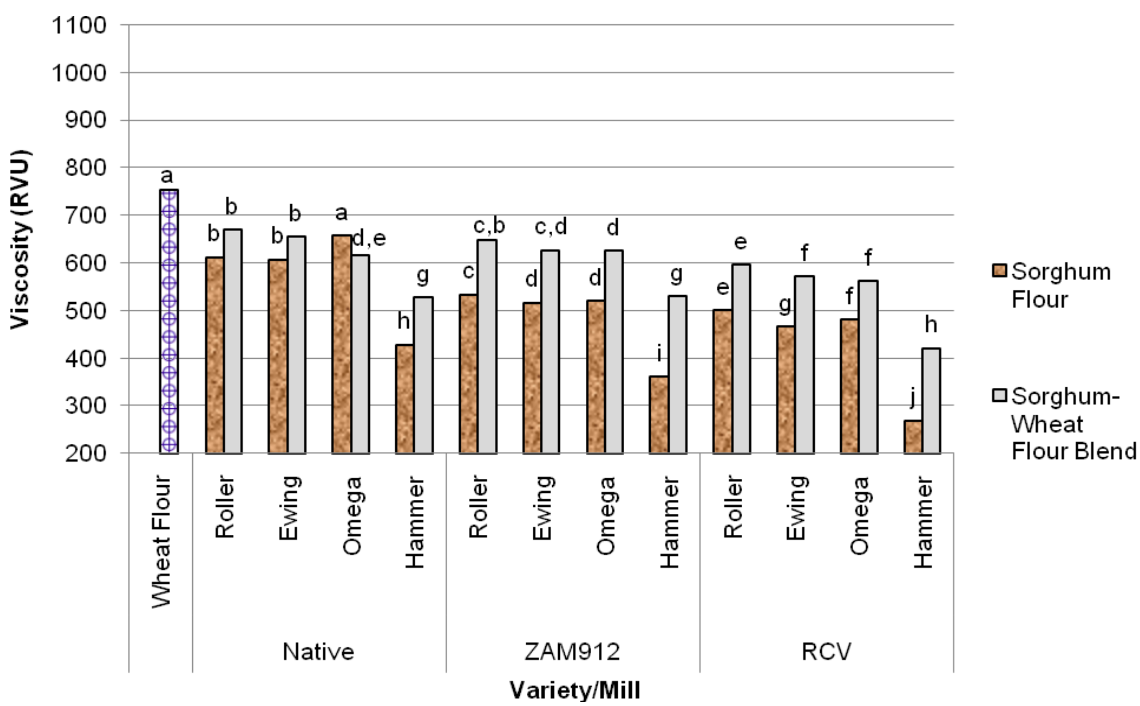

Fig.14. Peak viscosity among whole sorghum and whole sorghum-wheat blends for each variety/mill combination. Bars with same letters are not significantly different, α=0.05.

For RCV/hammer mill flour (Fig. 10) no maximum peak viscosity was reached for this sample with the solids level used (15%). Maximum viscosity for this curve was found at the end of the peak viscosity range. A higher percent of solids would have been more appropriate for the RCV/hammer mill (Fig.15), but not for the other flours. Therefore, hard grain flours that have larger particles will require more time to hydrate. The blend of this whole sorghum flour with all-purpose wheat flour had a better cooking profile than the sorghum alone (Fig. 11).

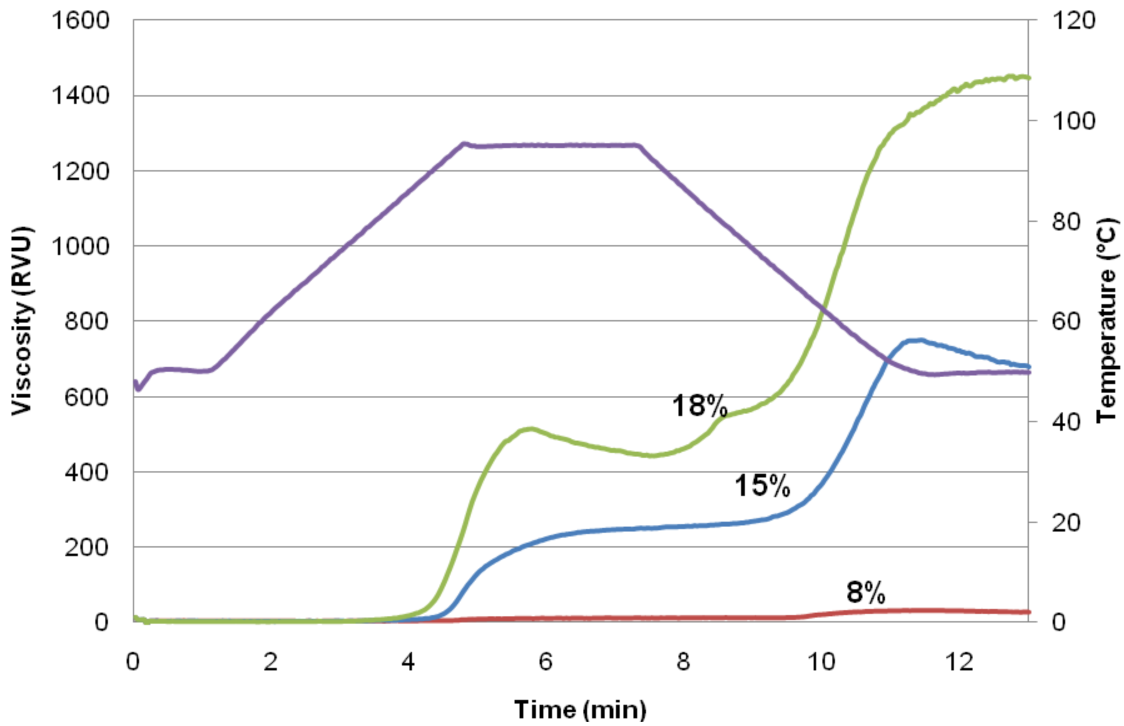

Fig. 15. RVA preliminary pasting curves at different solids concentration (8%,15%, 18%) for RCV/hammer milled sorghum flour.

In general, peak viscosities of sorghum-wheat blends were higher than sorghum flours alone. There was a strong correlation between the flours for this parameter ($r = 0.88$, $P \leq 0.0001$).

For setback (Fig. 16), a correlation between the sorghum flours and blends with all-purpose wheat flour was detected ($r = 0.75$, $P \leq 0.0001$). The high setback values observed for the blends of the roller milled flours, in the sorghum-wheat blends of Native and ZAM 912 varieties is related to the smaller particles. The degree of particle size reduction of whole grain to flour was increased for softer grains than for harder grains. In whole grains, production of smaller particles cause increased viscosity. Conversely, it has been reported that lipids released from the germ after milling whole grain sorghum affects sorghum setback viscosity (Zhang and Hamaker 2005). More impact of this can occur in roller milled flours than in hammer milled flours; germ size pieces are more intact in the coarse particle flours than in fine particle flours.

Setback in harder, whole grain flours could be due to protein content (Zhang and Hamaker 2005). This is further supported in previous studies on grain hardness effect on food characteristics; porridges made with harder grain flours had high setback viscosity (Bello 1995; Cagampang 1984). In addition, association between proteins and dietary fiber during food processing, can affect the swelling capacity of available starch and degree of retrogradation. Processing of sorghum products into food stuffs can augment levels of soluble dietary fiber, due to the increase in bound proteins (kafirins) and enzyme-resistant starch (Bach Knudsen 1985).

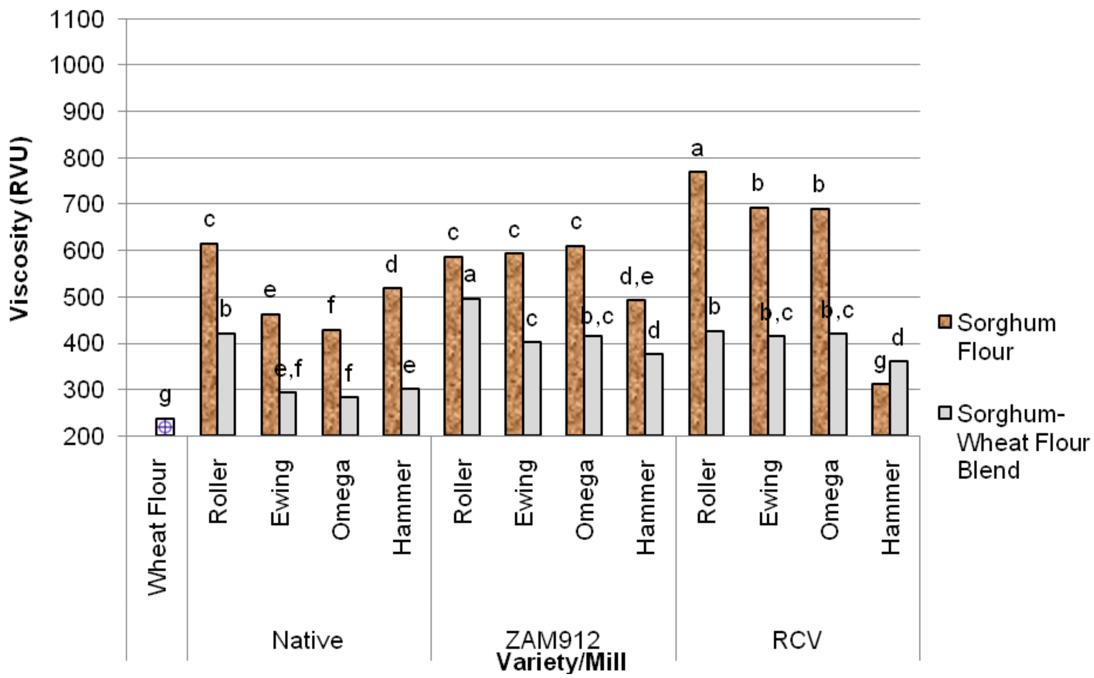

Fig.16. Setback among whole sorghum and whole sorghum-wheat blends for each variety/mill combination. Bars with same letters are not significantly different, α=0.05.

Whole Sorghum Flour Appearance

Fig. 17 depicts the appearance of the different flours produced from each variety/mill combination. The Ewing III and Omega VI produce flours with similar particle appearance. Conversely, a significant contrast between the hammer and roller milled flours is observed. For hammer milled flour, large pieces of corneous endosperm, germ and non-pigmented pericarp are in the coarse particle size proportion of its flour. The Native variety has smaller particles than the RCV variety. The difference in these particles at least partially explains the RVA Data.

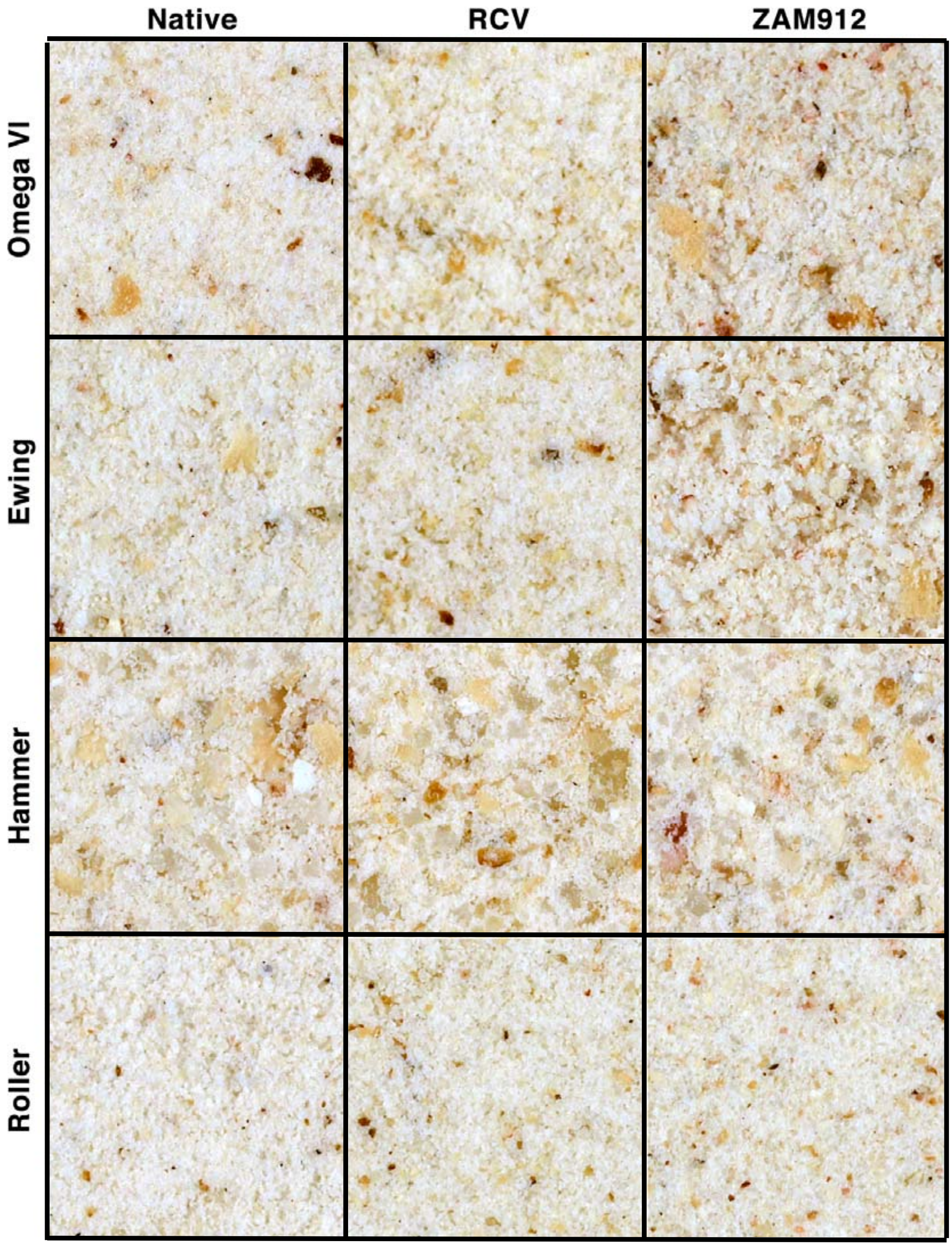

Fig. 17. Whole sorghum flour from each variety (columns)/mill (rows) combination.

Effect of Whole Sorghum Flour Color on Sorghum –Wheat Blend

Positive correlation of the L (r=0.75, P≤0.0001), a (r=0.85, P≤0.0001) and b (r=0.88, P≤0.0001) values were seen between the whole sorghum flour and its blend with all-purpose wheat flour. The combination of sorghum with all-purpose wheat flour increased lightness of the blend significantly. Figs. 18 and 19 have a common trend between the sorghum flours produced and their wheat blends. L values (Fig. 18) showed that the degree of lightness of the Native and RCV 50/50 flour blends is higher than that of the ZAM 912 blend.

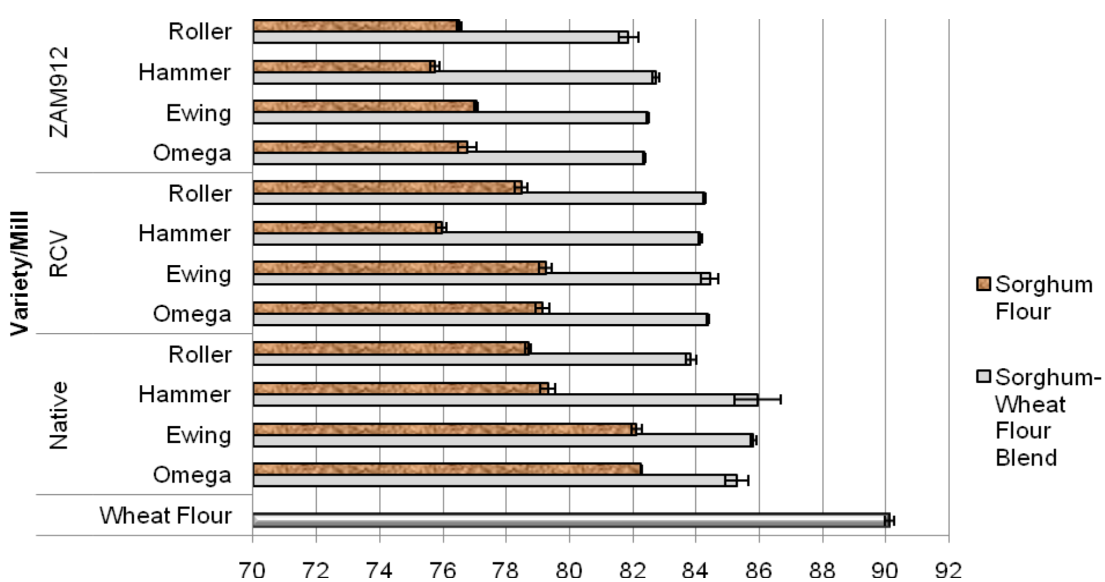

Fig.18. L* values (L indicates lightness) for whole sorghum flours and whole sorghum –wheat flour blends. Error bars represent standard deviation.

Likewise the red hue (a* value) in Fig. 19, is considerably lower for the lighter flours, Native and RCV. Within the RCV and the Native varieties, the sorghum flours from the Omega and the Hammer mill had more intense red hues than the flours from the Roller and Ewing mill. A decrease from red to green is perceived when these are combined with the all-purpose flour; the combination with wheat flour attenuates the degree of red hues found in the sorghum flour.

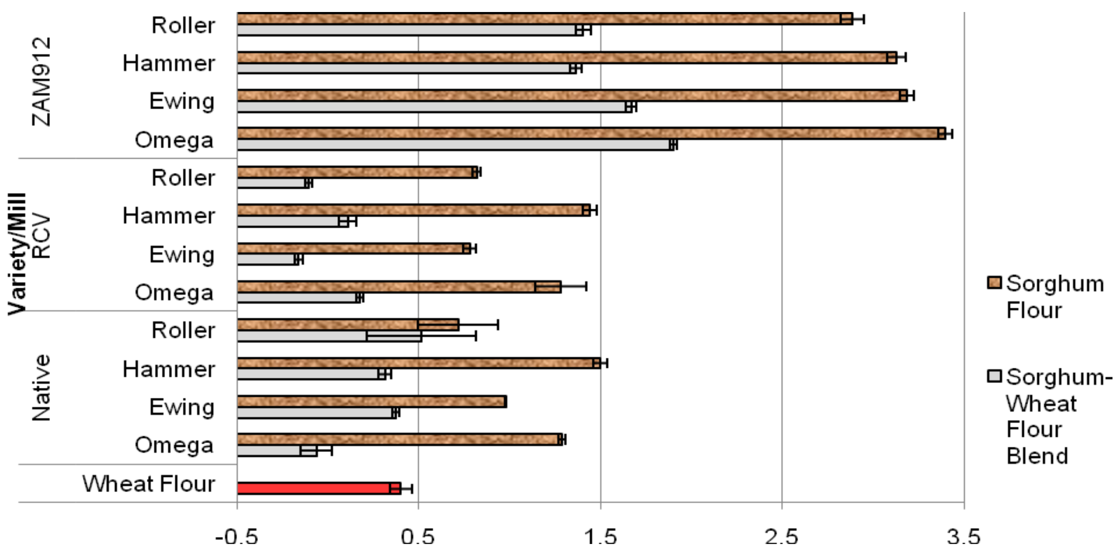

Fig.19. a* values (a*indicates hue on a green (-) to red (+) axis) for sorghum flours and sorghum –wheat flour blends. Error bars represent standard deviation.

For b values (Fig. 20), ZAM 912 had high levels of yellow hues. Native flours had slightly more intense yellow hue than the RCV flours. As with the a* value, all-purpose wheat flour diminishes yellow hue between the sorghum and its respective blend with wheat flour.

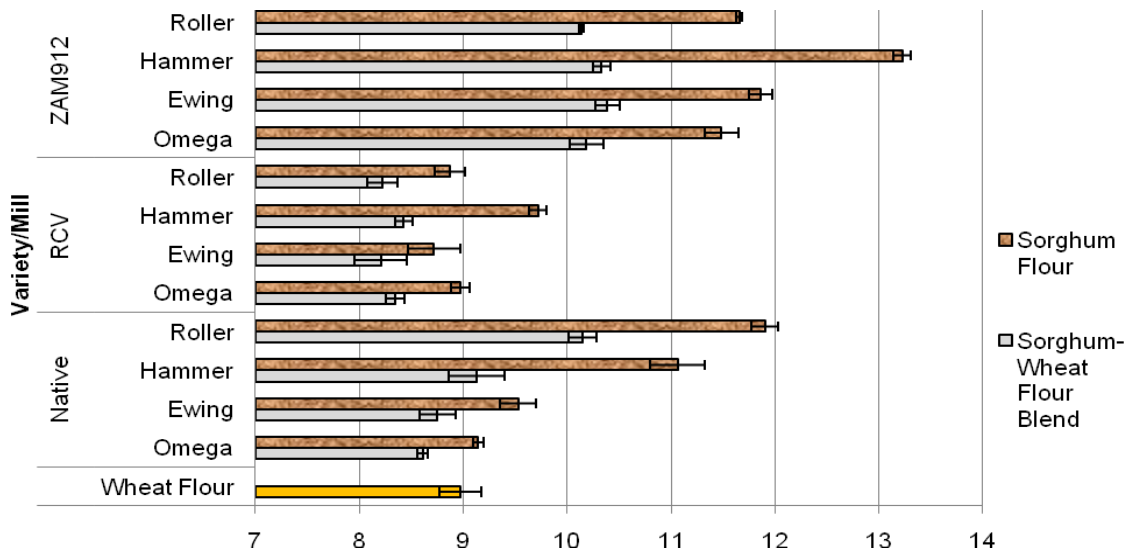

Fig. 20. b* values (b indicates hue on a blue (-) to yellow (+) axis) for sorghum flours and sorghum –wheat blends. Error bars represent standard deviation.

End-product Quality Evaluation

Physical Characteristics

The whole sorghum flours in combination with all-purpose wheat flour were used to make cupcakes. Physical characteristics (i.e. moisture content, color, volume index and texture) were measured on the product. Statistical analysis of moisture content did not show a significant difference among the cupcakes at α=0.05; values ranged between 27-29%.

L*a* b* values of the cupcakes measured the external appearance (tops) of the cakes. No correlations were observed between the sorghum and its blends with the L* values of the cupcake tops. Nevertheless, cupcakes made with the ZAM 912 blend had a darker hue than that of RCV and Native varieties (Fig. 21). This was observed in the color for flour mixes previously analyzed (Fig. 18) where the same varieties had a lighter color than that of ZAM 912.

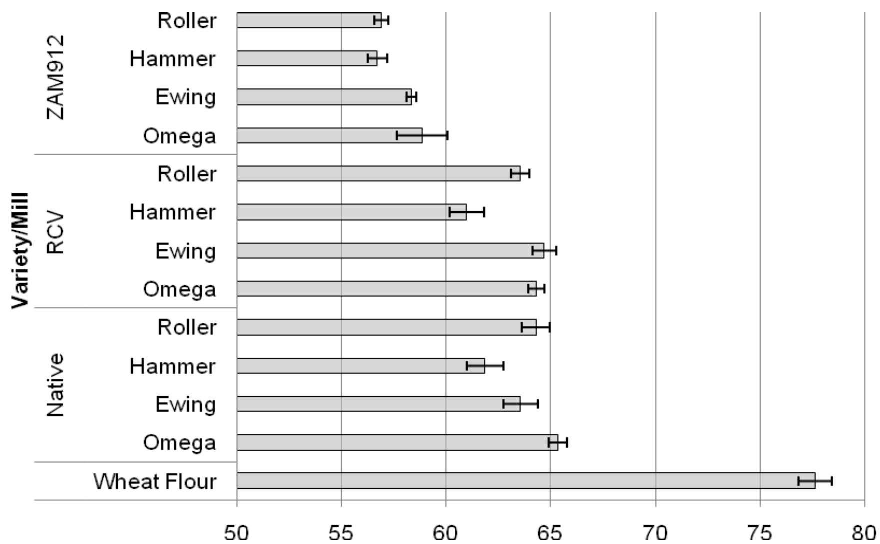

Fig. 21. L* value (L indicates lightness) for cupcake tops from flour of each variety/mill combination. Error bars represent standard deviation.

A weak negative correlation was seen for the a* value between the sorghum flour (-0.53) and its blends (-0.45). The inversely related trend among these could be due to the confounding effect of browning that occurs in the crust during baking by intensifying the red hues of the sorghum flours and the blends (Fig.22).

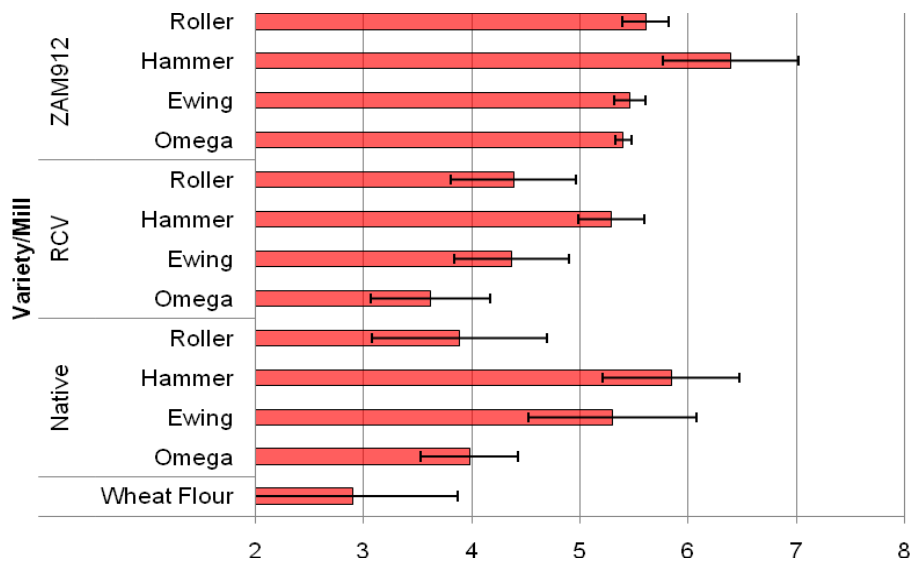

Fig. 22. a* value (a indicates hue on a green (-) to red (+) axis) for cupcake tops from flour of each variety/mill combination. Error bars represent standard deviation.

Like the L*values, no correlations were observed either between the sorghum and its blends with the b* values of the cupcake tops. No specific trend was observed among the three varieties (Fig. 23). However, yellow hue was higher for ZAM 912 and the Native varieties.

In general, absence of strong correlations among these samples could be due to effect of baking (surface browning reactions). Limitation of samples to perform the remaining physical tests precluded the measurement of color for the cake crumb.

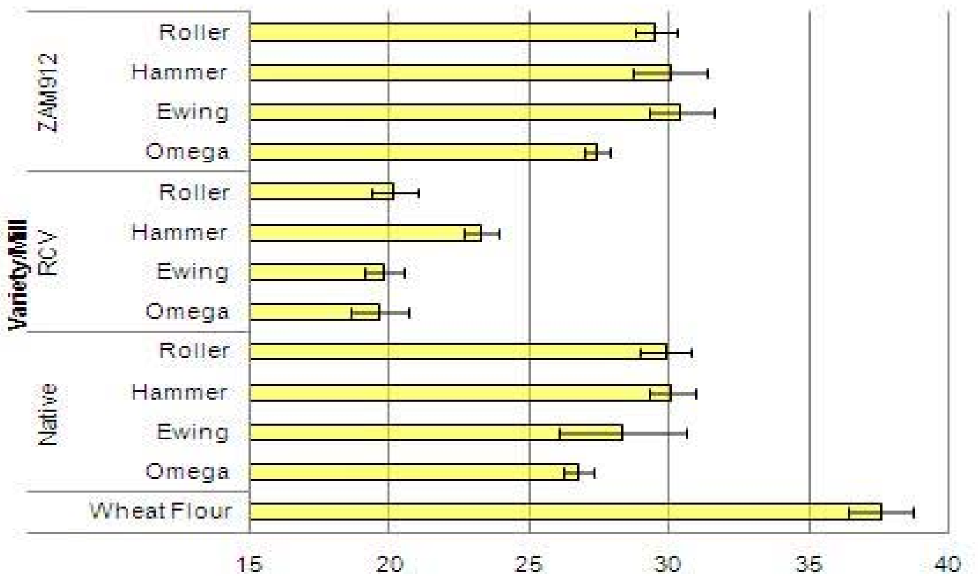

Fig. 23. b* value (b indicates hue on a blue (-) to yellow (+) axis) for cupcake tops from flour of each variety/mill combination. Error bars represent standard deviation.

Nevertheless, Figs. 24, 25 and 26 depicted the color variation among the different variety/mill product images for the crumb, the whole cupcake, and the cupcake tops respectively. These can be visually related to the previous trends observed in color for the sorghum flour and the blends. The subjective evaluation for crumb color for the control wheat cupcake was the lowest score (1). Native variety followed with an average score of 2 and hence lightest crumb color of the three varieties. Conversely, highest score (5) was given to the ZAM 912 cupcakes; it had the darkest crumb hue of the three varieties. RCV had average scores (3) for medium crumb hue; it was slightly darker than native, but less opaque than ZAM 912. Milling method had an effect on crumb color as well. Degree of crumb ‘specky’ appearance is noticeably higher for the cupcakes made with hammer milled grains. Therefore, even though the Native variety had the lightest hue, the cupcake made from hammer milled flour had the highest score of the four cupcakes (2). Conversely, lighter appearance can be observed for the finer particle flours, i.e. cupcakes from roller milled flours. This cupcake crumb had the lowest score (1), which is close to the control crumb appearance.

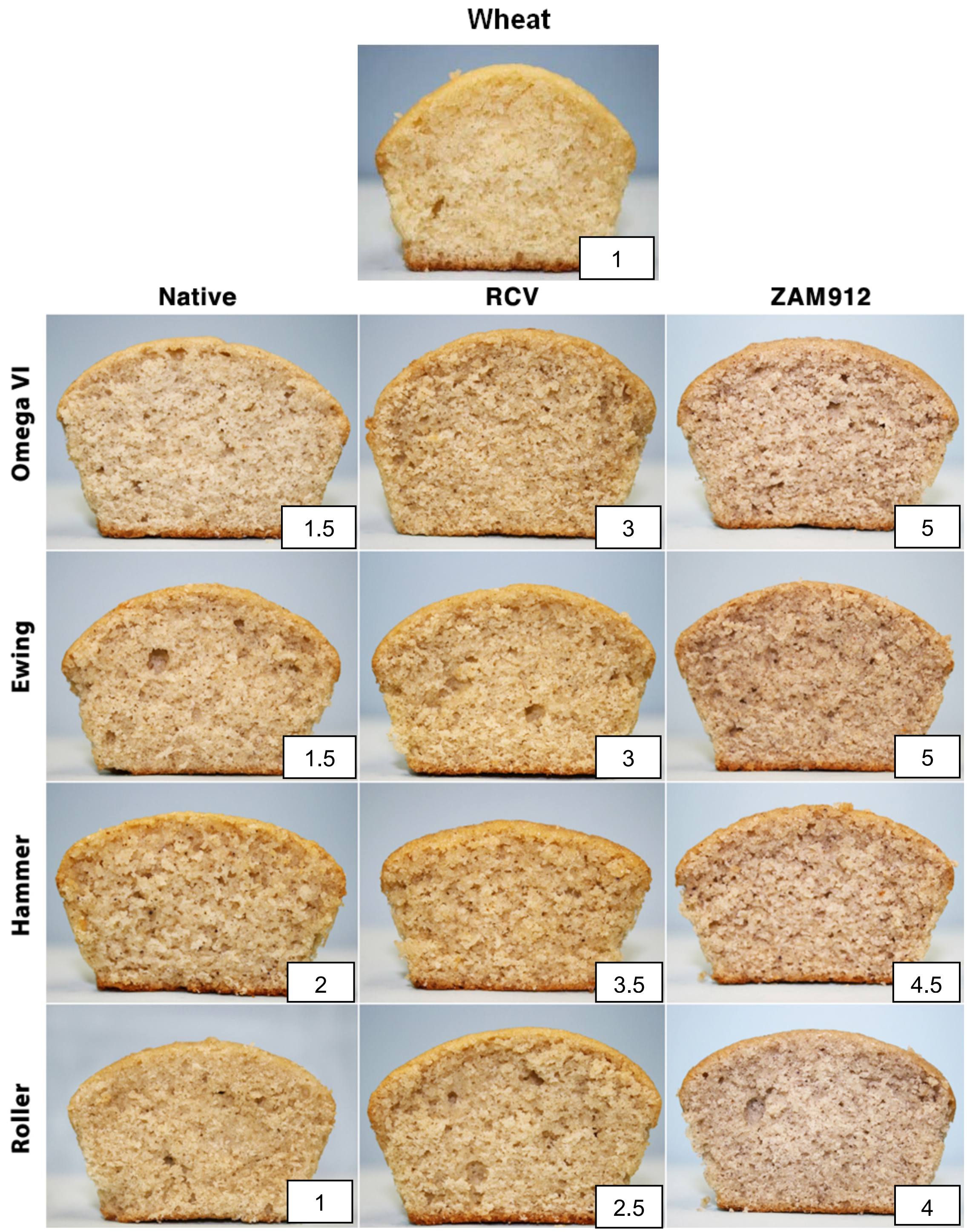

Fig. 24. Cupcake crumb sample from wheat cupcake control (top center) and each variety (columns)/mill (rows) combination. Numbers in the corner of each product image corresponds to its subjective color score on a 1 to 5 basis: 1= light, 5= dark.

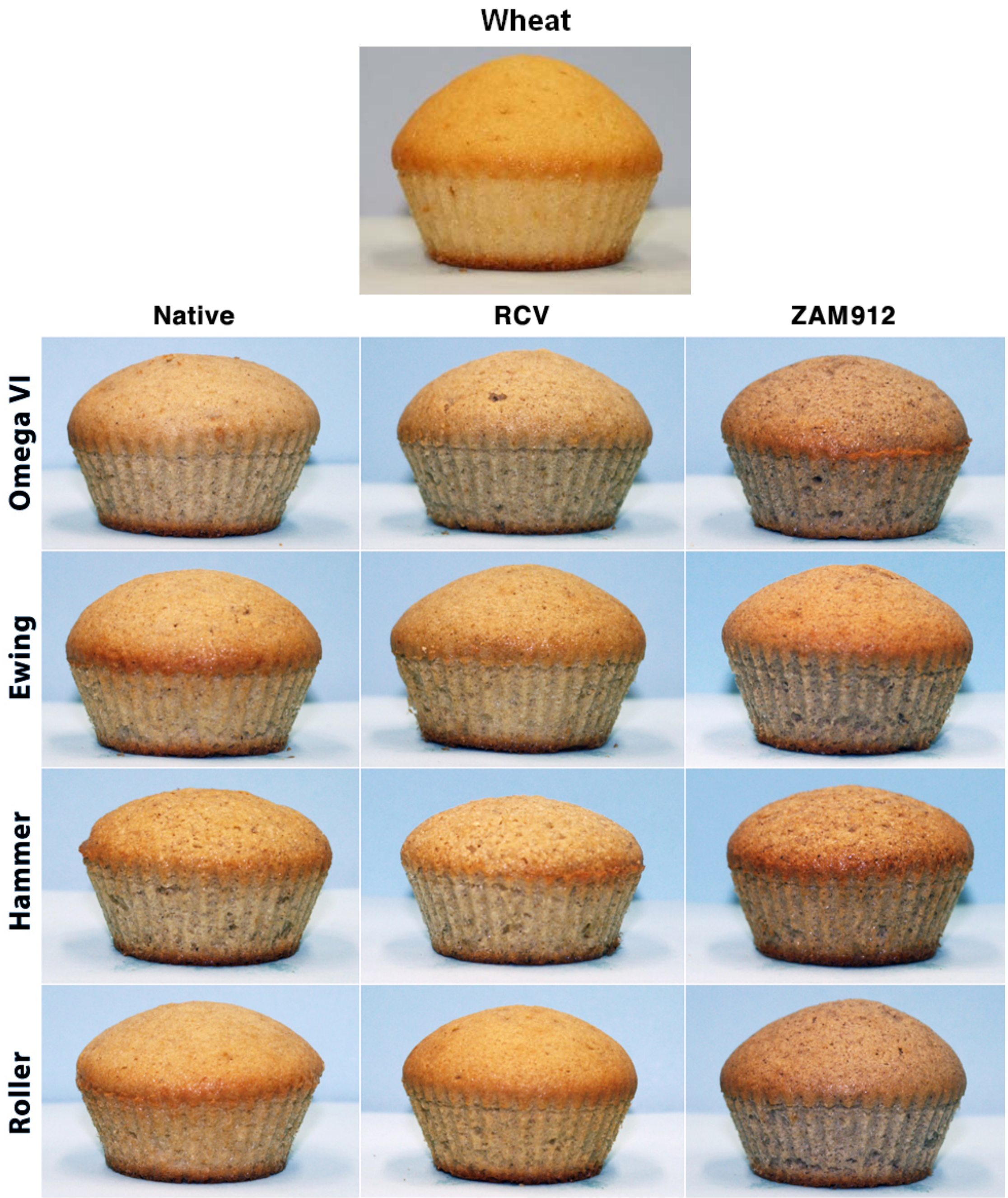

Fig. 25. Whole cupcake sample from wheat cupcake control (top center) and each variety (columns)/mill (rows) combination.

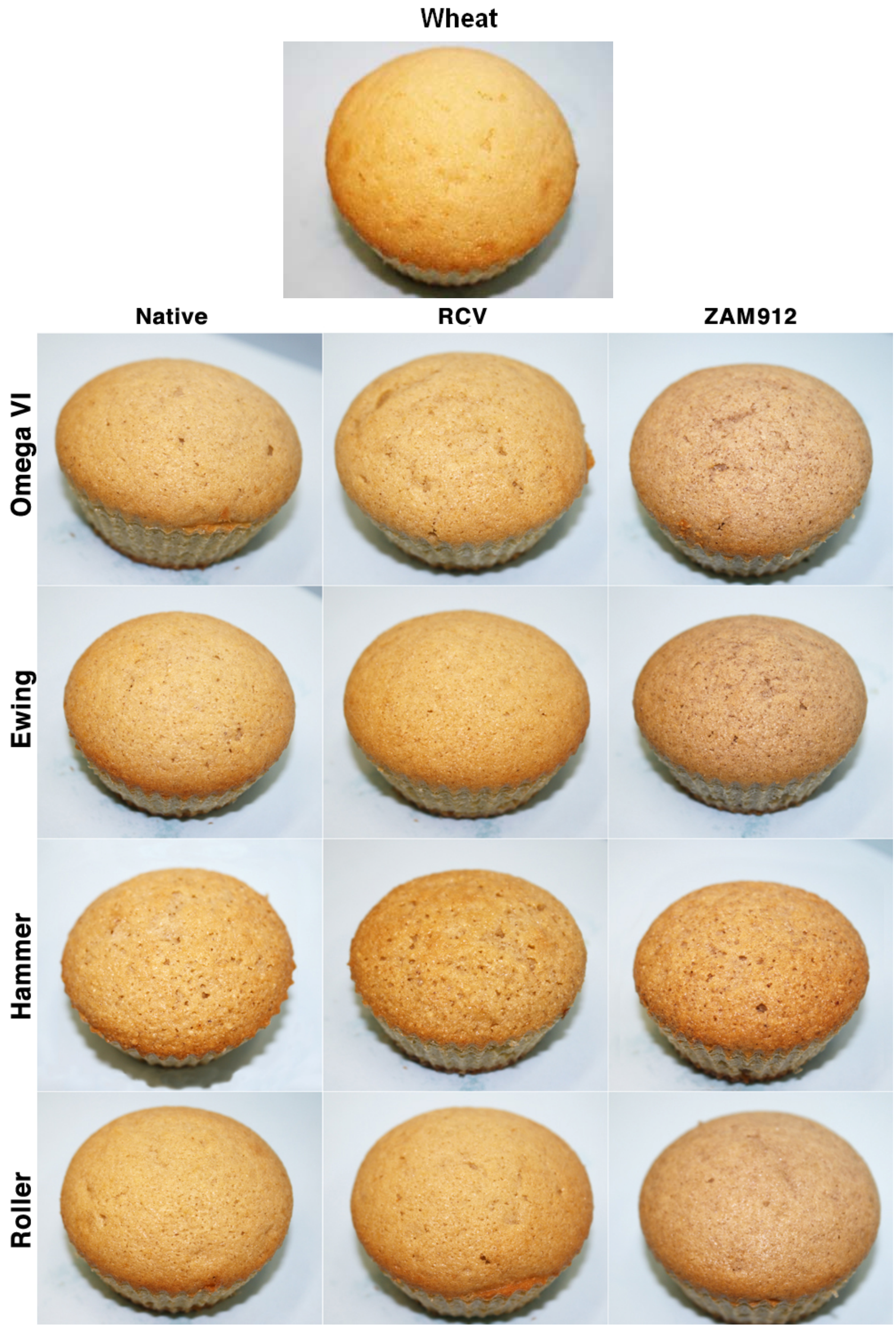

Fig. 26. Cupcake top sample from wheat cupcake control (top center) and each variety (columns)/mill (rows) combination.

Texture analysis showed a significant difference in hardness among cupcakes produced from the Hammer mill flours (Fig. 27). They were consistently harder than the cupcakes made with the other whole sorghum flours.

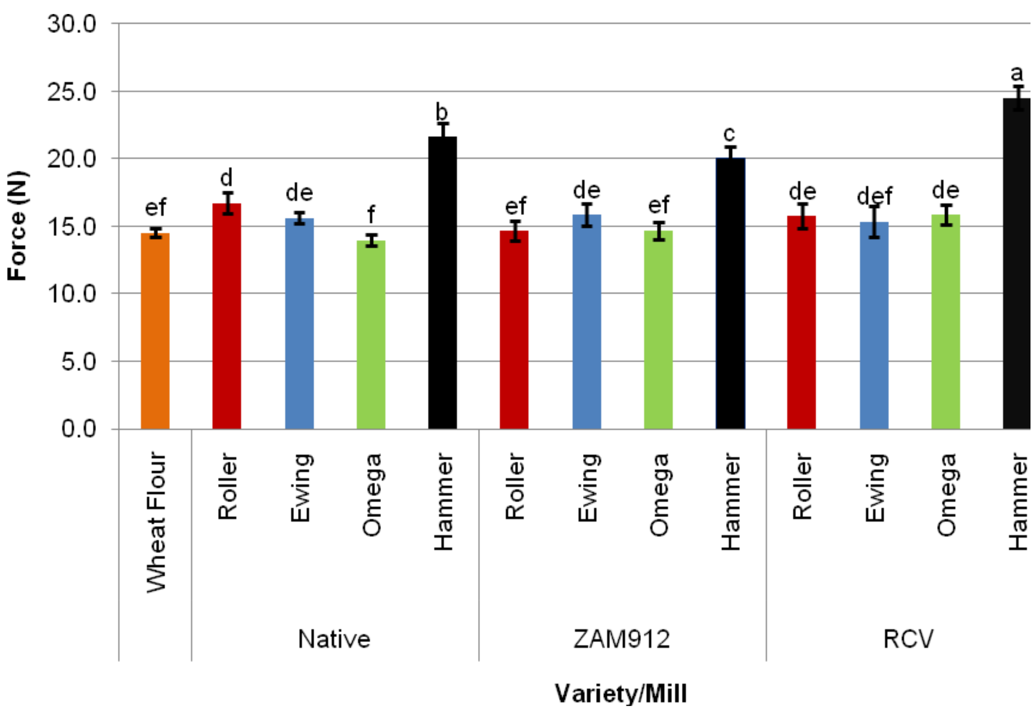

Fig. 27. Hardness of cupcakes made with flour from each variety/mill treatment. Bars with same letter for each column are not significantly different, α= 0.05. Error bars represent standard deviation.

Cupcakes from the hammer milled flours were expected to be more susceptible to the plate force. The proportion of coarse particle size was higher for these cupcakes, which would interfere with the formation of a continuous crumb structure. Measurements over time could have resulted in detecting this effect. These tests were not done since these products are usually made and consumed fresh. Hence, it is not of significance to the current consumption of the product. For the roller mill and the burr mills -Ewing and Omega- no significant differences in texture were observed among the cupcakes produced from these flours.

Cupcake springiness did not show a correlation with grain hardness. A slight numerical decrease in springiness of cupcakes was observed for blends made from softer grain varieties (~13 mm) to the harder grain variety (~12 mm) (Table V).

Strong correlations between grain characteristics T.A.D.D. ($r=-0.89$, $P \leq 0.0001$), Hardness index ($r=0.89$, $P \leq 0.0001$), endosperm texture ($r=0.93$, $P \leq 0.0001$), RVA grain hardness method – Peak viscosity ($r=-0.88$, $P \leq 0.0001$) and RVU/min ($r=-0.93$, $P \leq 0.0001$) and cupcake hardness were detected. Cupcake volume and grain hardness also had strong correlations: T.A.D.D. ($r=0.81$, $P \leq 0.0001$), Hardness index ($r=-0.89$, $P \leq 0.0001$), endosperm texture ($r=-0.81$, $P \leq 0.0001$), RVA grain hardness method – Peak viscosity ($r=0.78$, $P=0.0001$) and RVU/min ($r=0.76$, $P=0.0002$). These correlations suggest a strong effect of grain hardness on final product quality; hard grains result in lower cupcake volume and a harder texture.

Therefore, hard grain flours do not seem very advantageous in cupcake production applications, since softer and lighter texture is expected in this type of products. However, this may not affect its use in bakery products of relatively harder texture, i.e. *pepereche* or *semita* and cookies (Fig. 28).

Table V. Volume, hardness and springiness of cupcakes made for each variety/mill treatment*

Variety	Mill	Volume Index	Hardness (N)	Springiness (mm)
Control		106.7 [a]	14.5 [ef]	13.3 [a]
Native	Ewing	103.8 [bc]	15.6 [de]	13.1 [ab]
	Hammer	100.5 [e]	21.6 [b]	13.1 [ab]
	Omega	104.6 [bc]	14.0 [f]	13.2 [a]
	Roller	104.2 [bc]	16.7 [d]	12.9 [abc]
ZAM912	Ewing	103.4 [bc]	15.9 [de]	12.7 [bc]
	Hammer	101.1 [ed]	20.1 [c]	12.8 [abc]
	Omega	102.8[dc]	14.7 [ef]	12.8 [abc]
	Roller	105.2 [ab]	14.7 [ef]	12.8 [abc]
RCV	Ewing	104.0 [bc]	15.4 [def]	12.7 [bc]
	Hammer	99.3 [e]	24.5 [a]	12.7 [bc]
	Omega	103.3 [bc]	15.9 [de]	12.5 [c]
	Roller	104.8 [abc]	15.7 [de]	12.8 [abc]
Tukey HSD[1]		2.0	1.5	0.4

*Values with same letter for each column are not significantly different, α= 0.05,
[1]Tukey's Honest Significant Difference for means separation (P≤ 0.05)

Fig. 28. *Semita* filled with papaya jam.

CENTA food processing lab has trained people in the use of sorghum in food stuffs for several years (Fig. 29). Sorghum substitution in *semitas* (30%), various sweet breads (50%) and in cookies (100%) has been accomplished. Besides cupcakes and hard crumb pastries, sorghum flours produced with the burr mills have been used at 15-20% substitution in yeast breads (Fig. 30).

Fig. 29. CENTA food processing lab researcher during training of artisan bakers.

Fig. 30. Bread made with 15-20% whole sorghum flour.

Use of sorghum flours has been done in combination with other milled products. Entrepreneurs in El Salvador, for distribution in school lunch programs, have produced dry mixes of whole sorghum with added flavors or in blends with other milled products (i.e. sweet potato flour). Use in ethnic beverages is not limited to rice and corn; *atole*, *tiste*, and *pudin* have used sorghum in these typical Central American beverages. Roasted sorghum grains milled into meal are used in the production of coffee/tea beverage substitutes.

The use of sorghum in snacks and cookies is popular with Salvadorian children. Like the beverages, these deliver increased nutrients including dietary fiber, minerals and vitamins (Fig. 31). Latin American researchers have come to

CENTA for training in the use of this grain in products for children that suffer from autism, celiac disease and as a wheat extender.

Fig. 31. FIMRC clinic children (A, B) consuming sorghum *atole*, a Central American ethnic beverage (C,D).

International organizations (i.e. Food and Agriculture Organization, World Food Program) have become interested in the training of small food manufacturers located in Central America in the use and incorporation of sorghum in their products. It is clear that products made with whole sorghum flour have comparable uses as wheat extenders and beyond bakery products, like corn flour meal where the strong flavor of corn is undesirable.

SUMMARY AND CONCLUSIONS

Sorghum is a drought tolerant crop that affords a degree of food security when maize and other grains are not able to produce enough for human consumption. Sorghum is used alone or in combination with other cereal flours and used in ethnic beverages, *tortillas* and many other cereal based Salvadorian products. Increased wheat prices have augmented demand for an alternative, locally grown, more affordable cereal grain that can be used in foodstuffs. Numerous workshops have been conducted by the CENTA food technology lab, which has significantly increased food use of locally grown sorghum. Some farmers process sorghum into products that are sold in village markets and provide financial security to their family. This thesis has evaluated many factors affecting sorghum flour production and its use in a variety of products.

Milling of sorghum into flour is more efficient with the use of small burr mills that are inexpensive and have been accepted by many processors. Salvadorian sorghum has the capability of producing high quality flour. Cultivar used depends on the type of product that is desired. High correlations between grain hardness and product quality (volume and hardness) demonstrate that endosperm texture impacts the final product. Softer grains produce lighter flour color due to their soft endosperm. Locally produced sorghums are used in the production of foods with lighter crumb, e.g. breads and cakes. Harder grains generate flours with grittier texture, due to the high proportion of hard endosperm. RCV variety appears to be more suitable for production of coarse crumb products, e.g. cookies. Grains that produce flour with darker hues, like ZAM 912, may not be as suitable in the production of light colored bakery products. However, they would be useful in products with darker hue, e.g. chocolate cakes, cookies, multi-grain muffins.

The type of equipment used to produce flour is important. Particle size affects the quality of the product, which depends on the type of equipment used. Roller milling delivers the lowest proportion of coarse particles of the four mills tested. However, industrial operations focused on roller milling of sorghum are scarce and too expensive for small entrepreneurs using sorghum flour. Hammer mills are a practical solution in terms of lower cost than the roller mill. However, hammer milled flours have large particles that must be sifted before it is used in bakeries or further milled using burr mills to produce good flour.

Burr milled flour resembled the behavior of roller milling by reaching peak viscosity and pasting temperature at similar times. Unlike roller and hammer mills, burr mills offer low cost affordable technology that can be used by small millers. Other application is its use in hammer milled flours, which can result in production of high volume of product in a shorter time than just burr milling. Use of this technology in artisan baker’s cooperatives has permitted favorable economics for their businesses.

Future research should involve investigation of the behavior of flours produced from combined processes (i.e. hammer mill followed by burr mills). As entrepreneurs become interested in larger production and distribution of sorghum flours, studies on flour milling yields and keeping quality of these flours will be useful. Likewise, if larger Salvadorian food production industries become interested in mass production of sorghum baked goods, assessment of shelf life of diverse sorghum products and appropriate packaging materials will be needed.

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APPENDIX A

Table A-1. Nutritional Content of ADM Commercial Flour from US white sorghum hybrids grown in Texas.

Item	White Whole Grain Sorghum Flour (Per 100g)	Decorticated White Sorghum Flour (Per 100g)
Calories	345.07	348.55
Calories from Fat	29.00	13.26
Total Fat (g)	3.22	1.47
Saturated Fat (g)	0.56	0.32
Trans Fatty Acid (g)	0.00	0.0
Polyunsaturated (g)	1.69	0.71
Monounsaturated (g)	0.98	0.44
Cholesterol (mg)	0.00	0.00
Sodium (mg)	60.00	20.00
Total Carbohydrates (g)	77.56	80.24
Total Dietary Fiber (g)	11.46	7.83
Soluble Fiber (g)	3.33	2.33
Insoluble Fiber (g)	8.13	5.50
Sugars (g)	2.10	1.00
Protein (g)	9.57	9.06
Vitamin B2 (mg)	1.48	1.52
Folic Acid (mg)	0.27	0.18
Calcium (mg)	11.50	8.50
Iron (mg)	3.60	0.40
Moisture (g)	9.35	9.55
Ash (g)	1.14	0.47

Results tabulated by independent laboratory. Printed with permission from Archer-Daniels Midland.

Table A-2. United Sorghum Check Off program 2010 report: commodity sorghum compared to the WHO RNI of children ages 1-9 years

Nutrient	Commodity Sorghum (100g)	RNI 1-3 y	%RNI 1-3y	RNI 4-6y	%RNI 4-6y	RNI 7-9y	%RNI 7-9y
Energy (kcal)	339	997	34	1301	26	1629	21
Protein (g)	11.3	12.3	92	16.65	68	26.05	43
Total Fat (g)	3.3						
Carbohydrate (g)	74.6						
Fiber (g)°	2.7						
Calcium (mg)	28	500	6	600	5	700	4
Iron(mg)	4.4	5.8	73	6.3	70	8.9	49
Magnesium (mg) °	0.19	60	<1	76	<1	100	<1
Phosphorous (mg)	287						
Potassium (mg)	350						
Sodium (mg)	6						
Zinc(mg)°	1.54	4.1	38	4.8	32	5.6	28
Copper (mg)°	1.08		**		**		**
Manganese(mg)°	1.63		**		**		**
Iodine (ug)	n/a	90		90		120	
Selenium (mcg) ∞	trace	17	<1	22	<1	21	<1
Vitamin C (mg) δ	2	30	<1	30	<1	36	<1
Thiamin (mg)	0.237	0.5	40	0.6	40	0.9	26
Riboflavin (mg)	0.142	0.5	24	0.6	24	0.9	16
Niacin (mg)	2.927	6	37	8	37	12	24
Pantothenate (mg)°	1.25	2	42	3	42	4	31
Vitamin B6 (mg)°	0.59	0.5	98	0.6	98	1	59
Total Folate (mcg)°	0.02	150	<1	200	<1	300	<1
Vitamin B-12 (mcg)	0	0.9	0	1.2	0	1.8	0
Biotin (ug)	n/a	8		12		20	
Vitamin A (IU)δ	16	1333	<1	1500	<1	1666	<1
Vitamin D (ug)	n/a	5		5		5	
Vitamin E a-TE (mg)°	1.2	5	<1	5	<1	7	<1
Vitamin K (mcg)	n/a	15		20		25	

RNI = Reference Nutrient Intake

FAO/WHO Expert Consultation on Human Vitamin and Mineral Requirements 1998

FAO/WHO/UNU Report of Joint Expert Consultation on Human Energy Requirements, 2001

WHO/FAO/UNU Protein and Amino Acid Requirement in Human Nutrition. 2007

Nutrient Data from Commodity Reference Guide, with additional published sorghum data as noted.

°Waniska and Rooney (2000)

∞Neucere and Sumrell (1980)

ðBarrow -Agee Laboratories, LLC, Memphis, TN (2010)

*Iron RNI based on 10% bioavailability; Zinc RNI based on moderate bioavailability

n/a = not applicable or not available

Good Source = 10-19% of RNI; Excellent Source = 20% of RNI

**Using US RDA of 1.5 mg of copper and 440 mcg for manganese, the percent RDA for children 4-8 years of age for manganese (1.63mg/100g) is 92% and for copper (1080 mcg) is 245%

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APPENDIX B

Table B-1. Particle Size Distributions of each variety/mill flour*

Variety	Mill	Weight (%) - Particle size distribution (mm)					
		0.841 (# 20)	**0.425 (# 40)**	**0.250 (# 60)**	**0.180 (# 80)**	**0.150 (# 100)**	**<0.150 Pan**
Native	Ewing	0.04	2.0	16.3	36.8	15.6	27.7
		(0.03)[1]	(0.5)	(0.9)	(0.2)	(3.5)	(5.1)
	Hammer	3.99	19.7	29.6	13.7	22.6	9.0
		(0.10)	(0.2)	(0.1)	(0.8)	(1.9)	(1.2)
	Omega	0.05	6.5	50.2	19.6	7.6	11.8
		(0.01)	(0.2)	(5.9)	(2.7)	(1.7)	(2.0)
	Roller	0.01	7.3	43.7	18.7	9.0	18.5
		(0.01)	(2.5)	(3.7)	(0.7)	(0.6)	(0.2)
ZAM912	Ewing	0.08	2.7	29.6	26.2	19.8	20.3
		(0.03)	(1.0)	(4.1)	(1.1)	(2.1)	(1.7)
	Hammer	1.88	18.0	36.7	15.6	7.9	18.4
		(0.2)	(1.2)	(0.0)	(1.8)	(1.6)	(1.5)
	Omega	0.20	3.6	41.3	29.1	9.4	13.4
		(0.03)	(0.9)	(2.9)	(0.3)	(2.0)	(1.4)
	Roller	0.0	2.4	11.1	35.4	23.7	25.3
		(0.00)	(0.8)	(5.1)	(0.6)	(3.6)	(0.3)
RCV	Ewing	0.05	2.1	27.9	27.3	16.3	25.3
		(0.01)	(0.5)	(0.1	(0.2	(0.5)	(0.6)
	Hammer	5.32	24.2	32.1	9.7	7.1	21.0
		(0.00	(0.0)	(0.2)	(0.1)	(0.1)	(0.7)
	Omega	0.19	4.1	34.1	27.2	14.7	18.7
		(0.16)	(1.7)	(7.7)	(3.5)	(2.6)	(2.7)
	Roller	0.00	1.6	3.0	17.7	38.8	35.4
		(0.00)	(0.2)	(0.7)	(0.9)	(0.9)	(0.8)

* Values are means of two observations calculated as percent over for each sieve.
[1] Standard deviation

Table B-2. Sorghum Flour cooking properties for each variety and mill*

Variety	Mill	Peak Viscosity (RVU)	Peak Time (min)	Pasting Temperature (°C)	Holding Strength (RVU)	Breakdown (RVU)	Final Viscosity (RVU)	Setback (RVU)
Native	Ewing	607.0 [b]	5.0 [f]	76.5 [ed]	344.9 [cbd]	262.2 [b]	673.2 [g]	463.0 [e]
	Hammer	427.7 [h]	5.6 [c]	81.4 [c]	317.6 [fed]	110.1 [e]	697.2 [f]	519.0 [d]
	Omega	657.6 [a]	4.8 [f]	74.7 [f]	338.3 [ced]	319.3 [a]	639.7 [h]	429.3 [f]
	Roller	612.2 [b]	5.3 [de]	77.1 [ed]	407.6 [a]	204.7 [c]	852.7 [bc]	615.7 [c]
ZAM 912	Ewing	516.3 [d]	5.5 [dc]	77.2 [ed]	352.5 [cb]	163.8 [d]	788.7 [e]	593.9 [c]
	Hammer	361.0 [i]	6.0 [b]	87.5 [b]	302.4 [f]	58.6 [f]	661.9 [g]	491.9 [ed]
	Omega	519.9 [d]	5.5 [dc]	77.5 [d]	361.3 [cb]	158.6 [d]	809.4 [d]	610.0 [c]
	Roller	533.4 [c]	5.6 [c]	77.3 [ed]	369.1 [b]	164.4 [d]	797.0 [ed]	587.4 [c]
RCV	Ewing	466.0 [g]	5.4 [dce]	77.1 [ed]	344.2 [cbd]	121.9 [e]	864.1 [b]	692.8 [b]
	Hammer	268.5 [J]	7.9 [a]	91.1 [a]	268.50 [g]	0.0 [g]	579.8 [i]	311.3 [g]
	Omega	480.2 [f]	5.2 [e]	76.6 [ed]	313.1 [ef]	167.1 [d]	836.1 [bc]	690.2 [b]
	Roller	500.5 [e]	5.3 [de]	77.1 [ed]	344.1 [cbd]	156.4 [d]	927.8 [a]	769.3 [a]
Tukey HSD[1]		12.4	0.2	0.9	27.5	22.0	19.1	31.4

*Values with same letter for each column are not significantly different, α= 0.05,
[1]Tukey's Honest Significant Difference for means separation (P≤ 0.05)

Table B -3. Sorghum-Wheat blend cooking properties for each variety and mill*

Variety	Mill	Peak Viscosity (RVU)	Peak Time (min)	Pasting Temperature (°C)	Holding Strength (RVU)	Breakdown (RVU)	Final Viscosity (RVU)	Setback (RVU)
All-Purpose Wheat Flour		754.1^{a}	6.0^{bc}	67.2^{i}	447.2^{ab}	306.9^{a}	685.3^{e}	238.0^{g}
Native	Ewing	654.4^{b}	5.7^{d}	73.8^{g}	334.6^{ef}	319.9^{a}	628.9^{f}	294.3^{ef}
	Hammer	527.8^{g}	5.7^{d}	76.7^{c}	346.6^{e}	181.2^{c}	647.6^{ef}	301.0^{e}
	Omega	617.1^{ed}	5.6^{d}	69.9^{h}	299.4^{g}	317.6^{a}	582.1^{g}	282.7^{f}
	Roller	669.1^{b}	6.0^{bc}	76.3^{c}	427.6^{bcd}	241.5^{b}	849.2^{bc}	421.6^{b}
ZAM 912	Ewing	626.9^{cd}	6.1^{ab}	74.0^{g}	434.1^{bc}	192.7^{c}	837.3^{bc}	403.2^{c}
	Hammer	529.9^{g}	5.9^{c}	79.4^{b}	415.8^{bcd}	114.2^{e}	792.6^{d}	376.8^{d}
	Omega	625.6^{cb}	6.1^{ab}	74.9^{ef}	444.0^{b}	181.6^{c}	859.3^{b}	415.3^{bc}
	Roller	648.3^{cb}	6.1^{abc}	76.1^{cd}	478.4^{a}	169.9^{cd}	974.7^{a}	496.3^{a}
RCV	Ewing	571.9^{f}	6.1^{ab}	75.3^{de}	397.0^{d}	174.9^{cd}	812.0^{cd}	415.0^{bc}
	Hammer	420.4^{h}	6.1^{ab}	81.2^{a}	313.0^{eg}	107.4^{e}	673.9^{e}	360.9^{d}
	Omega	560.9^{f}	6.2^{ab}	74.1^{fg}	408.6^{cd}	152.3^{d}	828.4^{bcd}	419.8^{bc}
	Roller	595.6^{e}	6.2^{a}	76.2^{cd}	402.2^{cd}	193.4^{c}	828.9^{bcd}	426.7^{b}
Tukey HSD[1]		22.5	0.2	0.9	32.5	24.7	44.7	17.6

*Values with same letter for each column are not significantly different, α= 0.05,
[1]Tukey's Honest Significant Difference for means separation (P≤ 0.05)

APPENDIX C

Wheat Flour Characterization

The U.S. wheat flour used for the flour blend cooking characterization and in the cupcake formula was compared to the Salvadorian all purpose wheat flour. This was done to assure both flours had good mixing properties.

Evaluation of protein and moisture content of the U.S. and the Salvadorian all-purpose wheat flour was done using Near-Infrared Reflectance spectroscopy. NIR 6500 spectrophotometer was used in accordance to Approved Method 39-21 from the American Association of Cereal Chemist (AACC) (2000). Mixograms (AACC Method 54-40.02) were used as well to measure quality of wheat flours by observing peak time and mixing tolerance. Short peak time and mixing tolerance (length of the curve) were observed in flours with weak gluten development.

Results showed that there was a slight numerical difference in protein content of the samples. U.S. flour was 0.5% lower in protein content than the Salvadorian flour (12.02%). Moisture content for both flours was 13%. However, mixograph evaluations showed a peak point at the 4.5 min mark for both flours and similar mixing tolerance (Figs. C-1 and C-2). This means that the 2 flours had slightly different protein content (%) but have similar mixing performance (peak time, 4.5 minutes) and intermediate gluten development (short curve length).

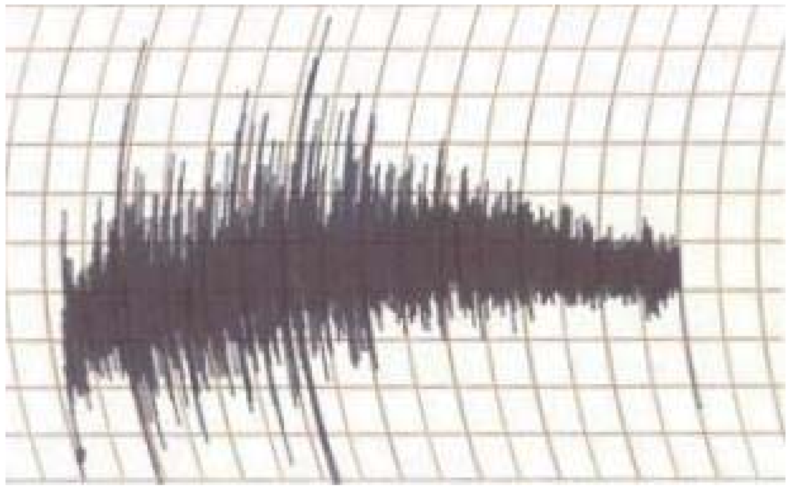

Fig. C-1. Salvadorian all-purpose wheat flour mixogram. (Protein: 12 %)

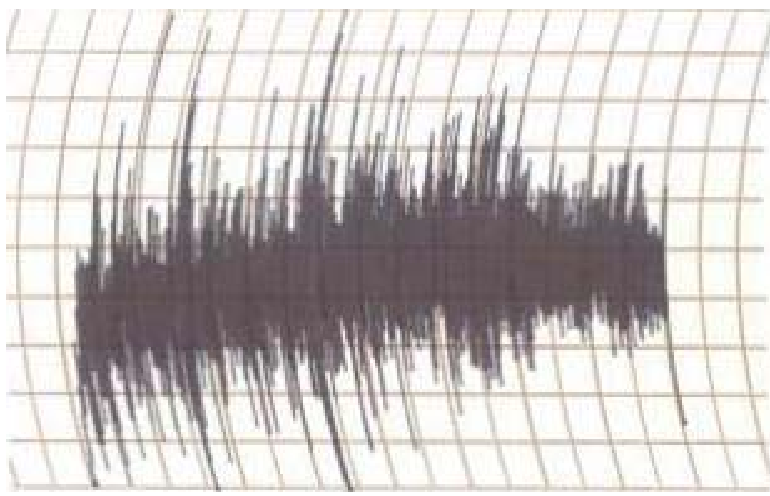

Fig. C-2. U.S. all-purpose wheat flour mixogram.(Protein 11.5 %)

VITA

Luz Eliana Pinilla received her Bachelor of Science degree in Food Science and Technology from Purdue University in 2007. She entered the Intercollegiate Food Science and Technology program at Texas A&M University in August 2008 and received her Master of Science degree in December 2010. For her thesis research, she had the opportunity to visit El Salvador on two separate occasions through sponsorship of INTSORMIL and Winrock International. During her trips, she had the opportunity to develop collaborative research with CENTA food processing lab researchers in the effort to increase utilization of the local crop –sorghum- in the manufacturing of foodstuffs. Her research interests include cereal milling technology and role in food security. She plans to become further involved in topics that engage the use of food technology in the improvement of quality of life in under developed countries.

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