CHANGES IN QUALITY OF WHOLE COOKED SORGHUM [*Sorghum bicolor* (L.) Moench] USING PRECOOKING METHODS

A Thesis

by

VILMA RUTH CALDERON DE ZACATARES

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 2007

Major Subject: Food Science and Technology

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ABSTRACT

Changes in Quality of Whole Cooked Sorghum
[*Sorghum bicolor* (L.) Moench] Using Precooking Methods.
(December 2007)

Vilma Ruth Calderon de Zacatares,
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Four sorghum cultivars (white, sumac, high tannin and black) differing in kernel characteristics were evaluated for cooking quality using whole, cracked and decorticated kernels. Whole grain had longer minimum cooking time (MCT) and lower water uptake. MCT ranged from 20 to 55 min for all varieties. Soluble solid loses (SSL) were lower than for cracked grain (1.0 to 1.5%). Formation of a gruel-like texture, darker pericarp color, splitting and agglomeration of kernels occurred especially for white grain.

Cracked sorghum had shorter MCT (8.8. to 17.5 min) but produced higher SSL (1.3 to 2.9%). Changes in color and appearance due to leaching of pigments especially for the sorghums with a pigmented testa occurred. Utilization of decorticated kernels reduced MCT (11 to 25.3 min), but nutritional value is affected with the removal of the pericarp, plus the SSL (0.5 to 0.7%) produced during cooking.

The long grain rice types have comparatively lower values in terms of MCT (22 min) than whole sorghum and SSL are similar to values obtained for cracked grain (1.7 to 2.2%) showing a minimum of splitting. Short and medium rice grain shows relatively long cooking time (30 to 35 min) but no longer than cracked or decorticated sorghum and produced higher SSL (28% to 40%) during processing, showing extensive disintegration.

When sorghum was precooked; cooking quality improved. The combination of dry heat and microwave reduced MCT and SSL from 31 to 49% and 6.6 to 41.3%, respectively for all varieties compared to the control. This treatment produced grain with softer texture, increased dietary fiber and higher antioxidant activity retention (67.8%) for the tannin varieties than the control (22.7%).

Evaluations of cooking quality of whole sorghum and the application of precooking process have more applications than just preparation of rice-like products. Whole boiled sorghum could be used in the elaboration of nutraceutical foods like an ingredient for yogurts, desserts or side dishes like exotic salads with other cereals. The inclusion of whole boiled sorghum as an ingredient in foods is promising with excellent potential health benefits.

DEDICATION

This thesis is dedicated
To the lord, my God, my ever present help.

"Trust in the Lord with all your heart and lean not on your own understanding;
in all your ways acknowledge him, and he will make your paths straight"
(Proverbs 3:5.6)

To the memory of my beloved parents
Juan Francisco Calderon Celis and Juana Chinchilla de Calderon
This accomplished goal is dedicated to them

To my husband,
Pedro Antonio
Whose love, trust and encouragement never failed.

And
To my family and friends.

ACKNOWLEDGMENTS

All my gratitude to Dr. Rooney for his guidance, patience and trust. He is the best professor that I ever had and better person. Thanks Dr. Lloyd Rooney for making possible the accomplishment of this goal.

Immense gratitude goes to Dr. Ralph Waniska, even though he was fighting for his life; he was always there providing ideas and suggestions to improve this research. This thesis is dedicated to his memory. Thanks to Dr. Cisneros and Dr. Bill Rooney for serving in my committee.

Thanks to Cassandra for her friendship and support. Thanks for being there always for me when I most needed.

Special thanks to our dear friend Fred Muhlheim. Fred, you are like an angel that God sent to our lives. Without your help this adventure in College Station couldn't be possible. God bless you.

Many thanks to the CQL crew: Ana Cardenas, Hway Seen Young, Nomusa Dlamini, David Guajardo, Novie Alviola, Giselle Cedillo, Gigi de Castro, Alejandro Perez, Nengue Nogmeta, Maria Gritsenko, Dylek Austin, Nathan Poland and Lynda Dykes, with whom I shared nice experiences during this almost 3 year journey. Guys, thanks for your friendship, support and for being helpful with the work in the lab. Thanks to Pamela Littlejohn for all her help during this process.

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CHAPTER I

INTRODUCTION

Sorghum [Sorghum bicolor (L.) Moench] is the world's fifth leading grain in production and is staple food for many in Africa, Asia and Central America. In these areas sorghum is used to produce traditional foods or as a substitute for other cereals like corn, wheat or rice in products such as baked goods, beer, tortillas, bread and rice-like products. The amount of sorghum for human consumption is increasing every year in these parts of the world (from 23% in 2000 to 35%) in 2006, (FAO/IAEA, 2007) because sorghum is a versatile, non-GMO, gluten free grain, with a variety of colors and some varieties with bland flavor, similar to rice.

Sorghum is also a good source of dietary fiber and antioxidants (Rooney et al.1986). Dietary fiber aids in treating coronary heart disease and gastrointestinal health through bulking fecal matter, decreasing constipation and reducing the absorption of carcinogenic metabolites (Khairwal et al.1977; Gregory, 1985). Certain sorghums high tannins have high antioxidant levels (Awika, et al. 2000). That abundance of antioxidants in sorghums is important due to the potential benefits of these compounds to human health.

Acceptable whole foods from sorghum have been made from sorghums that have tan plant color, white pericarp, intermediate endosperm structure without a testa and low levels of color precursors. However special black and red sorghums produced specialty products like snacks, tortilla chips, extrudates with unique flavor, texture and health promoting benefits like high antioxidant activity, dietary fiber, minerals and vitamins and could be consumed also as a whole boiled product or as component in other food products. (Serna Saldivar & Rooney, 1995)·

This thesis follows the style and format of Cereal Chemistry.

Whole, cracked or dehulled sorghum kernels are cooked to produce boiled rice-like products. Depending on the length of boiling, sorghum may have various changes in flavor, texture and colors as well as destruction of heat-remain sensitive nutrients and vitamins; also antioxidants are partially extracted and remained in the boiling water (Rumm-Kreuter, 1990).

Standard whole sorghum grain, depending on variety, kernel size and hardness, requires from 30 to 50 minutes to cook when boiled undisturbed (Murty & House, 1981). Physicochemical characteristics of the grain like hardness, size, pericarp thickness and moisture, affect cooking time and cooking quality of boiled sorghum. The relatively long preparation time restricts sorghum consumption in developing countries, where energy, fuel or biomass resources are scarce.

Some precooking treatments (quick cooking methods) applied to the grain prior to cooking can increase hydration rate and partial gelatinization of the grain, reducing cooking time and avoiding solid losses during cooking while improving nutritional value. Treatments like infrared, microwave or dry heating, have been used to reduce cooking time successfully in other cereals and legumes. A quick cooking sorghum with 5 to 20 min cook time would be useful to increase consumption of sorghum as a boiled whole product and at the same time improved its nutritional value.

The objectives of this study were:

1. To determine the cooking quality of whole grain compared with cracked and decorticated sorghum
2. To evaluate the effect of various precooking process on cooking time and physical properties of whole sorghum kernels
3. To determine the effect of cooking time and precooking on nutritional quality and antioxidant activity of whole sorghum

CHAPTER II

COOKING QUALITY OF WHOLE, CRACKED AND DEHULLED SORGHUM

LITERATURE REVIEW

Sorghum kernel structure and composition

The sorghum kernel is a naked caryopsis, varying widely in size and shape; thousand kernel weights vary from 3-80 g. The sorghum kernel is composed of pericarp, endosperm, and germ. The pericarp may be thick or thin and contains wax and pigments. Sometimes a pigmented layer or testa is present just beneath the pericarp; it varies in thickness and color (Serna Saldivar & Rooney, 1995). The pericarp of sorghum grain originates from the ovary and is divided into three histological tissues, the epicarp, the mesocarp and endocarp. The epicarp is the outermost layer and is generally covered with a thin layer of wax. The mesocarp contains starch granules and is different from that of most cereals. The endocarp is the internal layer, composed of cross and tube cells (Waniska & Rooney, 2000)

The endosperm is composed of the aleurone layer, peripheral, corneous and floury areas. The aleurone is the outer layer and consists of a single layer of rectangular cells adjacent to the testa or tube cells with large amounts of proteins, ash and oil. The peripheral starchy endosperm is composed of several layers of cell walls containing more protein bodies and smaller starch granules. The corneous and floury endosperm cells are composed of starch granules, a protein matrix, protein bodies and cell walls (Serna Saldivar & Rooney, 1995). In a corneous type endosperm, starch and protein form a compact structure; floury endosperm shows a rather loose arrangement of protein and starch because the protein matrix binding them together is not continuous (Waniska & Rooney, 2000). The germ is the remaining part of the kernel and represents approximately 10% of the total dry weight.

The color of sorghum grain is a combination of primarily anthocyanins and other flavonoids located in the pericarp and or in the pigmented testa if one is present. The R and Y genes determine the pigmentation. The seed coat (testa layer) may be highly pigmented, a characteristic that is genetically controlled (Rooney et al. 1992). In high Tannin sorghums the testa is pigmented which is controlled by the complementary B_1, B2 genes (Rooney & Murty, 1987).

Sorghum proximate composition varies significantly due to genetics and environmental factors. The protein content is usually the most variable. It is lower in oil than corn and usually has higher protein than corn.

The pericarp is rich in fiber, whereas the germ is high in crude protein, fat and ash. The endosperm contains mostly starch and protein with small amounts of oil and fiber. Some sorghum contains condensed high tannins, but most sorghum varieties do not.

The carbohydrates are composed of starch, soluble sugars, pentosans, cellulose and hemicellulose. Starch is the most abundant chemical component, while soluble sugars and crude fiber are low (Duodu et al. 2002). Starch exists in highly organized granules in which amylose and amylopectin molecules are held together by hydrogen bonding.

Regular endosperm sorghum types contain 23 to 30% amylose. In the native form they are considered pseudo crystals that have crystalline and amorphous areas. The native granules are insoluble in cold water, swell reversibly, exhibit birefringence (rotate the plane of polarized light) and are relative inaccessible to enzyme attack (Rooney & Murty, 1987).

Sorghum starch has a higher swelling power and higher peak and cold viscosity than maize. The gelatinization temperature range as determined by differential scanning calorimetry for sorghum starch is $71C^o$-$80C^o$. Corneous endosperm starch have higher gelatinization temperature and intrinsic viscosity compared to starch isolated from floury endosperm (Serna Saldivar & Rooney, 1995).

Traditional uses of sorghum

Whole sorghum food products are not commonly found in urban and semi urban markets in many regions of the world where this crop is cultivated, probably because of the drudgery involved in their domestic processing and the low prestige attached to them. Sorghum is considered a coarse grain, since it is hard to process. The flour or meal from sorghum is coarse and produces gritty products with a characteristic aroma (Polycarpe Kayoed, 2006). The grains are processed mainly at home using traditional household methods and the techniques used to prepare the grain are intended to mitigate the gritty characteristics of the food due to the hardness of the grain (Blanchet, 1987). Appropriate millings technologies have been developed to mechanically process sorghum but these technologies have not been established in many developing countries, where it is used as a staple food like Africa and Central America.

In general, sorghums are decorticated partially or completely by traditional methods before further processing and consumption. Whole grains might as well be directly dry-milled to give a range of products: broken or cracked grains, grits, coarse meal and fine flour (Bello et al, 1990). The flour thus obtained is used in the preparation of a range of simple to complex food products. Sorghum can be mixed with flours of other cereals such as wheat and rice or legumes to improve palatability, nutritional value and acceptance of the product (Rooney & Murty, 1986).

Porridges of varying consistencies and pH, different types of bread, pancakes, alcoholic and non alcoholic beverages, rice like products (steam-cooked, deep fried) and several other products and processing techniques are used to make many kinds of snacks and other popular foods in Africa, India, Asia and Central America (Rooney & Murty, 1987). These diverse processes affect the flavor, nutritional value and utilization properties of the product.

Boiled rice-like products

In many countries, sorghum is consumed like rice and is a very important component of the daily diet (Blanchet, 1987). Sorghum is often cooked to make boiled rice like products in regions where rice is used but scarce. The product is generally preferred by the rural population and prepared mostly for adults. (Taylor et al, 1997)

Whole, cracked or dehulled grains are soaked overnight and then cooked the next morning. Soaking the grain reduces cooking time and color intensity of the product and improves keeping quality, probably due to partial fermentation. Pearling or dehulling reduces significantly the nutrient content of the grain. Decortication leads to a loss of protein, fiber, fat, ash, high Tannin content and minerals (Osman, 2004) When the grits are used, white sorghum is preferred instead of red; the sorghum is decorticated or pearled, then broken into endosperm pieces. The grain is cooked in water (1:3 ratio) until soft. Flavorings and legumes such as beans, chickpea and groundnut are added (Blanchet, 1987). The cooked product is soft and fluffy with light yellow color and resembles boiled rice. The freshly prepared boiled sorghum product is consumed either as lunch or dinner with vegetables and sauces or used in side dishes like salads, soups and desserts (Rooney et al, 1986).

Pitimi, Annam or Ache, Oko Baba or Soru, Khicuri, Lehata Wagen, Kaohang mi fan and Nufio; are names for boiled pearled sorghum grains or grits that are consumed in countries like Haiti, India, Nigeria, Bangladesh, Botswana, China and Ethiopia, respectively. In India, especially in the south rice-like products are important (Young, 1999).

Whole grain definition and benefits of consumption

There is no universally accepted definition of whole grains. The new Dietary Guidelines, (2005) uses the American Association of Cereal Chemists' definition, which is "foods made from the entire grain seed, usually called the kernel, which consists of the bran, germ, and endosperm. If the kernel has been cracked, crushed, or flaked to be called whole grain, it must retain nearly the same relative proportions of bran, germ, and endosperm as the original grain. The 2005 Dietary Guidelines recommend that Americans consume at least 3 servings (3 oz. or 4g) of whole grains per day instead of refined grains.

The benefits from consumption of whole grains include reduced risk of coronary heart disease, Type II diabetes, and weight control. The array of nutrients in whole grains may work synergistically to lower heart disease risk. Whole grains contain fiber, B-vitamins, vitamin E, phytonutrients, magnesium, and selenium, which provide antioxidant protection and lowers blood cholesterol.

Dietary fiber from whole grains plays a key role in reducing diabetes risk, though the physiological mechanism is not fully understood. Interestingly, this potential benefit is only apparent for fiber derived from grains, not for fiber from fruit and vegetables (Albertson & Tobleman, 1995). Mechanisms of how whole grains affect body weight are not well understood, but higher intakes of fiber from whole grains are inversely associated with weight gain.

Sorghum cooking quality

Cooking quality of sorghum is affected by physicochemical characteristics of the grain. Factors like endosperm hardness, pericarp thickness, kernel size, moisture content and milling of the grain like cracking or dehulling grain, affect cooking time and quality for many cereal grains and legumes, including sorghum (Murty & House, 1981).

Sorghum requires a much longer cooking time than rice or other cereals, but less than maize and the cooked grain texture are usually firmer than rice. Wills & Ali, (1992) found that cooking time was related to the type of endosperm and grain size. Cooking time varied from 51 to 73 min for the whole grain and was positively correlated with kernel weight, density and grain volume (Sankarapandian, 2000)

Hardness is the most important and consistent characteristic that affected cooking time of grain when cooking quality is determined. Grain hardness has been linked to endosperm structure referring to the ratio of vitreous and floury endosperm sections. Vitreous endosperm has been characterized as a matrix of protein and starch that is tightly packed and strongly adheres to each other while floury endosperm is a more loose association of large and spherical starch granules with small air spaces in between the granules (Waniska & Rooney, 2000).

Small kernels with floury endosperm exhibit better cooking quality characteristics than large kernels with a hard corneous endosperm. A soft endosperm absorbs water at a faster rate than kernels with corneous endosperm due to a less densely packed endosperm structure affecting the ease of hydration during soaking and cooking (Young, 1990). Pericarp thickness is another important factor than affects the water uptake rate during soaking or cooking of whole grain. The rate of water uptake increases with thin pericarp kernels. Pericarp thickness is a genetic factor (Rooney et al. 1986)

Cultivars with soft endosperm had larger percentages of ruptured kernels during cooking of whole grain, which increases soluble solids losses into the cooking broth. This reduces the yield of cooked product because the endosperm disintegrates (Blanchet, 1987)

Considerable reduction of cooking time and increased weight and volume of boiled sorghum kernels (more than 100% of that of whole grains) occurred when pericarp was removed by decortication, but incomplete removal of the testa from the endosperm affected appearance of the cooked product (Sankarapandian, 2000).

The use of cracked kernels reduced cooking time as well but affected the appearance and color of the boiled products due to leaching of pigments into the exposed endosperm during cooking producing darker products. Higher solid losses were found when cracked kernels were cooked due to endosperm disintegration (Rooney et al, 1986).

Endosperm hardness affects the amount of solids lost during cooking. Soft endosperm sorghum varieties demonstrated higher solid losses than hard endosperm kernels. (Young, 1990). Length of cooking affected soluble solids losses as well and the color of the cooked grains (Rooney & Murty, 1987).

Oomah et al, (1981) found that preferred characteristics for boiled sorghum products were kernels with thin white pericarp with no testa, thin peripheral endosperm, corneous endosperm and larger grain. For Pitimi (sorghum product that cooks, looks and tastes like rice); sorghum kernels with corneous endosperm and white pericarp were usually preferred (Blanchet, 1987). Aboubacar and Hamaker (1999) reported that white hard and large sorghum kernels produced good rice-like products like Sori and Pitimi, preferred by consumers in Africa.

Rice cooking quality

Standard milled white rice, depending on variety and grain size (long, medium or short), requires from 20 to 35 min to cook to a satisfactory culinary acceptability when boiled according to usual recipe directions. Different rice varieties required different cooking times and yield different textural characteristics. Variations in cooking conditions also have a significant effect on texture, dryness or pastiness, flavor and general acceptability of the cooked rice.

Some standards of rice quality are observed in all countries. In the U.S. quality in rice is evaluated according to grain size, shape, uniformity and general appearance (color and translucency): milling yields, cooking and processing characteristics. Most rice unlike many other cereals is processed and consumed in whole kernel form and the physical properties of the intact kernels such as size, shape, uniformity and general appearance are of particular significance in describing its quality.

There are wide differences in preference for cooked-rice qualities depending of household preparations, personal and ethnic preferences (Houston, 1976). Long grain rice is quite distinct from medium and short grain rice in cooking and processing characteristics. Long grain is called “hard rice”, usually cook dry and flaky with a minimum of splitting and the cooked grain tends to remain separate. High quality short and medium grain varieties referred to as “soft rice” is more moist and firm when cooked than the long-grain varieties and the grain tend to stick together (Roberts, 1972).

Comparatively high amylose content and a medium high gelatinizing temperature characterize the long grain varieties. Medium and short grain varieties have lower amylose contents and lower gelatinizing temperatures than long grain varieties. Long grain rice is used for canned soups and quick cooking products. Medium and short grain varieties generally are used for making dry breakfast cereals and baby foods, and as and adjunct in brewing. Although long grain is preferred for cooked rice in most areas in the US. (Houston, 1976). Some of the more important uses and processing applications of rice included boiled or steamed rice (milled raw rice, milled parboiled rice, brown rice and quick cooking rice).

MATERIALS AND METHODS

Raw materials

Four sorghum cultivars {Sorghum bicolor (L. Moench} grown in the Texas Agriculture Experiment Station in Lubbock Texas in 2004 were selected for this study. The cultivars differed widely in physical characteristics (Table I; Fig.1).

The grain was bright and sound without weathering. Samples of 5 kg each were cleaned to remove trash, foreign materials, small and broken kernels. Cleaning losses was less than 2% of the original grain weight. The cleaned sorghum had moisture content of 11 ± 0.5%. The material was stored at –4ºC until processed. Raw grain samples were evaluated for color, hardness, physical dimensions and moisture content prior to measurement of cooking quality parameters.

Table I. Descriptive characteristics of sorghum cultivars

Cultivar	Pericarp Color/Thickness	Testa	Plant Color
ATX 635x436	White/thin	no	Tan
High Tannin	Red/thin	yes	Purple
Black	Black/thick	yes	Purple
Sumac	Red/thick	yes	Purple

Figure 1. Raw sorghum materials grown at Texas Agriculture Experiment Station at Lubbock, TX during 2004 season

Sorghum characterization

Color: An objective color measurement of the whole grain was obtained using a Minolta color meter (model CR-300, Osaka, Japan). Color was expressed according to the L a b system where L is lightness (100) or darkness (0), + a is redness, -a is greenness, + b is yellowness and –b is blueness.

Physical dimensions and hardness: The raw sorghum kernels were evaluated using the Single Kernel Hardness Tester (Model SKCS 4100, Perten Instrument Inc. Reno, Nevada) Three hundred individual sorghum kernels were selected and evaluated for average weight (mg), diameter (mm) hardness index and class. Measurements were taken in triplicate for each sorghum type.

Moisture determination: Moisture for raw and cooked kernels was determined using an OHAUS Moisture balance meter (model 6010, Ohaus Scale Corporation, Florham Park, N.J.). A sample of 10 grams of grain was weighed and placed under infrared light for 25 min. The moisture content was determined by weighing the grain after drying. The decreased weight of sorghum kernels was recorded. The physical characteristics are shown in Table II.

RAW MATERIALS PREPARATION

Sorghum cracking

Cleaned sorghum for each variety was cracked using an Attrition grinder (Glen Mills Inc; Maywood, N.J.). The grinder dial was closed at the reading of 10.25. The cracked sorghums were sieved to determine particle size distribution and the particles above sieve # 10 were used to obtain the Minimum Cooking Time (MCT) and cooking quality determinations. Half kernels were removed using a mesh screen. Material loss for cracked varieties was less than 5%.

Sorghum dehulling

Sorghum kernels were dehulled using a Tangential Abrasive Dehulling Device (TADD model 4E-115, Creative Technologies, I.C. Utah). A sample of 20 grams was put in each of twelve holes of the plate and the pearling time was set for 3-½ min. The bran and other fines were retained for addition during cooking.

The dehulled samples were collected with a vacuum sample collector and weighed. The experiment consists of three replications. The yield of pearled grains was calculated as follows:

% P.G.: (Initial Weight-Decorticated kernel Weight/Initial Weight) x 100

Table II. Physical characteristics of sorghum cultivars

Variety	Grain color (L, a, b)			Hard (%). Removal[2]	Hard. Index[1] (%)	Seed Weight (Mg)	Diameter (Mm.)	Moist. (%)
Sumac	37.5	10.0	7.6	20.7	45.3	16.5	0.5	12.5
Black	34.1	4.6	2.5	24.4	60.3	40.4	2.7	12.4
High	41.7	15.1	13.1	23.7	65.2	24.2	1.9	12.2
Tannin	62.4	4.09	18.8	33.5	88.6	28.9	2.4	12.5
White								

[1] Single Kernel Hardness

[2] TADD Hardness

COOKING QUALITY DETERMINATIONS

For cooking quality determinations, whole and cracked grain of the four varieties was used. Evaluations of decorticated grains were compared.

Minimum cooking time (MCT)

The minimum cooking time was determined by the Ranghino test (Murty et al. 1981) this is the cooking time after which at least 90% of the boiled kernels, when pressed between two glass plates, no longer exhibit an opaque center (Fig 2).

A portion of grain (20 g) was transferred to 250 ml glass beakers, containing 250 ml boiling water (excess water 2:1 proportion), the grain was left to boiled undisturbed for 5 min at that point a portion of grain was removed from the beaker, 20 intact kernels were spread into a glass plate, pressed with another plate and evaluated as described above. This procedure was repeated at 5 minutes intervals and continued after all 20 kernels lost the white core typical on an uncooked kernel (Fig 2). Pilot studies were conducted to determine the MCT. The samples were run in triplicates.

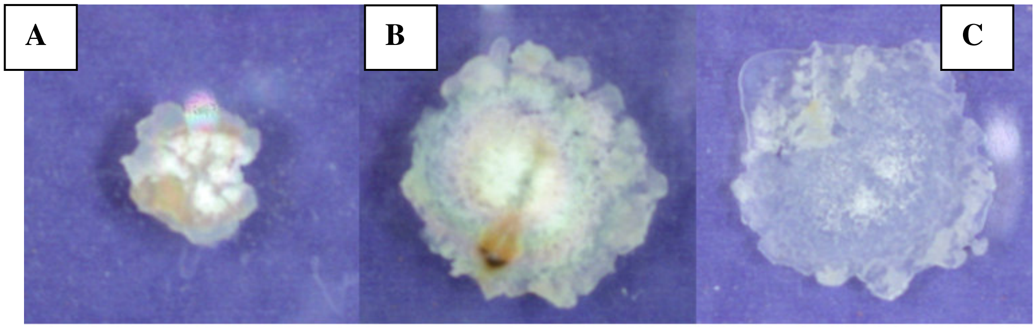


Figure 2. Determination of minimum cooking time (MCT) in whole boiled sorghum kernels. A. Partially cooked B. Intermediate cooked C. Fully cooked

Soluble solids losses (SSL)

Solid material lost during cooking was determined for all cooked samples by weighing an aliquot containing 1 ml. of the cooking broth in a tared evaporating dish and reweighing it after drying at 105ºC in a force draft oven (method 44.15A: AACC, 1996). Solids lost were expressed as a percentage of the starting material (dry weight).

Weight increase after cooking (WIAC)

The water uptake of sorghum grain was determined as the increase in weight of 20 g of kernels after boiling for the MCT. Free water on the surface of the cooked kernels was removed prior to weighing by blotting the kernels with paper towels. The percentage of water absorbed was calculated using the following formula: % W.A. = Final weight –Initial Weight / Initial weight) x 100

Texture

A TA.XT plus/TA.HD plus texture analyzer was used to determine the texture of cooked sorghum for the MCT. The Miniature Kramer Shear/Ottawa cell attached to the HDP/90 heavy-duty platform was used. A 5-blade head or compression platen was attached to the arm of the texture analyzer to measure the compression force necessary to determine hardness and firmness of the cooked kernels.

Statistical analysis

All the values reported in this study are the means of three observations replicated three times. Standard deviation of methodologies was reported where appropriate. ANOVA and Fisher least significant difference (LSD) was used for multiple mean comparisons. SPSS software was used for all data analyzed.

RESULTS AND DISCUSSION

The cooking quality parameters of whole, cracked and decorticated sorghum varieties were significantly different (Table III).

Minimum cooking time (MCT)

The minimum cooking time (as determined by the Ranghino test) ranged from 8.8 to 55 min. Whole sumac cooking time was shorter (20.0 min) than whole white sorghum (55.0 min). (Fig.3)

Table III. Cooking quality parameters of whole, cracked and decorticated sorghum kernels

Cultivar	Sumac	High Tannin	Black	White	LSD*
Whole					
MCT[a] (min)	20.0 ± 0.5	45 ± 0.9	40 ± 0.4	55 ± 0.6	5.1
WIAC[b] (%)	75.4 ± 1.2	65.1 ± 0.8	77.1 ± 1.1	76.5 ± 0.8	4.2
SSL[c] (%)	1.4 ± 0.6	1.0 ± 0.5	1.2 ± 0.3	1.5 ± 0.2	0.24
Texture[d] (N)	317 ± 1.2	353 ± 0.4	379 ± 2.1	398 ± 0.9	25.2
Cracked					
MCT[a] (min)	8.8 ± 0.2	11 ± 0.4	12.1 ± 0.3	17.5 ± 0.6	0.6
WIAC[b] (%)	170.8 ± 0.8	108.1± 1.3	110.8 ± 0.9	182.7 ± 0.7	2.5
SSL[c] (%)	1.7 ± 0.1	1.3 ± 0.3	1.8 ± 0.6	2.9 ± 0.5	0.7
Texture[d] (N)	160 ± 0.7	244 ± 0.8	175 ± 0.5	275 ±1.2	17.1
Decorticated					
MCT[a] (min)	10.7 ± 0.4	11.0 ± 0.5	24.0 ± 0.6	25.3 ± 0.8	0.83
WIAC[b] (%)	141.2 ± 0.5	78.1 ± 0.8	82.2 ± 1.1	131.2 ± 1.2	14.6
SSL[c] (%)	0.5 ± 0.6	0.6 ± 0.3	0.7 ± 0.9	0.6 ± 0.2	0.09
Texture[d] (N)	225 ± 1.1	217 ± 0.9	298 ± 0.6	250 ± 0.4	11.7

[a] Minimum Cooking Time (Ranghino, 1966)
[b] Weight increase after cooking. (Water taken up during boiling for the MCT)
[c] Solid lost to the boiling water for the minimum cooking time
[d] Texture measured with the TA.XT plus/TA.HD texture analyzer (texture of cooked kernels for the minimum cooking time) Tough means the required force in Newton applied to deform kernels.
* Least Significant Difference. Means significance at (α =0.05)

Endosperm structure and other physical characteristics like grain hardness and size may explain the differences in cooking time obtained for all varieties. Soft and intermediate endosperm types and smaller grains such as sumac had shorter MCT than cultivars with a hard endosperm and large kernels like white food grade sorghum (Rooney & Murty, 1987). Black and high Tannin sorghum could be classified as sorghum of intermediate texture due to its floury to corneous endosperm ratio 1:1. These sorghums varieties had similar MCT.

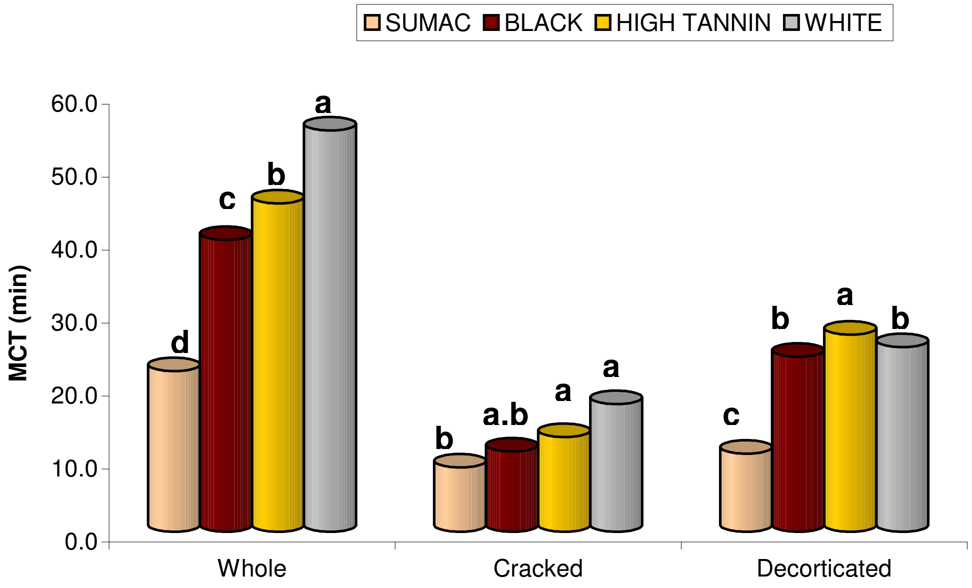


Figure 3. Minimum cooking time (MCT) for whole, craked and decorticated sorghum kernels

MCT for cracked and decorticated grain the MCT was significantly reduced. The required cooking time decreased with increasing endosperm exposure or endosperm milling, because water uptake became easier for the smaller endosperm particles and gelatinization of starch was produced quickly. Decorticated grain had longer MCT than cracked grain, even if pericarp was removed. Pericarp act like a physical barrier that avoid faster hydration rate during cooking increasing MCT.

Whole grain sorghum compared to long grain rice had longer MCT (55 min and 30 min respectively). The starch components of rice, particularly the amylose content or amylose: amylopectin ratio, its gelatinization temperature and its pasting characteristics are largely responsible for major differences in rice cooking and processing behavior (Houston, 1976).

Weight increases after cooking (WIAC)

Water taken up during boiling of the grain for the MCT was determined by the increase in weight of kernels after cooking (Fig. 4).

WIAC ranged from 65.1% to 182.7%. The differences in WIAC may respond to differences in pericarp thickness and endosperm structure for the varieties evaluated. Whole sorghum hydration rate was reduced by the presence of the pericarp that acts like a barrier that slows during soaking and cooking. Rice kernels when boiled presented a moderate water uptake capacity at 77^0C (110 to 150 ml per 100 g), lower compared to whole sorghum. Water uptake values at 77^0C were higher (300 to 400 ml per 100 g) for short and medium grain varieties of the preferred types.

The less tightly packed structure for the soft and intermediate endosperm sorghum varieties (sumac, high tannin and black) allowed water uptake in a shorter time than the more tightly packed hard endosperm types (white sorghum) (Young, 1989).

Cracked endosperm allowed more water uptake than decorticated grain, because the exposed smaller endosperm pieces (mesh # 10) become hydrated more easily than decorticated kernels. Thus, water uptake increases with the increasing of endosperm exposure (cracking and decortication).

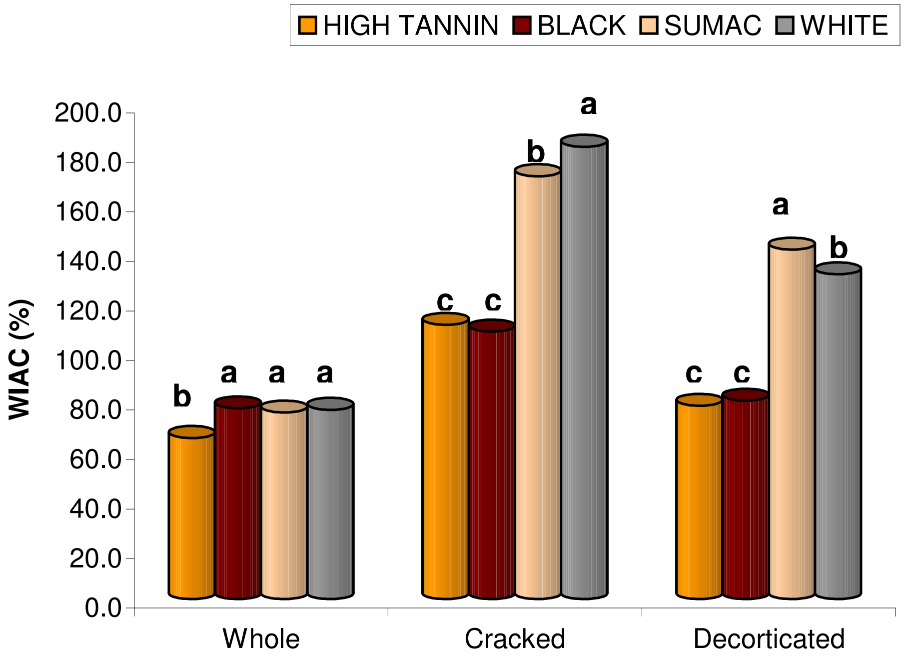


Figure 4. Weight Increase after cooking (WIAC) for whole, cracked and decorticated boiled sorghum kernels

Solids losses during boiling (SSL)

Solids Lost during boiling for the MCT where higher for whole and cracked than for decorticated grain (Fig. 5). Solid material lost during cooking for all samples ranged from 0.5% to 2.9%. The MCT and hardness of grain seems to be the major factors involved in determining this amount. The harder the grain, the longer the cooking time, which allowed soluble solids losses to increase in cooking broth.

For whole grain, rupturing of the kernels due to excessive water uptake at temperatures above starch gelatinization caused greater dry matter losses due to partial endosperm disintegration.

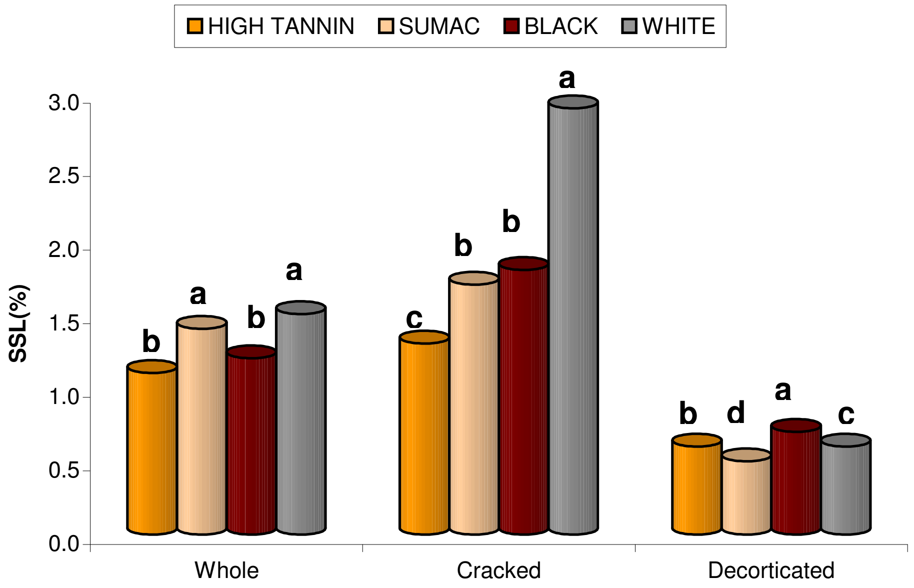


Figure 5. Soluble solids losses (SSL) for whole, cracked and decorticated boiled sorghum kernels

For cracked grain, pericarp and endosperm pieces were more exposed allowing water penetration easily; which reduced cooking time but solids losses increased as well.

Apparently most of the cooking broth solid losses consist of anthocyanins, starch, gums, sugars and soluble vitamins and minerals (Duodu et al, 2002). For decorticated grain the major part of the pigments, starch and soluble vitamins present in the outer layers of the kernels were lost during milling. Thus, the loss of solids in the broth was low. The preferred long grain types in terms of percent solid loss during processing is comparatively low (17 to 22%) and the kernels show a minimum of splitting and fraying of edges and ends. Short and medium grain varieties show relatively high solid losses (28% to 40%) during processing and the kernels show extensive disintegration.

Color and appearance of the cooked grain

The color of the cooked whole, cracked and decorticated kernels was affected by the MCT. For whole kernels the longer the cooking time the darker the color of the grain, apparently due to caramelization of sugars and non-enzymatic browning during cooking (Figs. 6, 7, 8 and 9).

Color for cracked and decorticated sumac, high tannin and black were affected by leached out of pigments because these grains have a pigmented testa. The use of tap water for cooking apparently induced pH changes in structure of the anthocyanins and enhanced extraction of colored compound in a more acidic medium (pH of tap water is 5.9) (Young, 1990). Whole white ATX 635X436 variety had a mushy and gruel-like texture after cooking that caused handling problems. The endosperm was adhered to other kernels and formed agglomerates, probably due to the presence of some gums and wax in the pericarp, which affect the appearance of cooked kernels. (Fig.10).

The percentage of ruptured kernels after cooking was larger for whole sumac and whole black. This is further proof that kernels with soft endosperm absorbed water more readily and the water is apparently more available for reaction with starch.

Pericarp removal by mechanical decortication for soft and small grains like sumac is more difficult than for white grain because of the hardness of the grain. In spite of solids lost to the boiling water and as a rupture of kernels the cracked and decorticated white ATX635X436 (tan plant) grain gave firm though, not tough, separate kernels with a uniform light appearance and a slight yellowish hue. Food products manufactured from sorghums with a tan plant color are usually lighter and better in appearance than those manufactured from cultivars with a purple plant and straw colored glumes (Rooney et al 1986).

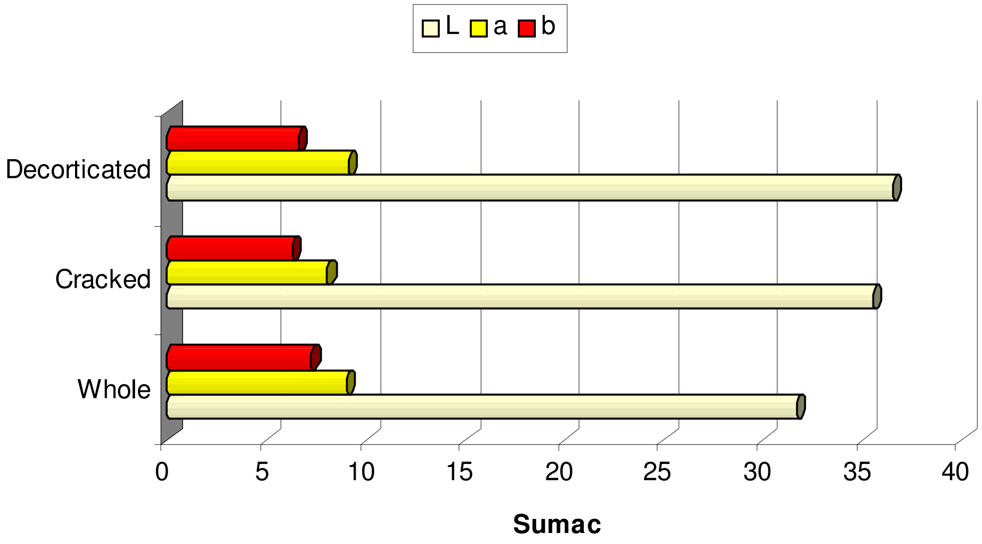


Figure 6. Color of cooked whole, cracked and decorticated boiled sumac sorghum kernels

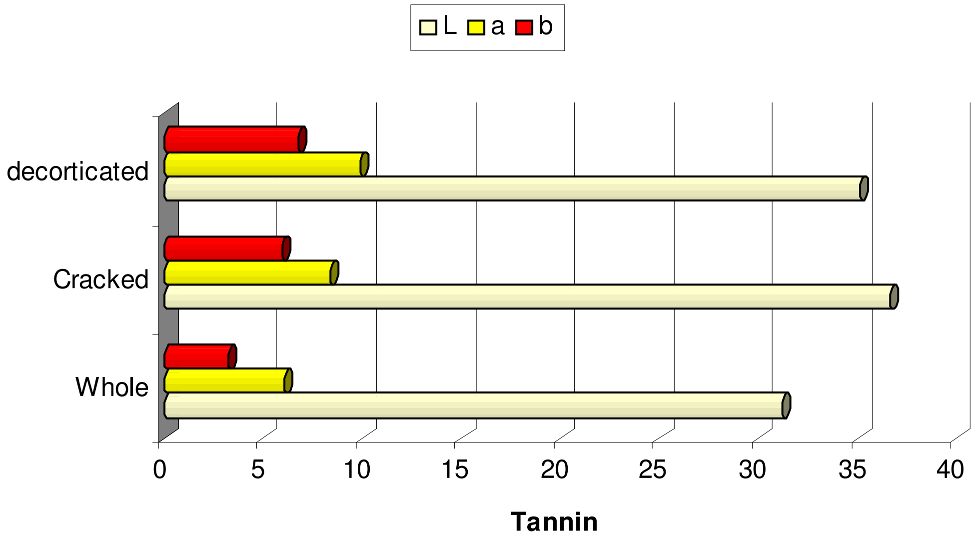


Figure 7. Color of cooked whole, cracked and decorticated boiled high tannin sorghum kernels

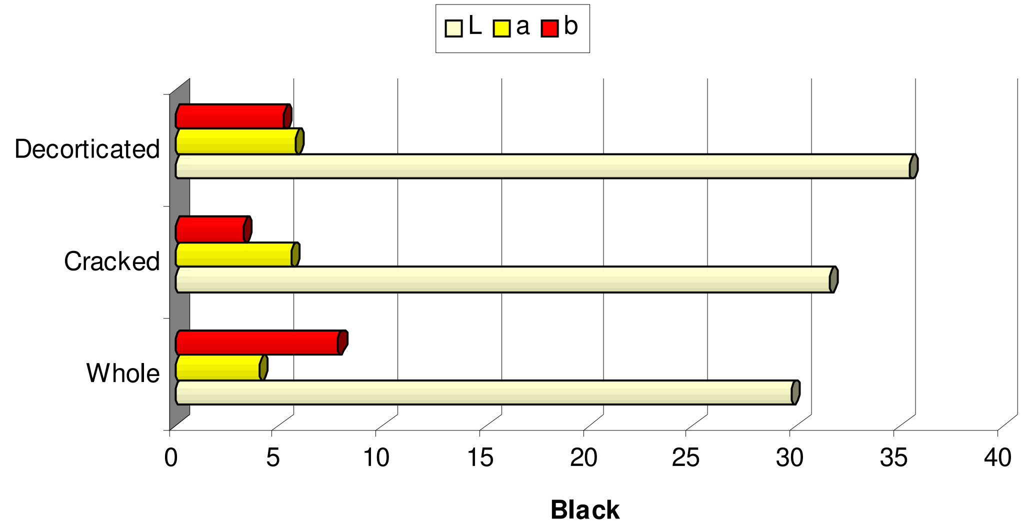


Figure 8. Color of cooked whole, cracked and decorticated boiled black sorghum kernels

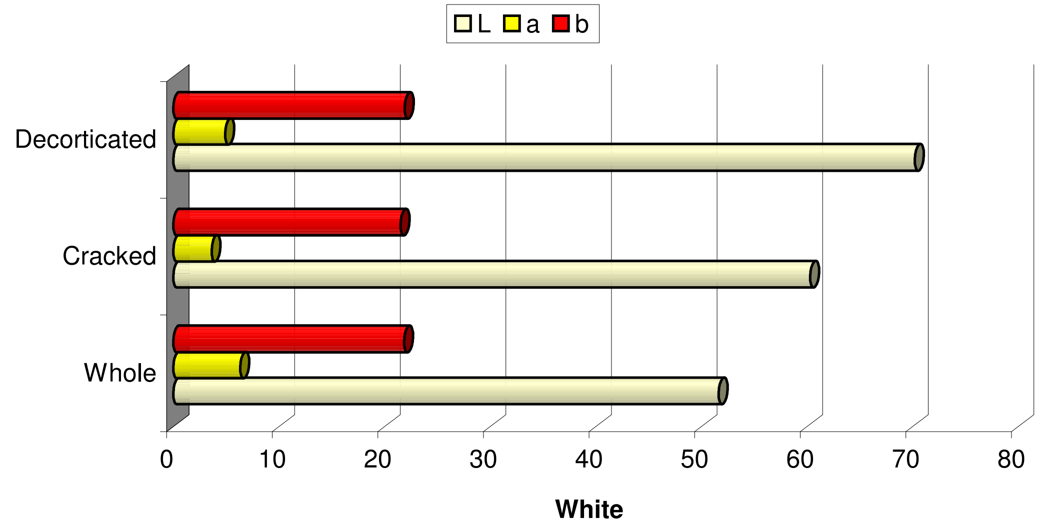


Figure 9. Color of cooked whole, cracked and decorticated boiled white sorghum kernels

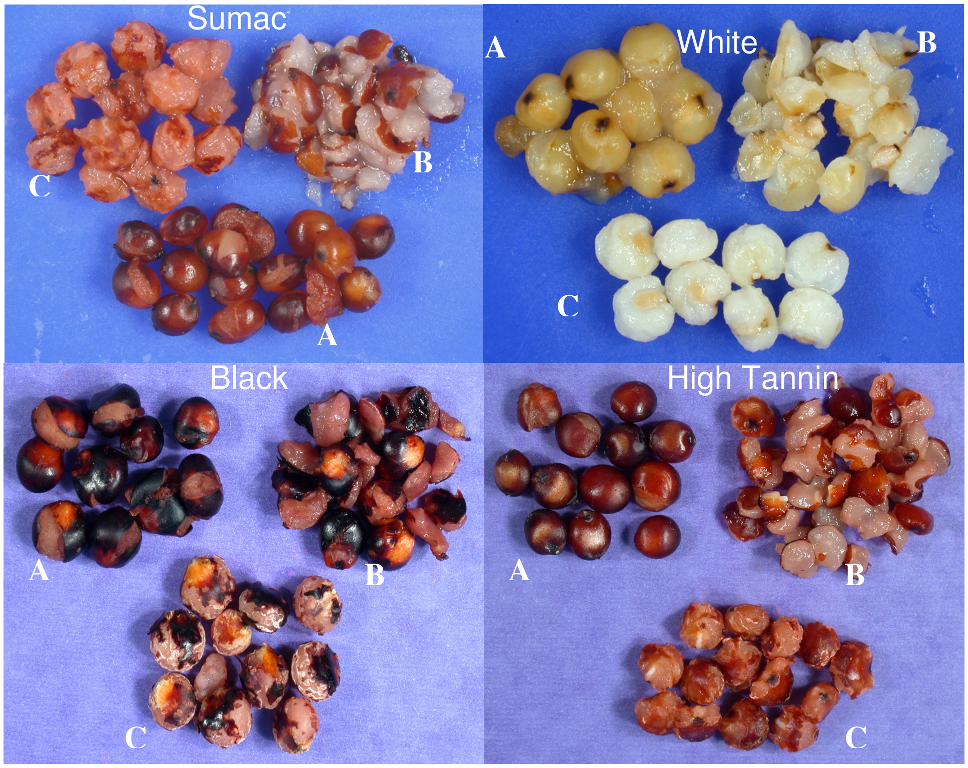


Figure 10. Color and appearance of cooked whole (A), cracked (B) and decorticated (C) white, high tannin, black and sumac sorghum

Color of the milled rice is often referred to as general appearance of the cooked product. Rice varieties in the U.S. have either light (straw) or dark (gold) colored hulls. Light colored hull are preferred by processors because they don't impart as much color to the processed product as do dark-colored hulls under similar parboiling conditions. Most consumers also prefer light colored rice. The U.S. standards specify that cooked milled rice grade N^{o} 1 shall be white or creamy and rice grade N^{o} 2 should be not darker then slightly gray.

Texture of the cooked grain

Whole grain increased the resistance to deformation and energy (hardness) used to crush a layer of cooked kernels (8 kg) compared to cracked and decorticated kernels (Fig. 11). Whole grain was significantly tougher (more force required to reach yield point) than the rest of the kernels, apparently due to differences in hydration rates, size, endosperm structure and cooking time between samples. Whole grain “per se” always had a hard texture after cooking Cracking or dehulling helped solve the hard texture but may decrease nutritional value.

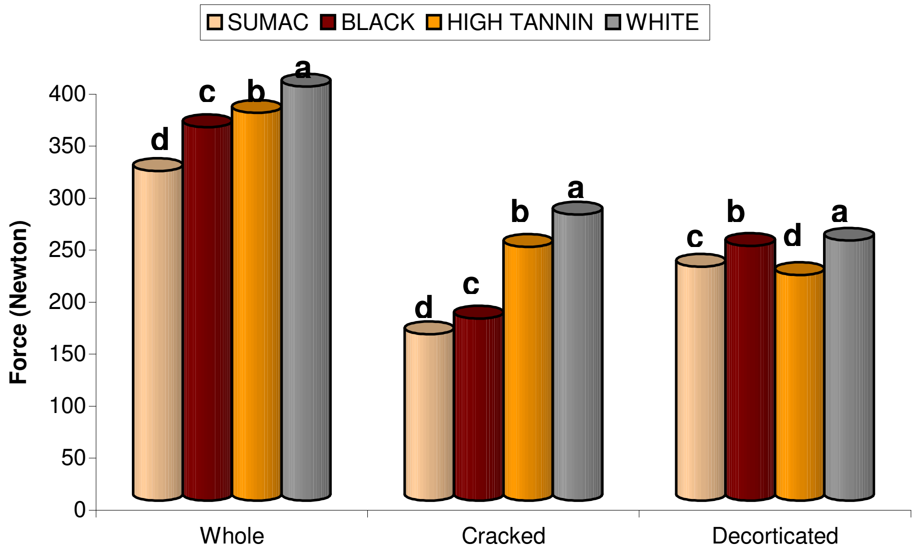


Figure 11. Force in Newton required to deform whole, cracked and decorticated sorghum kernels

Decorticated grain had an acceptable texture, yielding firm but soft, separate kernel with acceptable appearance. When the pericarp was eliminated heat transfer and water absorption was improved, which caused greater cooking of the starch, greater expansion and much better texture.

In general the cracked sorghum kernels had better texture in terms of hardness of the grain, but presented gruel like and viscous texture towards the end of cooking that made the grain difficult to handle. Cooking characteristics for this grains are similar to those of brown rice and short white rice, in terms of sticky texture and color.

It is recommended to improve texture and chewness of the whole cooked kernels modified the processing conditions like increase the moisture up to 30% prior to cooking, cook the grain longer than the MCT, or apply a pretreatment to pre-gelatinize the starch in some extent to reduce cooking time and get softer kernels**.**

Rice quality in terms of texture defined the best rice like “hard rice”, that usually cooks dry and flaky with a minimum of splitting and the cooked grain tends to remain separate. High quality short and medium grain varieties referred to as “soft rice” is more moist and firm when cooked than the long-grain varieties and the grain tend to stick together (Roberts, 1972).

CONCLUSIONS

Minimum Cooking Time as determined by the Ranghino test (1966) for whole grain was longer than for cracked and decorticated grain for all varieties. Cultivar characteristics and specifically endosperm hardness and pericarp thickness may affect cooking time and other variables like soluble solids.

The cultivar with soft endosperm (sumac) had shorter cooking time and hydrated faster than the hard endosperm sorghum (white ATX635X436). High tannin and black sorghum had similar MCT due to similar endosperm characteristics. Rupture of whole kernels due to excessive water uptake at temperatures above starch gelatinization caused significant solids losses for soft and intermediate texture varieties, most for white harder kernels.

The boiled products were different in color and affected by the MCT. Whole white grain presented a gruel-like texture and mushy appearance characteristic of an overcooked grain. Cracked and decorticated white grain had lighter colors and firmer separated intact grains than decorticated or cracked sumac, high tannin and black, which gave a brownish-gray colored product with a low L-value, increased a and reduced b values due to leaching of pigments into the endosperm which affected the appearance of the cooked products.

Whole grain was significantly tougher (more force required to reach yield point) than the rest of the kernels probably due to differences in hydration rates, kernel size, endosperm structure and cooking time between samples.

Cooking and processing quality of long grain white rice can be compared to those of decorticated white sorghum kernels**,** according to grain size, shape, uniformity and general appearance (color and translucency). Cracked sorghum characteristics can be compared with those of short and medium rice grain in terms of sticky texture and appearance (lump and aggregated kernels) of the processed products.

Consumption and processing of cracked sorghum is practical in terms of reduced cooking time and softer grain texture but nutritional quality and appearance of the boiled product is affected due to high soluble solids (phenols, vitamins, minerals etc) and leaching of pigments into the exposed endosperm. When decorticated sorghum is used considerable losses of fiber, vitamins and minerals are produced when outer layers of the grain are removed.

Whole sorghum cooking quality characteristics differs significantly from those of rice, but the physicochemical criteria could meet the requirements to eat sorghum like rice or as a food ingredient. Since different ethnic groups prefer various rice textures and colors a wide range of types of different sorghum could be used to meet the requirements for processed whole boiled sorghum products**.**

CHAPTER III

EFFECT OF PRECOOKING ON COOKING QUALITY AND PHYSICAL PROPERTIES OF WHOLE SORGHUM

INTRODUCTION

Utilization of whole sorghum provides the opportunity to increase consumption of bioactive compounds, fiber and other health promoting components significantly. Whole sorghum depending on variety, kernel size and hardness, requires from 30 to 55 min of steaming. A quick cooking sorghum with a 5 to 15 min cook time would be useful to increase consumption of sorghum as a boiled whole product and at the same time reduces energy consumption.

Precooking treatments (quick cooking methods) applied prior to cook can increase grain hydration and gelatinization rates, reducing cooking time. In most cases quick cooking includes a pre-cook process that consist of hydrating the grain to a given moisture content (32%-35%), followed by a short period of heating (microwave, infrared or dry heat), then cooked or gelatinized to some extent in water to produce a quick cooked and consistently uniform high quality product in short time (Roberts, 1972; Houston, 1976).

The quick-cooking grain may vary in texture, bulk volume, appearance, taste and quality. The final product could be used in different food applications like canned or dry soups, salads), desserts, instant cereals, weaning foods or consumed fresh like rice with meat, vegetables and a sauces.

Some of the precooking treatments described in this chapter consist of low technology techniques that would be suitable for use at home or small businesses in sorghum consuming countries where existing equipment and technologies does not permit the manufacture of acceptable sorghum products.

During this phase of the study, different hydrothermal treatments were applied to raw grain and its effects on physicochemical properties of boiled sorghum were measured and compared with that of raw grain (control).

LITERATURE REVIEW

General types of precooking methods

Since the early 1940's several precook treatment have been used mainly to produce rice, barley and oats products (Roberts, 1972; Ozai-Durrani, 1972). More than ten different approaches have been used, plus several combinations of these (Houston, 1976). The following are the principal commercial useful methods:

1. Water is removing for rice by circulating in hot air (57-82 C^0) per 10 to 30 min to create transverse striations in the rice grains.
2. Raw grain is tempered to 30% moisture, then pretreated in a blast of hot air (about 65ºC to 150ºC) to dextrinize, fissure or expand the grains somewhat (Bumping treatment)
3. Gun-puffing a combination of some preconditioning plus high temperature, followed by explosive puffing to atmospheric pressure or into a vacuum
4. Freeze drying of thoroughly cooked grain
5. Microwave heating. Grain is tempered to a moisture content of 25-30%, then heated with either steam or microwave and then cooked
6. Infrared heating (Roasting/Micronization)
7. Combinations of two or more above.

Microwave, infrared and dry heating treatments and combinations of these techniques were evaluated in this study to reduce cooking time and improve cooking quality of whole sorghum. A brief description of the methods and commonly used commercial applications are described as follows:

Soaking

Many cereal grain and grain legumes are soaked before further processing. Cereal grains must be hydrated to allow gelatinization of starch on subsequent heating and cooking of the grains. Grains are hygroscopic and will absorb water, both as vapor and as liquid. During soaking, water enters the kernel by molecular absorption, capillary absorption and hydration. Initially the rate of water imbibition is high, but it levels off after a few hours. The rate of water uptake can be regulated by controlling temperature of the soaking water. Soaking gives a volume increase in the grain. The amount of swelling is proportional to the moisture content of the grain (Wray & Cenkowski, 2002).

By formulating a relationship among volume change, moisture content and temperature the swelling of grains in water can be estimated. These relationships are useful in the design of the equipment for grain processing (Young, 1990). Soaking is the bottleneck of many hydrothermal processes. Starch gelatinization degree and texture of finished products (eating quality characteristics) depend on water content and distribution.

Infrared heating

Food irradiation is emerging as a major food processing and preservation technology. Infrared (IR) heat treatment of moisture-conditioned grains and legumes can reduce cooking time by 50% for lentils and 30% for peas.

Infrared heating occupies part of the electromagnetic spectrum with a frequency beyond that of visible light. When infrared waves hit a material, they are reflected, transmitted or absorbed. Absorbed waves are transformed into heat; temperature of the material increases and the surface seems roasted or burned (Ohlsson, 1994a).

Infrared radiators can be divided into the following main groups: gas heated radiators (long waves), electric tube heaters (medium and short waves) halogen lamps (ultra-short waves). Long-waves IR heating at wavelengths around 30μ has long been in use for industrial cooking and drying applications achieving shorter processing times than by convective heating. Short waves IR (1μ) makes it possible to reach working temperatures in seconds and has a penetration depth of several millimeters in many foods. (Lewis & Heppel, 2000).

Infrared heating followed by flaking (Micronizing) has typically been used to process grain for feed (Wray & Cenkowski, 2002) and for the production of flakes included in breakfast cereal formulations. Other commercial applications include drying of low moisture foods such as breadcrumbs, cocoa, flour, grains, malt and tea.

Microwave heating

Microwaves used in the food industry or domestic uses for heating have frequencies between 915 and 2450 MHz (Blaszczak, 2002). The principle of microwave cooking is different from that of conventional cooking where foods are cooked by frictional heat produced by the action of microwaves on water molecules causing them to vibrate at high speed (Ohlsson, 1994a).

When a microwave is applied to a food, dipoles in the water and ionic components such as salt, attempt to orient themselves creating heat. The outer parts of the food receive the same energy as the inner parts, but the surface losses heat faster. The distribution of water, ions and shape of a food has a major effect in the amount of heating received (Wray & Cenkowski, 2002).

The depth of penetration of microwave energy is determined by the dielectric constant and the loss factor of the food, but they vary with the moisture content, temperature and frequency of electric field. Uniform temperature control during microwave heating is difficult. These difficulties are the major limitation for industrial application of microwave heating methods (Ohlsson, 1984a). The use of microwaves has positive ratings for drying rate, baking and cooking, tempering, microbial stability, enzyme inactivation, precooking and rehydration capacity of foods.

Dry heat

A hot air blast can be any source of dry heat that can produce internal heating of the grain, exciting the water molecule that raises the water vapor pressure and causes the grain to expand almost to the point of eversion. (Mwangwela, et al. 2005; Wray & Cenkowski, 2002). Hot air poppers or even an iron pan with or without sand over an open fire can be used as a hot air blast.

Dry heat application causes gelatinization of the starch. Grain evenly hydrated to about 30 to 35%, requires only about 2 min of steaming at atmospheric pressure to gelatinize it (Khairwal et al. 1977). This process has been commercially applied to produce popcorn, caramel popcorn, and for drying low moisture foods and grains.

Effect of precooking in cereals and legumes

There is little information on the application of precooking treatments in sorghum and its effects on physicochemical properties of the grain These methods have been applied successfully in rice, oats, barley, legumes and lentils and many forms of quick cooking (pre-cooked) products have been developed and marketed in the last twenty years.

Some of the effects of hydrothermal treatments on physicochemical properties and cooking quality of some cereals and legumes are described above.

Effects of infrared heating (IR)

Long wave IR heating around 30 µm has been used for industrial cooking and drying applications, achieving shorter processing times than by convective heating or microwaving (Rowley, 2001) Infrared heating pre-gelatinizes the starch and denaturates proteins. Physically this treatment has been shown to increase hydration rate for some legumes. (Abdul-kadir et al.

1990). Increased cooking time, a hardening of texture and reduced water absorption capacity has also been reported in infrared heated chickpeas and cereal grains (Sarantinos & Black, 1996, Mwangwela, et al. 2005)

Infrared heating has been used successfully to shorten cooking time by 50% in some legumes and lentils, pre-gelatinizing the starch and denaturating protein and disrupting the endosperm structure an increasing hydration rate during. However, for in chickpeas infrared increased cooking time by firming the texture and reducing water absorption capacity (Mwangwela, 2005).

Sorghum exposed to infrared treatment changed physical structure and chemical properties, causing physical fissuring of the pericarp and reduced the bulk density of treated seeds. Heat denaturation and protein coagulation occurred before starch gelatinization and this resulted in a physical barrier that restricted water uptake and swelling of the starch granules during cooking (Zylema, 1985).

Some studies of micronization in wheat kernels showed that infrared heated grain at radiation doses of 1-10 KGy promoted changes in endosperm microstructure as examined by SEM. The cell content was clearly separated from the wall and protein matrix and protein bodies were deposited on the surface of starch granules, adhering firmly to each other. Gel-liked properties of starch granules were promoted and hydration properties increased (Blaszczak, 2002).

The functional properties of infrared heated potato starch had improved stability of cooked starch because viscosity was similar to native starch; micronization restrains the swelling of the starch (Duodu et al, 2002).

Another study showed that infrared heating of peas increased dry matter digestibility by 37.6% by increasing the amount of available protein by 6% and gelatinizing the starch and therefore requiring 91% less energy to melt the available starch during cooking (Wray & Cenkowski, 2002). The old process of used the infrared to warm up the kernels of sorghum and then the kernels were flaked to knock out the steam inside the material.

Effects of microwave heating

In a few studies reported of microwaved grains, wheat kernels treated with microwave heat had marked structural changes, which were enhanced by longer treatment time. The microwave heating of wheat grain clearly influenced kernel microstructure when the temperature of grain exceeded 64 C^o. At $70C^o$ to 80 C^o the disruption of cell integrity included protein denaturation as well as deformation of starch granules. Statistically significant changes in wheat grain moisture content, grain vitreosity, sedimentation value, dough energy as well as bread volume where induced by microwave heating, when grains reached 79 C^o and 98 C^o (Blaszczak, 2002).

Microwave treatment of grains longer than 90 seconds caused marked changes in kernel endosperm structure, like protein denaturation creating visible fibrils as well as high swelling and gelatinization of starch granules (Zylema et al, 1985). More knowledge is needed about the influence of geometry, size and shrinkage of the kernels and stress cracking during microwave heating.

In cereals like rice and oats, the amounts of damaged and resistant starch increase with microwave energy absorbed and the temperature of treatment, mainly at the moisture of 30% and the temperature of $100C^o$. Other physicochemical properties like gelatinization temperature, maximum viscosity, breakdown value; gel value and soluble amylase content were slightly higher in the microwave treated grains. Microwaved cereals significantly reduced the nutritional quality of cooked samples as well. Fat, thiamine, iron, calcium and phosphorus were significantly reduced. (Polycarpe, 2006)

An application of microwave energy to produce quick cooking rice is presented by Houston, (1972); Raw rice is soaked in water to 30% moisture, then heated in a microwave for 1 min. Microwave energy is said to provide advantages by its volume-heating effect, which cooks the rice with minimum clumping together of individual grains and a very rapid heating effect, which can impart porous structure to the precooked rice grains.

Effects of dry heat

This method has been applied commonly in white and brown rice. The treatment consist to remove 3 or 4 % of water from the rice in its natural state by circulating air at 57 to 82 C^0 per 10 to 30 min., to create transverse striations in the rice grains, thus yielding a quick cooking product (Hoseney, 1998). This method is used to produce “minute rice”, the endosperm of the grain becomes quite opaque and chalky. Some degree of swelling of starch occurred as well as fracturing of the surface and the starch is dextrinize to some extent. This product can be prepared for serving in about 15 min. a similar quick cooking white-rice product has been produced by the same general process and has had very good consumer acceptance.

Data on the use of dry heat treated-cereal as a quick cooking method and its effects on physicochemical properties of sorghum grain are still needed. In the few studies conducted, cooking time of sorghum grain applying dry heat was positively correlated with grain weight and density, besides swelling capacity also showed significantly positive correlation with swelling index and diameter of popped grain. (Sankarapandian, 2000). A Similar observation was made by Khairwal et al (1977) and Louis & Heppel, (2000).

Quick cooking rice characteristics

Even if cooking time of rice is not to long as cooking time for other cereals, considerable effort has been directed to develop quick cooking rice products with the view toward increasing the consumption of rice and developing profitable new products. A quick cooking rice is expected to be serve about 5 to 15 after being added to boiling water .The variation in cooking time depend on the process used to produce the product and the recipe adapted to the product. (Ozai Durrani, 1972)

In most cases quick cooking rice is considered to have been precooked to some degree. The partially cooked rice is usually dried in such as manner as to retain the rice grains in porous and open-structured conditions. The finished product should consist of dry individual kernels, free of lumps and aggregates and approximately 1.5 to 3 times the bulk volume of raw rice initially used. (Khairwal et al. 1977).

General types of quick cooking rice process were described initially in this chapter, but in general consisted of soak-boiled-steam dry methods, expanded dry pregelatinized methods, dry heat treatments, microwave treatments, gun-puffing, freeze-drying and combinations of this methods. There is still active interest in developing new and improved quick cooking rice products with the view to increase yields, reducing processing and capital equipment cost, shortening of processing times and improving appearance and convenience to the consumer.

Referring to the quality of quick cooking rice the majority of US consumers prefer long-grain, light, fluffy, slightly dry individual kernels having essentially no gritty or hard uncooked centers. This is commonly referred as “Chinese type” cooked ricer and has been the target for most quick cooking rice development in the past years.

MATERIALS AND METHODS

Whole grain from: ATX 635X436 (food grade sorghum) sumac, high tannin and black sorghum varieties were used for this part of the study. Characteristics for the raw materials are shown in Table I and II of chapter I.

The raw whole grain was precooked using different hydrothermal treatments. After pretreatment, samples were cooked and cooking characteristics were measured including minimum cooking time (MCT), Soluble

Solid Losses (SS) and Weight Increase after cooking (WIAC), using the same methods described in chapter I. Texture of cooked kernels and changes in endosperm structure were determined.

Quick cooking methods description

Precooking methods described in Table IV were applied to uncooked raw whole sorghum kernels from all varieties prior to cooking. All sorghum samples were soaked overnight (16 hours) in excess water to increase moisture to 30-32% before application of precooking methods, with exception of the control.

Texture determination

A TA.XT plus/TA.HD plus texture analyzer was used to determine the texture of pretreated cooked sorghum for the MCT. The Miniature Kramer Shear/Ottawa cell attached to the HDP/90 heavy-duty platform was used. A 5-bladed head or compression platen was attached to the arm of the texture analyzer to measure the compression force necessary to determine hardness and firmness of the cooked kernels

Environmental scanning electron microscopy (ESSEM)

Scanning electron microscopy (ESSEM) was used to observe structure of corneous and floury endosperm in precooked sorghum samples. Kernels were cut longitudinally in half, mounted on aluminum stubs with silver paste, coasted with gold palladium and viewed with a JEOL T330A, scanning electron microscope model E3 at an accelerating voltage of 20 KV. Pictures were taken at about the same location in each kernel.

Statistical analysis

Statistic methods used in this phase of the study are the same as described in chapter I. Fisher least significant difference (LSD) was used for mean comparison between samples. The data was analyzed using SPSS.

Table IV. Description of precooking treatments applied to raw grain before boiling

Treatment	Description
Dry Heat	Grain is soaked at room temperature, then exposed to circulating hot air stream (80C$^{0)}$ in a corn popper (model Nº 0482107 National presto Inc, WI) for 45 sec or just prior to eversion (popping)
Microwave	Grain is soaked at room temperature, then microwaved on high for 1 min (120 C^{0}) in a domestic microwave (model 210T Matusi, Japan frequency 2480 MHz)
Combination of Microwave and Dry Heat	Grain is soaked, then heated in a microwave for 45 sec and exposed to circulating hot air stream in a hot air popping machine for another 45 sec
Infrared heating	Grain is soaked, and then exposed to a gas infrared burner for 10 min time (150^{o} C) model Nº 36/52 Schwank innovative solutions, Georgia, US
Control	Cleaned, raw dry grain.

RESULTS AND DISCUSSION

Minimum cooking time (MCT)

The different precooking processes applied reduced the minimum cooking time significantly for all varieties. The MCT ranged from 13 to 55 min. (Table V; Fig 12).

Microwave and dry heat treatments combined, produced the shortest cooking time with a reduction of 41% for sumac (softer grain) and 31% for white sorghum (harder grain). Cooking time reduction for high tannin and black was 32.5% and 49%, respectively this grain had intermediate endosperm structure. This treatment produce a synergistic effect on kernels, which increased grain temperature and produced endosperm expansion almost to the point of eversion, creating some ruptures in the pericarp that allowed water uptake and consequently rapid starch gelatinization. When using this treatment, 30% moisture in the grain promoted starch gelatinization after 90 sec of heat application.

For dry heat applied by itself, not in combination, MCT reduction ranged from 15% to 48% for all sorghum varieties. This treatment was effective to produce internal heating and starch gelatinization to reduce MCT in comparison with control. Minute rice is processed using this method.

When microwave energy was applied, MCT reduction for this treatment ranged from 11 to 23% for all varieties evaluated. In previous studies microwave energy applied to wheat kernels, longer than 90 sec caused marked changes in endosperm structure like protein denaturation and gelatinization of starch granules, a decrease in amylase inhibitory activity and an increase in damaged and resistant starch (Blaszczak, 2002, Duodu, et al. 2002).

Infrared heated sorghum show low hydration rate and kernel shrinkage. MCT reduction ranged from 5% to 11% and was lower than for other treatments. Infrared heating reported to produced drastic changes in kernel microstructure and physical properties in some legumes like chickpeas like protein coagulation producing a physical barrier which inhibited hydration and did not allow gelatinization of the grain, increasing cooking time (Mwangwela, 2005)

Weight increases after cooking (WIAC)

There was a significant difference in water absorption capacity between treatments and between varieties (Table VI).

Table V. Changes in minimum cooking time (∆ MCT) for precooked sorghum compared the control

MCT[a] (min)	Sumac	High Tannin	Black	White	LSD[b]
Control	22	40	45	55	8.5
Microwave	17	32	40	46	11.3
∆ MCT [c]	5	8	5	9	
MCT Reduction (%)	23	20	11	17	
Dry Heat	15	35	39	48	7.3
∆ MCT	7	5	6	7	
MCT Reduction (%)	32	12.5	13.3	12.7	
Dry heat-microwave	13	27	23	38	13.2
∆ MCT	9	13	22	17	
MCT Reduction (%)	41	32.5	49	31	
Infrared	21	38	42	49	2.6
∆ MCT	1	2	3	6	
MCT Reduction (%)	4.5	5	7	11	

[a] Minimum Cooking Time.
[b] LSD Least Significant Difference (α 0.05)
[c] Change in Minimum Cooking time using precooking methods.

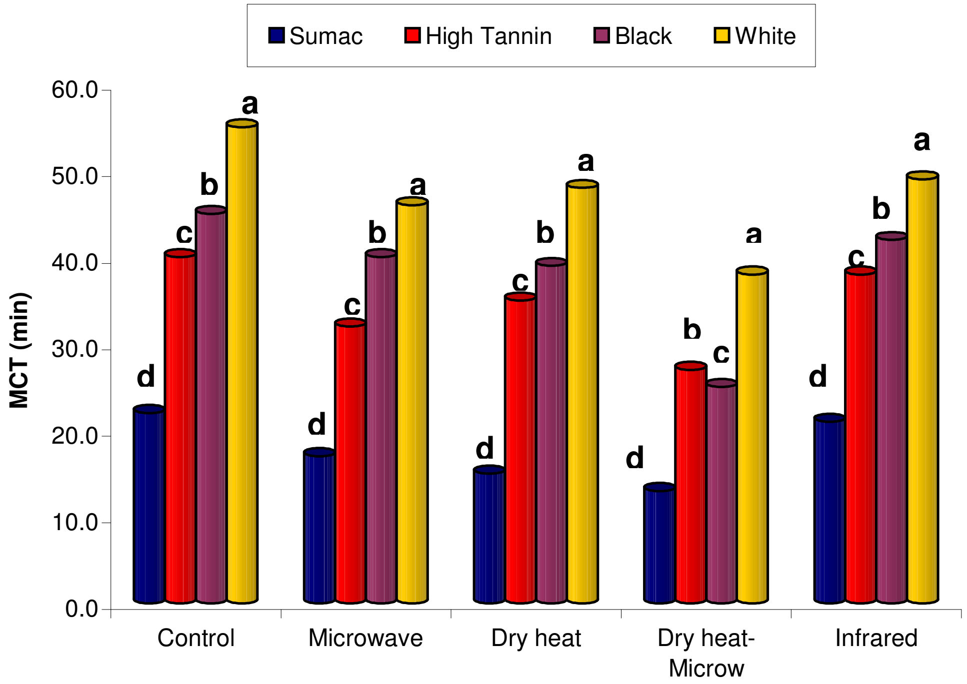


Figure 12. Changes in minimum cooking time using precooking methods

Water absorption was measured by the increase in weight after cooking at the MCT. Higher increase in weight was shown by dry heat and microwave combined (Fig 13). This treatment caused ruptures in the pericarp and stress cracking of kernels, which allowed higher hydration rates during cooking and effectively increased cooked kernel yield by 75.3% to 82.9% for all varieties evaluated. WIAC for white and sumac sorghum was not significant for most of the treatments. Infrared heated grain had the lowest hydration rates for all sorghum varieties, apparently due to protein bodies coagulation and deposition on the surface of starch granules, phenomenon that occurred prior to starch gelatinization inside the kernel and produced a physical barrier that restricted water uptake and starch gelatinization during cooking (Mwangwela, 2005).

Table VI. Changes in weight after cooking (ΔWIAC) for precooked sorghum compared to the control.

WIAC[a] (%)	Sumac	High Tannin	Black	White	LSD[b]
Control	75.4	65.1	77.1	76.5	5.8
Microwave	70.4	59.9	70.3	66.5	7.5
Δ WIAC [c] (%)	5	5.2	6.8	10	
Increment (%)	93.3	92	91.1	86.9	
Dry Heat	72.3	62.5	76.0	68.0	2.7
Δ WIAC (%)	3.1	2.6	1.1	8.5	
Increment (%)	95.8	96.1	98.5	89	
Dry heat-microwave	75.3	80.0	82.2	82.9	3.3
Δ WIAC (%)	10	14.9	45.1	6.4	
Increment (%)	99.8	122	106.6	108.3	
Infrared	16.8	20.0	15.9	7.5	2.6
Δ WIAC (%)	-58,6	-45.1	-61.2	-69.3	
Increment (%)	-77.7	-69	-79.3	-90.1	

[a] **Weight Increase after cooking for the MCT**

[b] **LSD Least Significant Difference (α 0.05)**

[c] **Change in Δ WIAC using precooking methods.**

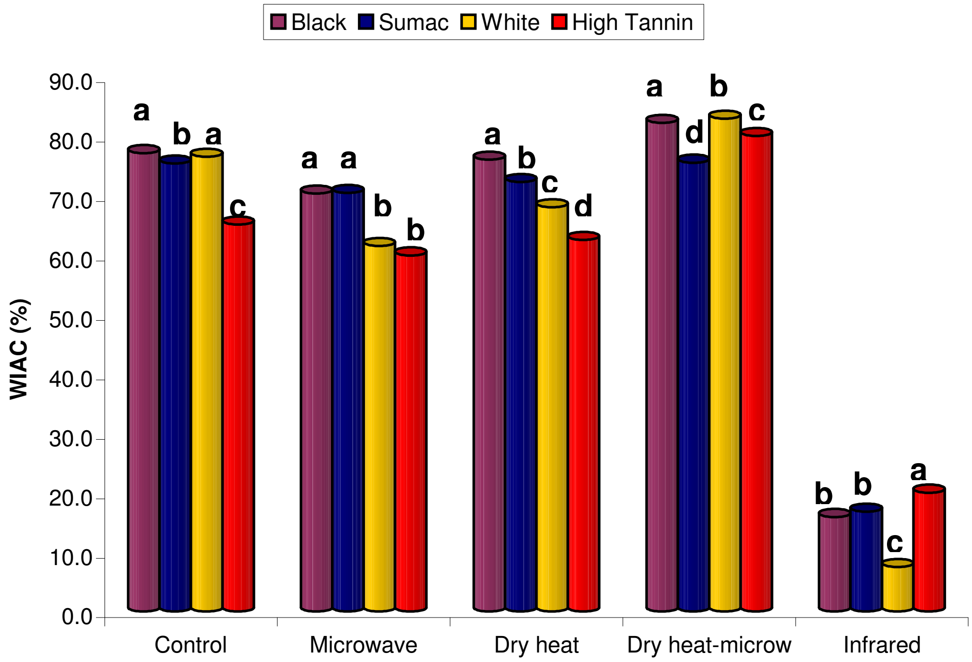


Figure 13. Changes in sorghum kernel weight after cooking using precooking methods

Kernels show shrinkage and bulk density reduction. The increment in weight was negative compared to the control. Kernels show a reduction in bulk density and significative shrinkage. Microwaved and dry heated grain, when applied separately, not combined show good hydration rates as well. Microwaved sorghum yielded from 66.5 to 70.4% of increase in weight after cooking and dry heated increase in weight ranged from 62.5 to 76%. Good yield of cooked kernels after cooking is desirable characteristic for food processors and consumers.

Soluble solid losses (SSL)

Soluble solid losses show significant differences for all varieties and treatments applied. SSL were higher for varieties with harder endosperm that takes longer to cook like white, high tannin and black sorghum. MCT could influence SSL amount due endosperm disintegration and splitting of the grain during cooking above starch gelatinization temperatures especially for harder grains. Solid Losses during cooking may be influenced by different physical parameters of the grain like MCT, hardness, hydration rate and others (Table VII, Fig 14).

Table VII. Changes in soluble solid loses (ΔSSL) for precooked sorghum compared to the control

SSL[a] (%)	Sumac	High Tannin	Black	White	LSD[b]
Control	1.7	1.5	1.8	2.9	0.80
Microwave	0.6	0.7	0.9	0.8	0.31
Δ SSL [c] (%)	1.1	0.8	0.9	2.1	
Reduction (%)	35.2	46.6	50	27.5	
Dry Heat	0.5	0.8	0.6	0.9	0.25
Δ SSL (%)	1.2	0.7	1.2	2.0	
Reduction (%)	29.4	47.0	33.3	31.0	
Dry heat-microwave	1.3	1.4	1.5	1.7	0.10
Δ SSL (%)	0.4	0.1	0.3	1.2	
Reduction (%)	23.5	6.6	16.6	41.3	
Infrared	0.3	0.6	0.4	1.2	0.3
Δ SSL (%)	1.4	0.9	1.4	1.7	
Reduction (%)	82.3	60.0	77.7	58.6	

[a] Soluble Solid Lost for the MCT
[b] LSD Least Significant Difference (α 0.05)
[c] Change in Δ SSL using precooking methods.

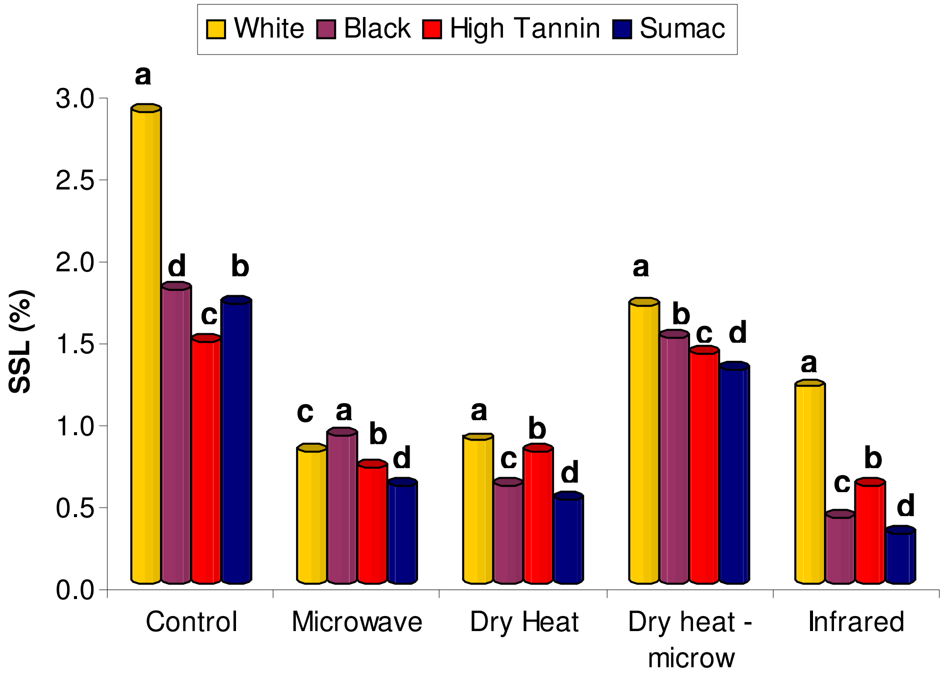


Figure 14. Changes in sorghum soluble solid losses (SSL) in cooking broth using precooking methods

SSL for precooked grain where higher for dry heat and microwaved treatment combined, but amount was lower than for control. SSL with this treatment ranged from 1.3 to 1.7% and reduction in SSL ranged from 6.6 to 41.3%. This reduction was significative for all varieties. Reduction in SSL is good because may improve the nutritional quality of the grain by retaining soluble vitamins and minerals.

Microwaved and dry heat treatment reduced the amount of SSL in cooking broth for all varieties. The reduction in soluble solid losses ranged from 27.5 to 50% using these treatments. Infrared heated grain had the lowest SSL in cooking broth. SSL with this treatment ranged from 0.3 to 1.2%. Infrared heating inhibited water hydration during cooking, thus SSL were lower for all varieties.

Color and appearance of precooked grain

The color of the whole precooked kernels was almost similar to the control (Fig. 15). White sorghum kernels presented a uniform light appearance and brighter color with slight yellowish hue. Sumac high Tannin presented brighter reddish-brown hue, with low b values. Black sorghum presented a brighter black-brownie hue, with low b value.

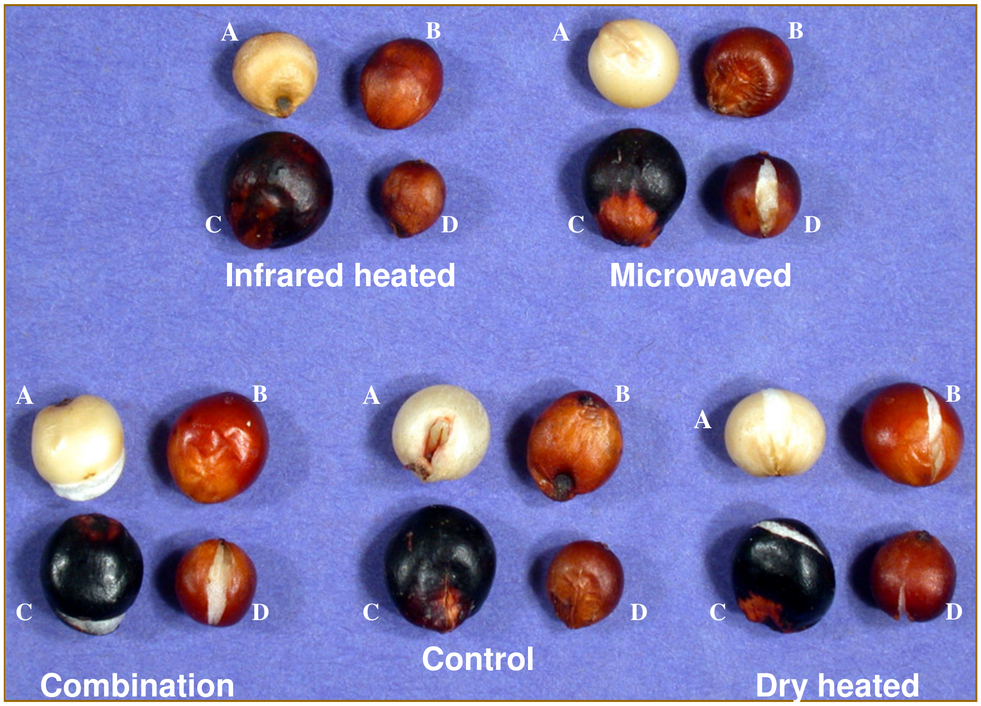


Figure 15. Color and appearance of precooked non-boiled sorghum kernels. White (A) high tannin (B), sumac (C) and black (D) sorghum kernels.

Most of the treatments (infrared, microwave, dry heat and combination of the last two) had those color characteristics with exception of the infrared heated kernels, which pericarp surface was roasted with an off color, presenting kernel shrinkage and a drastic reduce in bulk volume.

Microwaved grains presented shrinkage as well, but no so drastically as with Infrared heated grain and had no changes in pericarp color. The rest of the precooked kernels had an increase in size related to the control than can be observed marked in the dry heat and microwave treatment combined.

In general, precooked kernels after boiling in water had darker color compared to the control probably due to non-enzymatic browning and caramelization of sugars during cooking. (Fig. 16 and 17). White kernels had a mushy gruel-like texture after cooking which affected appearance of the product. In grain that took longer to cook this problem was marked, characteristics of harder endosperm grains.

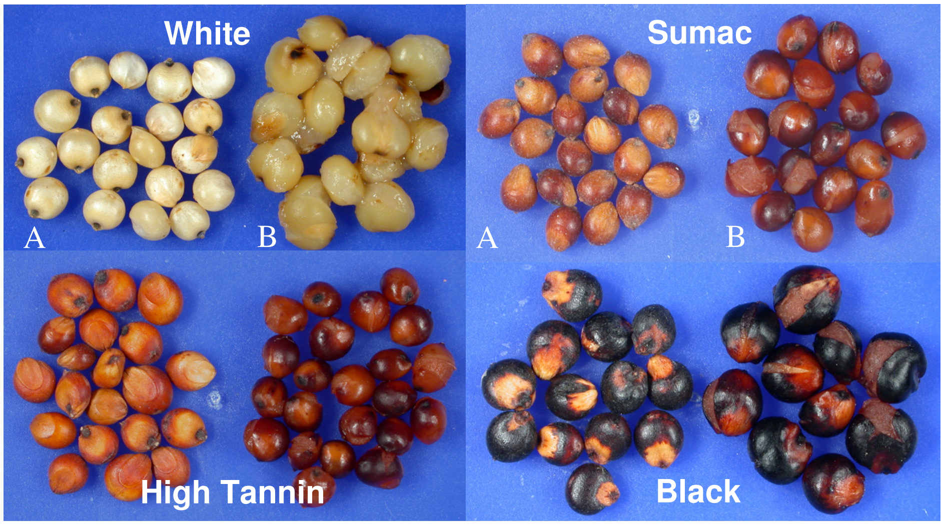


Figure 16. Color and appearance of precooked boiled sorghum kernels using combination of dry heat and microwave. A. Raw grain (left) and (B) cooked grain.

Precooked sumac, high tannin and black had darker pericarp color also, apparently due to some leaching of pigments into the endosperm through the split pericarp, formed during cooking. This happened in grain that had a pigmented testa. Most of the treatments had separate, firm and intact kernels with exception of the control, which had longer MCT and produced overcooked kernels with a mushy appearance.

The differences in size in and color of cooked kernels may be influenced by variables like minimum cooking time, endosperm hardness, hydration rates and other factors inherent to the treatment applied like temperature, residence time, doses of radiation and the way that heat was transferred into the kernel (Duodu et al.2002).

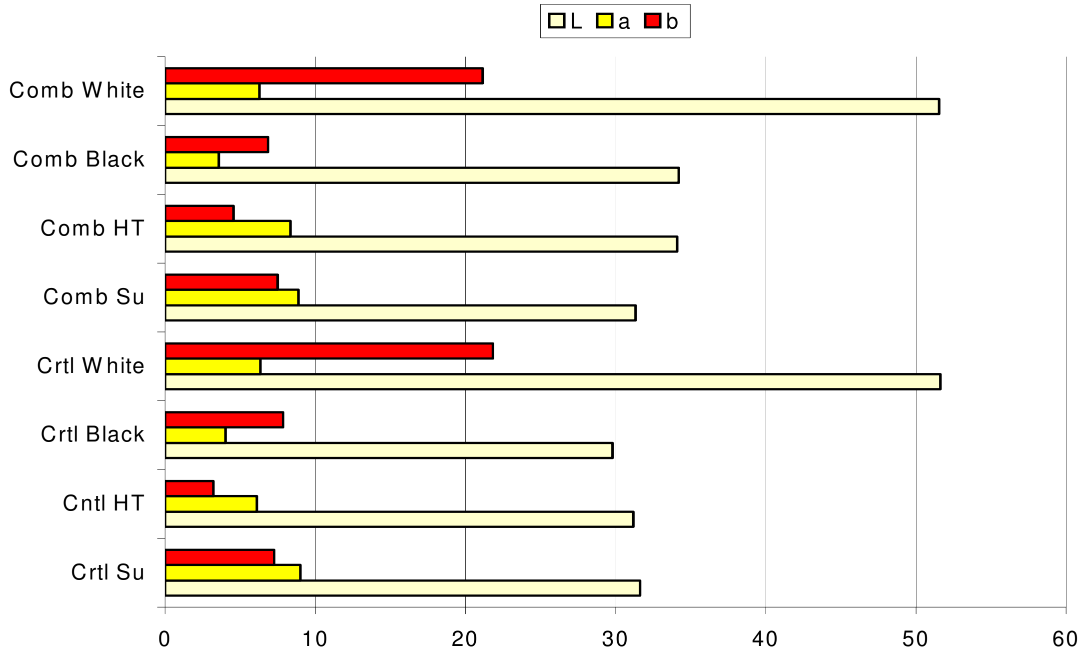


Figure 17. Color of control and precooked grain using combination of dry heat and microwave

Texture of precooked boiled kernels

Infrared heated grain for all varieties increased resistance to deformation used to crush a layer of cooked kernels (8 kg) compared to the rest of the treatments (Fig. 18). Significant differences in force required to crush the kernels were found. Infrared grain produced grain significantly tougher (more force required to reach yield point) than control grain. When this treatment was used water uptake was restricted with inhibited gelatinization of the starch producing Kernels with harder texture

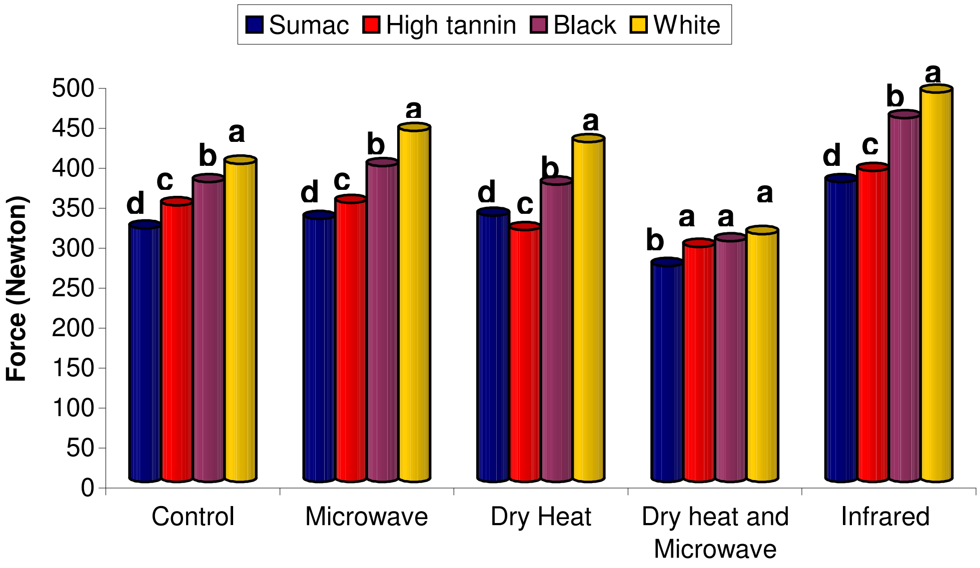


Figure 18. Force in Newton required to deform precooked boiled sorghum kernels

Precooked grain using a combination of dry heat and microwave produced the softer grain for all sorghum varieties. The toughness of the grain was almost similar for white, sumac and high Tannin sorghum using this treatment.

Dry heat and microwaved applied separately produced grain with similar toughness, but had harder texture compared to the control.

The softness of the grain in this case could be related to MCT and SSL during cooking. Also precooking treatments that caused major physical changes like endosperm splitting or stress cracking during heating and cooking produced softer kernels as observed with combination of dry heat and microwaved treatment.

Other parameters causing marked differences in softness among treatments are: the extent of starch gelatinization, endosperm structure, moisture content of grain and transfer of heat within the grain during the pretreatment application that caused some retrogradation and annealing of the starch in areas of the starch granules where moisture is limited or evaporated for example in the peripherical endosperm of microwaved or infrared heated grain.

In this study precooking methods were not modified for sorghum and were applied using the same conditions (temperature, residence time, moisture content) as described for rice. To improve texture and chewness of precooked boiled sorghum; is important to conduct further research to investigate the adequate precooking conditions in terms of moisture content, temperature and residence time, depending on cultivar characteristics, to get a better product.

Changes in structure of precooked kernels

Dry heat and microwave combined, produced the best treatment for quick cooking sorghum, so changes in kernel structure produced using this treatment were examined for all varieties.

Changes in structure were observed. The internal structure of white precooked sorghum kernels had many starch granules from the floury and corneous endosperm that retained their individual shape and did not form a continuous network (Fig.19 A).

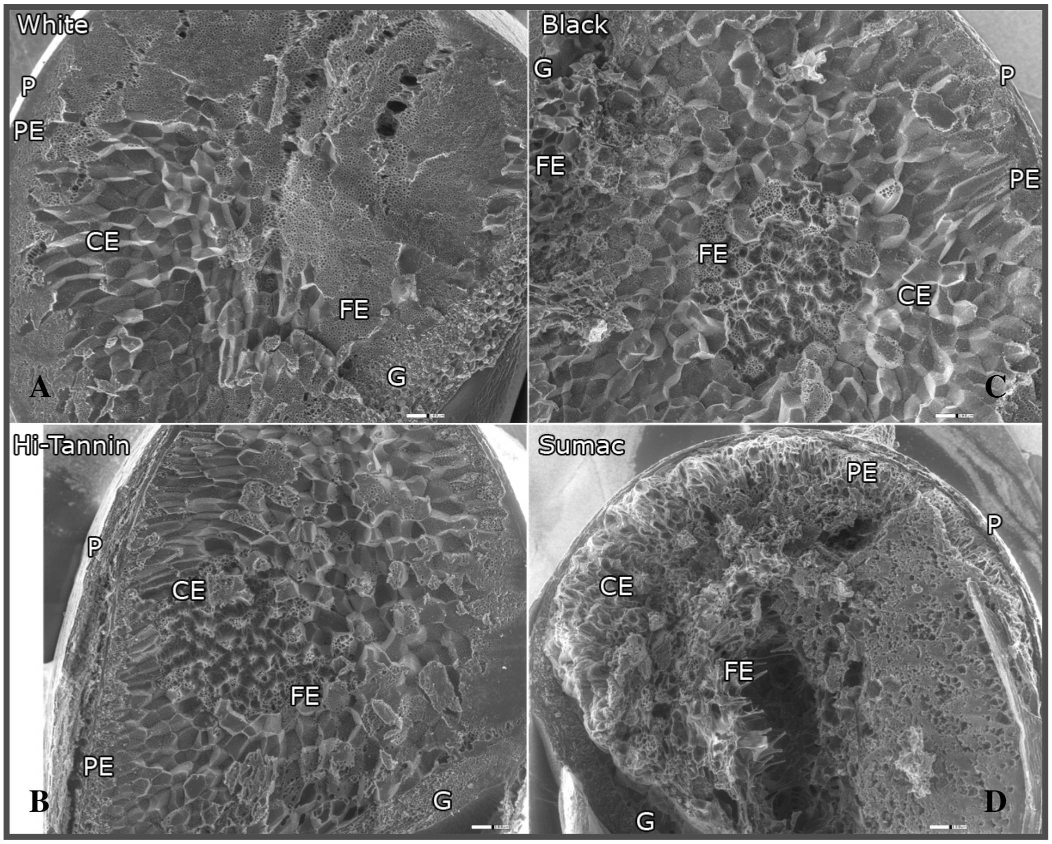


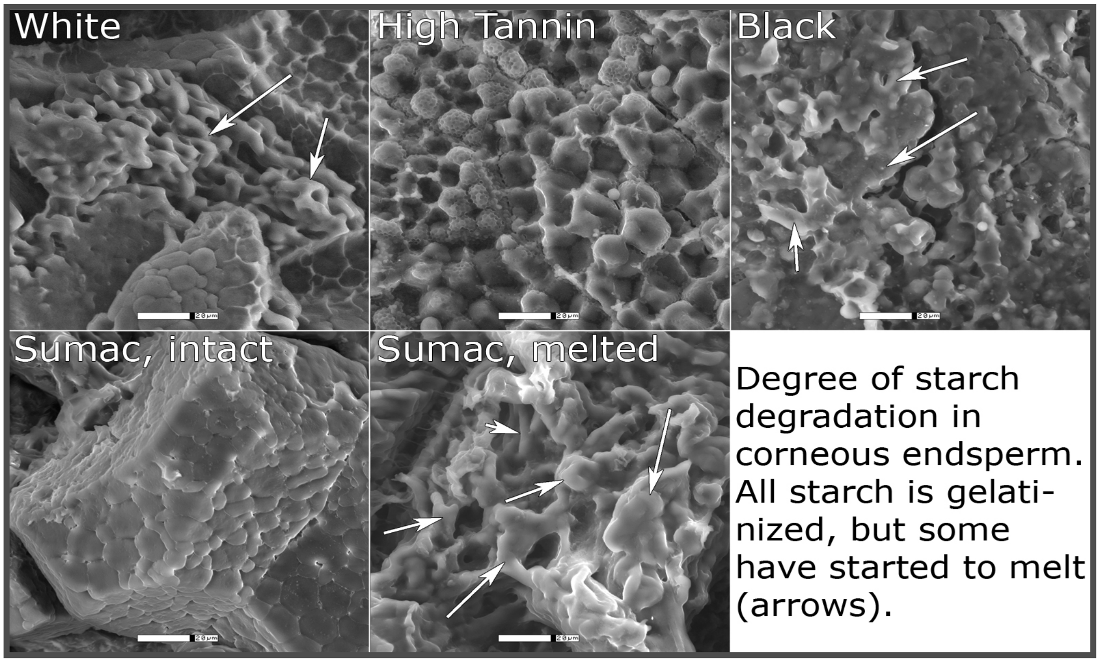
Figure 19. Photomicrograph of cross-sections of precooked sorghum kernels; P. pericarp; PE. peripherical endosperm; CE. corneous endosperm; FE. Floury endosperm; G. Germ. A. white kernel; B. high tannin kernel; C. black sorghum kernel and D. sumac kernel

However some areas of the corneous endosperm had partially and completely gelatinized starch granules. The internal moisture evaporates without leaving air tunnels, which explains the tightly packed hard endosperm of white sorghum. The moisture inside the kernel was probably not chemically available to the crystalline areas in the starch granules for gelatinization to take place during the limited heating tie (90 sec). Besides, a large amount of non-gelatinized starch was observed in the peripheral endosperm.

High tannin and black sorghum had intermediate hardness, so the starch granules in corneous areas are partially gelatinized, showing more completely gelatinized starch in floury endosperm area than white kernels. (Fig.19 B and C). No air tunnels were formed when moisture evaporated from the interior of the kernel. In the peripherical endosperm partially gelatinized starch granules were observed.

The internal structure of the precooked sumac (Fig.19 D) had more gelatinized starch in both corneous and floury endosperm, the internal moisture upon evaporation formed large air tunnels that disrupted all the structure at the center of the kernel. The disrupted starch-protein matrix made it easier for water absorption in pretreated sumac kernels during cooking.

Precooked boiled white kernels had more completely gelatinized starch granules in the corneous endosperm (Fig. 20), with a small proportion of non-gelatinized starch that retained their individual granule shape, which is typical of a hard endosperm grain. High Tannin and black presented similar characteristics but high tannin grain retained a large portion of unchanged granules in corneous endosperm and protein bodies appeared normal and embedded in a thick protein matrix. A higher degree of starch gelatinization was observed in black corneous endosperm because this grain is softer than high tannin sorghum, but both grains are classified as grain of intermediate endosperm hardness.



Degree of starch degradation in corneous endsperm. All starch is gelatinized, but some have started to melt (arrows).

Figure 20. Photomicrograph of cross-sections of corneous endosperm in precooked boiled sorghum kernels showing the degree of starch gelatinization

The sumac kernels had completely gelatinized starch. Starch was completely melted and embedded in a continuous network, characteristic of an overcooked grain. Air tunnels and bubbles formed during the evaporation of the internal moisture during heat application are observed. Soft endosperm grain types like sumac tended to swell and melt more extensively than hard or intermediate endosperm types (Mwangwela. 2005).

All varieties, responded significantly different to this combined treatment, although treatment conditions were held exactly the same for all grains. This treatment was the most effective for sumac because of its soft, floury endosperm structure and reduced kernel size. Processing conditions like temperature moisture and residence time could be modified and controlled to obtain better results when these treatments are applied depending on the cultivars characteristics.

CONCLUSIONS

Application of precooked treatments (specifically the combination of dry heat and microwave) to sorghum kernels before cooking was effective to produce a quick-cooked sorghum. This treatment produced a sorghum cooked in less time than control and cooking parameters were less affected than for control (less SSL and higher weight after cooking).

This is a practical method that can be suitable at home for household preparation or for utilization in small food business and results can be compared with the one obtained for boiled or steamed quick cooking rice, when long grain is used (rice whit high amylose content and a medium-high gelatinizing temperature). Rice consumers prefer grain rice that cooks dry and fluffy, with kernels that retain their conformation and remain separate after cooking. Thus, this treatment yielded a soft product with firm kernels, nice color and appearance.

MCT reduction with this treatment ranged from 41% for sumac (softer grain) and 30.9% for white sorghum (harder grain). Cooking time reduction for high Tannin and black was 32.5% and 49%, respectively. A higher increase in weight was shown by this treatment as well; cooked kernel yield was in the range of 75.3% to 82.9%. Wich is a good characteristic for food processors and consumers,

Precooking conditions didn’t affected significant the appearance of the kernels. Most of the precooked grain showed an increase in size and volume, some pericarp splitting and similar color to the original raw grain. Infrared heated grain had a pericarp surface that looked roasted of burned showing a decreasing in size and kernel shrinkage for all varieties.

Appearance of cooked kernel was acceptable, but harder grains with longer MCT like white kernels; presented gruel like and mushy texture. Cooking parameters of grains with pigmented testa (sumac, high tannin and black) resemble those of brown rice, in terms of color and appearance.

Texture for infrared heated grain was significantly tougher (more force required to reach yield point) than for the rest of the treatments. Softer grains were produced by a combination of dry heat and microwave,

When endosperm structure was examined, results shown that dry heat and microwave when combined; was effective harder endosperm varieties, softer endosperm like sumac had overcooked characteristics.

The response to treatment conditions like time-temperature profiles etc produce significant changes in the structure of this grain. Changes in physical and structural characteristics of pretreated whole sorghum may respond to inherent properties of each sorghum variety like size, hardness, endosperm type etc.

CHAPTER IV

NUTRITIONAL QUALITY OF WHOLE BOILED SORGHUM

INTRODUCTION

Sorghum has been dietary staples for centuries in parts of India, Africa, China and Central America. Today, these crops are significant contributors to the protein and energy requirements of millions of people. Various processing methods used to produce sorghum foods, affect the nutritional value of sorghum. Most African foods are processed from decorticated sorghum, grits or cracked kernels, which significantly reduces the amount of fiber, minerals, proteins, and lysine (Serna-Saldivar & Rooney, 1995). The development of new or modification of the existing processing methods to cook whole sorghum without affecting nutritional quality is important to improve the diets of many people.

In this chapter the evaluation of nutritional quality of whole boiled grain in comparison with precooked boiled sorghum was evaluated. No systematic research on the changes brought about by the use of precooking treatments and cooking of whole sorghum like rice has been reported. The objectives of this chapter were to determine changes in levels of constituents of the grain as well as antioxidant activity of whole boiled sorghum.

LITERATURE REVIEW

Whole sorghum composition and nutritional value

Sorghum grain composition is significantly affected by genetic and environmental factors. Whole sorghum grain generally contains: starch (75-79%) as the major component, followed by protein (9.0-14.0%) and oil (1.5-5.0%). Approximately 80%, 16% and 3% of the protein is in the endosperm, germ and pericarp respectively. Prolamins constitute the major protein fraction in sorghum followed by glutelins. These fractions are mainly located within the protein bodies and protein matrix of the starchy endosperm. (Rooney & Serna Saldivar, 1990).

Sorghum generally contains 1% less oil and significantly more waxes than maize. Lipids in sorghum are located in the scutellum and consist mainly of non-polar or neutral lipids (93.2%) that are composed by tryglicerides (85%) and diglycerides. The germ and aleurone are rich in fat-soluble and B-vitamins.

Fiber consists of endogenous components of plant materials that are resistant to digestion by enzymes in the monogastric stomach and upper gastrointestinal tract of animals. The major individual components are cellulose; hemicellulose, lignin, pectin and gums located in the pericarp and endosperm cell walls. Most of the fiber in sorghum is present in the pericarp and cell walls. Sorghum contains 6.5-7.9% insoluble fiber, hemicelluloses and cellulose and 1.1-1.2% of soluble fiber (Waniska and Rooney, 2000). Sorghum is an important source of minerals located in the pericarp, aleurone layer, and germ. Whole sorghum is considered an adequate source of magnesium, iron, zinc, and copper that are reduced by germination and decortication. (Appendix, A)

Phosphorous is the mineral found in greatest amounts but availability depends on the amount bound by phytates (Rooney & Waniska, 1992). In addition to these components, whole sorghum contains other health promoting components such as phytochemicals, which include phenolic compounds that have antioxidant properties and can protect against degenerative diseases (Towo & Ndossi, 2003).

The definition of a phenolic compound is any compound containing a benzene ring with one or more hydroxyl groups like phenolic acids, flavonoids and condensed tannins (proanthocyanidins) etc. (Awika, et al. 2000).

Sorghum phenolic antioxidants

Sorghum, as other cereal grains, fruits and vegetables have phytochemical compounds, which have been evaluated for antioxidant properties (Dlamini, 2007) and anticancer activities.

Phenols are valuable antioxidants that contribute to the natural body defense system in scavenging free radicals, chelating metals and repairing lipids, proteins and DNA. Phenolic compounds also provide flavor and color characteristics to fruit juices, wines and other foods.

The phenolic acids identified in sorghum include gallic, protocatechuic, vanillic, ferulic, caffeic, cinnamic, p-coumaric, and p-hydroxybenzoic acids. In cereal grains, the phenolic acids exist as free acids, soluble and insoluble esters and are concentrated in the outer layers of the kernel (pericarp, testa and aleurone).

Flavonoids consist of three major groups: flavones, flavonols and flavans, but the major group of flavanoids in sorghum are the flavans. The major flavans in sorghum are the anthocyanidins (flavan-3en-3ols), which are the major pigments of flowers, stalks and leaves. The other group present is catechins (flavan 3-ols) and the third group is leucoanthocyanidins (flavan 3-4-diols).

Tannins are effectively classified as water-soluble phenolic compounds with high molecular. Chemically there are two classes of tannins: hydrolysable tannins and condensed tannins. The tannins found in sorghum are the condensed tannins of flavolans; they are also referred to as proanthocyanidins because when treated with mineral acids, anthocyanidins are released (Abdul Kadir, 1990).

Sorghums with more than 1% based on grain weight condensed tannins are regarded as high Tannin sorghums (Type III). More recently any sorghum with a pigmented testa is classed as tannin sorghum. Significant variation occurs in tannin content among sorghums with a pigmented testa.

Phenolic antioxidant act by donating a proton to a free radical, this stabilizes it, while the antioxidant free radical that is generated is stabilized by resonance due to the presence of the benzene ring. The free radicals in food systems are usually derived from fatty acid auto-oxidation, which results in chain reaction leading to production of more free radicals. The ability of polyphenols to chelate iron and copper further supports their role as preventative antioxidants in terms of inhibiting transition metal catalyzed free radical formation (Awika, et al. 2000).

The total phenol content of sorghums is significantly correlated with antioxidant activity (Awika, et al. 2003; Dykes et al. 2005). Sorghums with a pigmented testa have increased antioxidant activity due because of tannins. Sorghums containing condensed tannins have consistently shown the highest antioxidant activity in vitro. The quantities exceed the antioxidant levels of most if not all fruits and vegetables.

Antioxidant activity increased when sorghum had purple/red secondary plant color, a black or dark-red thick pericarp and a pigmented testa and a spreader gene (Dykes et al. 2005). Kernels that contain condensed tannins usually but not always have a thick highly pigmented testa; these sorghums are potent sources of antioxidants (Taylor, et al. 1997).

Tannin sorghums like high tannin, black or “sumac” are special sorghum varieties with the highest levels of phenols and antioxidant activity. Awika, (2003) reported that tannin and black sorghum bran contained higher antioxidant activity showing 2400 and 1008 μmol Trolox equiv/g, respectively.

Sumac grain had the highest antioxidant activity value of 360 μmol Trolox equiv/g (ABTS) in contrast with white sorghum (non pigmented) contained the lowest amount 14 μmol Trolox equiv./g (ABTS).

Determination of antioxidant activity

Antioxidant activity can be evaluated with different mechanisms. The most commonly used are ABTS (2,2'-azinobis-(3-ethylbenzothiazoline-6-sulphonic acid) and DPPH (α,α diphenil-β-picrylhydrazyl radical) The ABTS radical is used in the Trolox equivalent antioxidant capacity assay (TEAC), where the ability of antioxidants to scavenge the radical cation (ABTS) is measured relative to Trolox (6-hydroxy-2, 5,7,8 tetramethylchorman-2-carboxylic acid) a water soluble analogue of vitamin E or ascorbic acid. When Trolox is used the antioxidant activity capacity is expressed as Trolox equivalent antioxidant capacity (TEAC). (Awika, 2003).

Dietary fiber and sorghum bran

Sorghum is an excellent source of insoluble dietary fiber. That is composed of compounds that cannot be broken down by digestive enzymes in the small intestine, but can be fermented by bacteria in the large intestine. Thus insoluble fiber increases fecal bulk and decreases fecal transit time through the large intestine. Soluble fiber includes pectins, gums and beta-glucans, which affect absorption and related activities in the small intestine. Soluble fibers slow nutrient absorption and are fermented by gut microflora, which produce short chain fatty acids, that may lower serum and LDL cholesterol, glycemic response and insulin levels (Rooney & Murty, 1987).

Cereal bran is a rich and common source of dietary fiber as well as various vitamins and minerals. Bran from cereals like rice, oats, sorghum and barley are highly effective sources of dietary fiber in animal and human studies.

Effect of processing sorghum on antioxidant activity and nutritional value of sorghum foods

Processing of grains may lead to variable effects on the extractable phenolic compounds, dietary fiber, vitamins and minerals (Albertson &

Tobelman, 1995). Tannins bind to proteins, carbohydrates and minerals and thus they may reduce digestibility of these nutrients. To reduce the negative effects, of high Tannin, decortication, germination, fermentation or chemical treatments are used. Information on the effect of processing on the antioxidants of sorghum-based foods is generally scanty, but work done by Awika, (2003) has shown that most processes decrease retention of assayable proanthocyanidins in food products. Processing tannin or black sorghum into food products affects phenol levels. For example various thermal processes like roasting (200 C^0 for 5 min), microwave heating (For 1 min) and blanching (100 C^0 for 2 min) caused 14, 93 and 98% reduction of assayable high tannins in foods.

Bread and cookies fortified with sorghum bran, retained 57 and 72% respectively of the original bran antioxidant activity. Awika et al. (2003) also reported that extrusion of tannin sorghum caused an 85% decrease in polymeric tannins while the lower molecular weight tannins increased by 29 to 478%.

Phenol levels of maize tortillas containing black or brown sorghum bran decreased by 33-38% and 47-50% respectively (Cedillo-Sebastian, 2005)

Frying into tortilla chips reduced phenol levels by 52-55% for black sorghum and 60-66% for tannin sorghum bran respectively compared to the original tortillas. Awika et al. (2003) reported that extrusion decreased the degree of polymerization (DP) in proanthocyanidins, in comparison with raw grain. Dlamini (2007) reported that tannin type III sorghum extrudates retained only 21% of their original assayable tannin content and 89% of their original antioxidant activity. Total phenolic compounds measured in sorghum porridges decreased by 38 to 65% after cooking.

Reduction of detectable tannins in thermal processing can be attributed to structural breakdowns and chemical rearrangement. Thermal food processes in general cause polyphenols to form insoluble complexes with protein, vitamins and minerals. This in turn decreases nutrient bioavailability and high tannin extractability.

Nutritional losses with thermal processing, alkaline cooking and boiling in water, are generally not great for grain products, although they can be significant with fruits and vegetables. Cooking sorghum (boiling) in water, depending on its length, reduces the tannin concentration in sorghum and enhances dietary fiber and the development of resistant starch, which leads to increased dietary fiber and enlargement of the fecal volume in animals and humans (Duodu & Taylor, 2002).

Four dietary factors: Resistant starch (RS), Dietary fiber (DF), protein content (kafirin fraction) and polyphenols explain the variation in nutritive values of raw uncooked and cooked boiled sorghum products. The RS and nitrogenous substances formed in response to boiling, serve as energy and N substrates for gut microflora resulting in a slight reduction of protein digestibility. Food processing by application of 100 C^0, results in protein denaturation and aggregation reactions.

During boiling, antioxidants and other soluble vitamins and minerals are partially extracted in the boiling water; if this water is discarded these antioxidants and soluble solids are lost. Iron (FE) and Zinc (Zn) solubility decreased for the cooked grains (Polycarpe kayoed, 2006)

Matuscheck et al, (2001) reported a significant decrease in soluble solids and soluble vitamins and minerals like Iron and Zinc, after cooking of sorghum grain in water and related this to the chelating effect of phytate and phenolic compounds.

Whole boiled sorghum as a nutraceutical food

Nutraceuticals or functional foods have components that collectively impart a physiological benefit that enhances overall health including disease treatment and/or prevention (Gordon et al. 2000).

Functional foods are not strictly defined but include dietary supplements, medical foods, enriched or fortified foods, processed cereals, beverage products and isolated nutrients and phytochemical components.

Specialty sorghums have already been used to produce products with desirable qualities and show promise as functional food components (Appendix B). Rooney et al. (1992) reported that sorghum and pearl millet bran were excellent bulking agents compared to wheat. They also reported that tannin sorghums are slowly digested. Diets rich in tannin sorghums contribute to a longer period of fullness and satiety.

Sorghum also has anticarcinogenic properties. A study by Re et al. (1999) shows that black and high tannin sorghum bran reduced colon carcinogenesis in rats. In their study rats fed diets containing black or tannin sorghum bran had fewer aberrant crypts than those fed diets containing cellulose or white sorghum bran. The reduction could be due to antioxidant activity of the black and tannin sorghum bran.

Sorghum bran is also a good source of dietary fiber, which aids in gastrointestinal health through bulking fecal matter, decreasing constipation and reducing the absorption of carcinogenic metabolites. Dietary fiber also aids in lowering plasma and liver cholesterol levels and maybe a significant factor in treating coronary heart disease (Re et al. 1999).

The antioxidant potential of tannin sorghums is important due to the potential benefits of these compounds to human health. Oxidative compounds in the human body, when out of balance cause cellular destruction leading to degenerative diseases like arthritis, Parkinson’s, cancer and cardiovascular diseases. Antioxidants react with these compounds to impede or prevent oxidative chain reactions (Awika, et al. 2003).

Rice nutritional quality

The composition of milled rice varies depending upon the variety, its agronomic conditions during growth and excellent milling. The outer layer removed during milling determines the nutrient composition of rice (Sotelo et al. 1990). Rice has about 7% high quality protein and only traces of fat. Varietal differences in protein content have been established. Milled rice has been reported to contain less total lipids (1.09%) in comparison with brown rice (2.65%) or bran (20.24%). Predominant fatty acids identified in rice were palmitic, linoleic and oleic acid. Milled rice is almost 90% composed of starch on a dry basis, which in turn is composed of amylose and amylopectin (Hoseney, et al. 1998).

The cooking and eating quality of rice is influenced by its amylose content (Houston, 1992). The mineral content of rice also varies depending upon the growing conditions and degree of polishing .The grain is a rich source of B complex vitamins, which are present in the outer layers of the grain. Abrasive milling greatly reduces the vitamin content (Subramanian, et al. 1991).

There are many primary processed rice products, most of the produce is consumed in the form of cooked grains and their physicochemical and cooking quality varies considerably. The cooking quality also depends on the method of cooking used. In previous studies have been reported that cooking of rice influences its nutritional quality. The nutronal value of raw and cooked rice varieties changed significantly. (Wells & Davis, 1994).

The fat content of rice cooked using microwave and pressure-cooking brought about a significant decrease (20-60%), but between cooking methods there was not significant difference in fat content. In the same study thiamine, iron, calcium and phosphorus content of cooked samples were determined. All this elements shown significant decreases in the cooked samples. Thiamine decreases by 29-63% (pressure cooked) and 38-69 (microwave cooked); iron decrease by 33 to 50% on cooking (Polycarpe Kayoed, 2006).

The total dietary fiber of boiled white milled rice increase after cooking from 2.24 to 3.03 g/100g. Also the in vitro protein digestibility was slightly higher from 80 to 90.8%. The starch digestibility of cooked samples was significantly higher than raw rice samples (Houston, 1992).

MATERIALS AND METHODS

In this phase of the study two sorghum varieties were selected for further analysis of nutritional value and antioxidant activity. The varieties selected were food grade white sorghum ATX635x436 and sumac. The white sorghum variety was based on the preference of people for consumption, and acceptance. These sorghum varieties are well adapted, produce consistent crops and are often preferred for food production in Africa, Asia and Central American countries.

Sumac is an especial unique sorghum variety with excellent physical, properties (small grain and softer endosperm), good cooking quality, plus possible health benefits due to high tannin content. The characteristics of the raw materials are shown in Table I and II of chapter I.

Precooked white and Sumac, using combination of dry heat and microwave and control (grain non-precooked just boiled) were evaluated for proximate composition and antioxidant activity (ABTS). The results were compared with proximate analysis and antioxidant activity of raw sorghum of both varieties.

Proximate analysis of samples

Samples of precooked and cooked white and sumac sorghum were freeze dried using liquid nitrogen to remove all the moisture and then ground into flour using a UDY cyclone sample mill (model 3010030, U.D. Corp., Boulder, Colorado) equipped with a 1.0 mm screen. The flour was stored in plastic bags at –4ºC until analyzed for protein, ash, minerals and dietary fiber. The samples were analyzed for proximate analysis using standard AAAC, (2006) approved methods.

Antioxidant activity of samples

The Antioxidant activity of cooked whole non-pretreated and pretreated (with a combination of dry heat and microwave) white and sumac samples were evaluated using the (ABTS) method modified by Awika, et al. (2003). For the ABTS assay the phenols were extracted for two hours using acidified methanol. The ABTS radical was generated overnight (12 hours) by reacting in the dark, equal volumes of 8 mM ABTS solution in distilled/deionized water with 3mM of potassium persulfate. The working solutions were prepared by diluting ABTS free radical mixture with a pH 7.4 phosphate buffer containing 150 mM NaCl, to an absorbance of 1.5 wavelength of 734 nm (Re, et al. 1999; Awika et al. 2003).

RESULTS AND DISCUSSION

Changes In chemical composition and antioxidant activity of precooked sorghum

Processing and the application of precooking methods on whole grain sorghum affected levels of the major chemical components of sorghum grain and antioxidant activity. A comparison of chemical composition and antioxidant activity of precooked sorghum and control (non-precooked just boiled) is shown in Table XIII).

Protein content

An increase in protein content was observed for cooked non-pretreated sorghum grain for both varieties. This could be attributed to a relative enrichment of the kernel in nitrogen due to the loss of water-soluble solids low in nitrogen during boiling as was observed in parboiled sorghum (Young, 1990). Thermal processing of protein results in varying levels of structural changes, which depend on the severity of heat treatment and other conditions. According to Subramanian et al. (1981) protein in cereals containing significant amounts of carbohydrates can be susceptible to heat processing because interaction between functional groups within protein chains or between protein chains and other grain constituents like high tannins are known to form cross linkages.

Cooking reduces digestibility of sorghum kafirin through disulfide-mediated polymerization principally among protein found at the periphery of the protein bodies. The quality of protein as determined by its amino acid content may be affected by the severity of heat processing (time and temperature) which affected the digestibility of processed grains (Rum-Kreuter & Demmmel, 1990).

Table VIII. Effect of precooking on chemical composition and antioxidant activity of whole precooked sorghum

Cultivar	Protein (%) (N X 6.25)	Fat (%)	Ash (%)	Crude Fiber (%)	Dietary Fiber (%)	ABTS[a] (Trolox/g)
White						
Raw[1]	9.98	2.62	1.33	1.52	9.07	14.0
Control[2]	10.96	2.86	1.45	1.86	11.25	8.50
Precooked[3]	10.37	2.47	1.19	1.49	13.68	9.70
Sumac						
Raw[1]	10.24	2.84	1.40	1.59	12.87	360.0
Control[2]	10,81	3.18	1.54	1.65	10.93	81.62
Precooked[3]	10.11	2.63	1.37	1.43	14.00	173.10

[1] whole raw sample
[2] whole boiled grain
[3] whole precooked (using combination of dry heat and microwave) and boiled in water
[a] Antioxidant activity of sorghum samples expressed as Trolox equivalent of antioxidant capacity (TEAC).

Protein content of precooked samples decreases in comparison with cooked non-pretreated samples, but were significantly higher than protein in raw.

Crude fat

Cooking significantly increases fat content in non-precooked grain for both varieties and lower values were observed for precooked grain in comparison with raw whole sorghum values. The influence of boiling on the quality of lipids in some grains was reported to increase due to hydrolysis of tryacilglycerols into free fatty acids and accelerated the formation of hydroperoxides and secondary oxidation products (Ohlsson, 1994a). In general the peroxide values of lipids heated where water is the heat transfer medium are nearly twice those produced by other ways of heating.

Crude fat in sorghum is composed of essentially free, non-polar lipids (Waniska & Rooney, 2000) and about 0.2 to 0.5% of wax from the cutin layer covering the pericarp. For precooked samples the physical damage of the wax containing cutin layer to the cooking broth under conditions of high temperature and constant stirring could account almost entirely for the reduced crude fat content. In microwaved and pressure-cooked white and brown rice fat estimated as total fat or crude ether extract range from 0.5 to 0.6 g/100 g in raw rice. Cooking by both methods decreased the fat content. The authors attributed this to a different degree of polish of the rice varieties and the washing process, wherein the lipids on the surface of rice grains were washed off during cooking. Most of the lipids are concentrated in the outer layer on the grain (Re et al.1999)

Ash content

Ash content reported was higher in cooked non-pretreated grain for both varieties. It has been reported that the mineral composition and content of the sorghum grain largely depends on the availability of soil nutrients. Some minerals are stable during heat processing, but cooking should bring about a significant decrease in ash content. The losses of mineral compounds during cooking occurs due to a combined effect of soaking and cooking since the samples were soaked prior to cook, losses of soluble minerals like iron, calcium, zinc and phosphorus may occurred (Polycarpe kayoed, 2006), as was observed in cooked pretreated grain.

The ash content in precooked samples, decreased from the original raw grain content in both varieties. The pericarp, aleurone layer and germ are rich sources of ash (Duodu, et al, 2002). Much of the mineral content is located in the pericarp therefore ash content was reduced significantly by physical damage of the pericarp (ruptures) that caused leaching of the soluble minerals into the cooking broth, reducing its content due to MCT and SSL that was longer than for pretreated grain. Similar results were observed in the total ash content of microwaved and pressure cooked white and brown rice, where cooking brought about a significant decrease in ash content (11-38%), including losses of iron, calcium, and phosphorous due to age and variety of samples, climatic conditions and the extent of milling plus the effect of washing, soaking and cooking. (Houston et al. 1972).

Phytin the storage form of phosphorus in seeds is the most recognized and documented antinutritional factor that chelates divalent minerals such as Fe and Zn, forming insoluble complex with this minerals and reducing their bioavailability. Other inhibitors of the absorption of divalent minerals are phenolic compounds, which affect activity and biological availability of metal ions by chelating the metal. Phytate and phenolic compounds maybe partly responsible for the widespread mineral deficiencies observed in populations that subsist largely on sorghum and other cereals (Zheng, et al. 1998; Polycarpe kayoed, 2006).

Soaking and cooking reduces the phytate content and high Tannin concentration, in sorghum. Soaking overnight at room temperature caused 15-

35% and 42-58% reduction of these compounds respectively (Osman, 2004) improving mineral availability in the cooked products.

Crude fiber and dietary fiber

Crude fiber content of non-pretreated grain was significantly high. The fiber in sorghum is mainly insoluble fiber (82.6%). Sorghum contains 6.5 to 7.9% of insoluble and only 1.1 to 1.23% of soluble fiber including B-glucans, which comprise most of the soluble part. Thermal processing of cereals is known to cause redistribution of insoluble and soluble dietary fiber. In addition small amounts of resistant starch have been detected in the insoluble dietary fiber fraction, which increases with increasing heat treatment (Osman, 2004) These two factors may be responsible for the increased dietary fiber content recorded on pretreated sorghum samples.

In high tannin sorghum like sumac, cooking may increase the amount of dietary fiber due to the formation of polyphenols-protein complexes. Among major cereals, high Tannin sorghums are thought to contain the most protein associated with the dietary fiber fraction (Waniska & Rooney, 2000).

In a study of dietary profiles of milled Basmati, white, brown and Jeere rice, total dietary fiber (TDF), insoluble (IDF) and soluble dietary fiber (SDF) fractions, ranged from 2.08 to 2.82; 1.97 to 2.74 and 0.53 to 0.80g/100g, respectively. Cooking resulted in a non-significant increase in dietary fiber of rice varieties; the increase was higher for microwave-cooked samples than pressure-cooked samples. The increases in dietary fiber for pressure cooked samples were: TDF, 5-24%; IDF, 4-5% and SDF, 6-42%; while in microwaved cooked samples the increases were: TDF, 7-35%, IDF, 9-29% and SDF, 6-42%.

Antioxidant activity

As was expected, Antioxidant activity of processed sorghum decreased (Table VIII). The antioxidant activity of non-precooked sorghum was drastically reduced. Retention in cooked non-pretreated was 22.7% for sumac and 60.7% for white grain.

Precooked samples retained more antioxidant activity related to the original content of raw grain (Table IX). Retention for pretreated sumac was 67.88% and 74.74% for white. As was explained before, Awika, (2003) and Dlamini, (2007) reported that most processes decrease assayable proanthocyanidins retention in final products. In general, processing high tannin or black sorghum into food products affects its phenol levels. Longer MCT and higher SSL in non-pretreated samples, plus structural breakdowns and chemical rearrangement of proanthocyanidins polymers that are forming insoluble complexes with protein vitamins and minerals, during cooking, may influence these results.

Table IX. Retention of ABTS antioxidant activity (µmol TE/g) in sorghum after cooking. TE= Trolox Equivalents

Treatment	Before	After boiling	Retention (%)
Sumac			
Control	360.0*	81.6 ± 3.01**	22.7
Precooked + boiled	255 ± 0.3**	173.1 ± 1.32**	67.8
White			
Control	14.0*	8.5 ± 0.49**	60.7
Precooked + boiled	9.75 ± 0.6**	7.25 ± 0.66**	74.7

*Values corresponding to unprocessed sorghum. Adapted of Guajardo et al. (2006)
** Measured values of sorghum samples

During boiling, most of the phenolic compounds are partially extracted in the boiling water; reducing the antioxidant activity of the boiled product. If this water is discarded, as is usually done, all soluble solids compounds are lost in the cooking broth; reducing significantly the nutritional value of the cooked sorghum. In this study sorghum was cooked in excess water as is done in many parts of the world, so, studies about cooking quality parameters of sorghum grain cooked in limited water should be investigated and can solve the problem of nutritional deficiency of boiled cereal grains.

In this study a preliminary trial cooking whole sorghum in limited water was performed, but the method was not practical in terms of time, energy consumption and handling problems of the cooking product. By the time that water was absorbed completely, a sticky gruel like sorghum paste was formed at the bottom of the cooking pot, apparently formed by lipids hydrolization present in the germ and pericarp, which caused handling problems. The real cooking time of sorghum could not be evaluated appropriately. Adding more water to initiate the boiling process again was significantly time and energy consuming. The sorghum looked overcooked at the end of the process. The exact water amount needed to reach minimum cooking time couldn't be measured adequately.

CONCLUSIONS

Precooking treatment (In this case combination of dry heat and microwave) applied to raw grain before cooking produced a nutritive sorghum grain cooked in less time; with increased dietary fiber and high antioxidant potential for consumption like rice or as a component in other food products such as salads, desserts, etc.

Chemical composition of precooked samples changed after cooking in comparison with raw and control grain. Fat, protein and ash content were slightly reduced. Dietary fiber and antioxidant activity were relatively high. This samples retained more antioxidant activity related to the control. These changes may be attributed to differences in heat processing (time and temperature profiles) and soluble solid losses produced during cooking.

The nutritional quality of pretreated samples could be compared with the results analyzed for milled white long grain, brown rice and basmati rice when microwaved or pressure cooked (Houston, 1972). The changes in the nutritional profile with the application of those thermal treatments behave the same as for sorghum. Cooking in excess water influenced the nutritional quality of sorghum due to high soluble solids lost in cooking broth. Cooking sorghum in limited water could solve the problem of nutritional deficiencies in boiled cereals if a practical method to do it is developed.

In this study a preliminary trial shows that this method is not practical in terms of time, energy consumption and handling problems of the cooking product. The real cooking time and the exact amount of water need to reach minimum cooking time of sorghum could not be evaluated appropriately. Adding more water to initiate the boiling process again was significantly time and energy consuming.

CHAPTER V

SUMMARY

COOKING QUALITY OF WHOLE, CRACKED AND DECORTICATED SORGHUM

Minimum cooking time (MCT) for whole sorghum ranged form 22 to 55 min and soluble solid losses (SSL) ranged from ranged from 1.0 to 1.5%. Cultivar characteristics like endosperm hardness, kernel size and pericarp thickness may affect cooking quality parameters. Cracked and decorticated grain had shorter MCT. This ranged from 8.8 to 17.5 min and from 11 to 25.3 min, respectively.

The cultivar with soft endosperm (sumac) had shorter cooking time when utilized whole, cracked or dehulled and hydrated faster than sorghums with hard or intermediate endosperm hardness (white ATX635X436, black and high tannin).

Processing of cracked sorghum was practical in terms of short cooking time and production of grain with softer texture, but higher soluble solids (ranged from 1.3 to 2.9%) and leaching of pigments into the exposed endosperm and cooking broth occurred. Utilization of decorticated kernels reduced cooking time also, but nutritional value is affected with the removal of the pericarp, plus the SSL (ranged from 0.5 to 0.7%) produced during cooking.

The long grain rice types have comparatively lower values in terms of MCT (22 min) compared to whole sorghum and SSL are similar to values obtained for cracked grain (1.7 to 2.2%). kernels show a minimum of splitting. Short and medium rice grain shows relatively longer cooking time (30 to 35 min) but no longer than cracked or decorticated sorghum and higher SSL (28% to 40%) during processing. The kernels show extensive disintegration.

Cooking in excess water influenced the nutritional quality of whole sorghum due to high soluble solids lost in cooking broth (ranged from to1.0 to 1.5% for all varieties evaluated). Cooking sorghum in limited water could solve the problem of nutritional deficiencies in boiled cereals if a practical method to do it is developed. In this study preliminary trials show that this method is not practical in terms of time, energy consumption and handling problems of the cooking product. The real cooking time of sorghum could not be evaluated appropriately. Adding more water to initiate the boiling process again was significantly time and energy consuming. The sorghum looked overcooked at the end of the process. The exact water amount needed to reach minimum cooking time couldn't be measured adequately.

PROCESSING CHARACTERISTICS OF WHOLE COOKED SORGHUM

Precooking was evaluated in whole grain of white, sumac, high tannin and black sorghum kernels. When sorghum was precooked the cooking quality characteristics were improved.

The most effective treatment was application of dry heat and microwave energy combined. This treatment reduced MCT and SSL for whole sorghum from 31 to 49%; and 6.6 to 41.3%, respectively for all varieties compared to the control. Higher yields of cooked grain can be obtained using this process (weight increase was increased from 75.3 to 82.9% in comparison with the control not precooked), which is a good advantage for food processors and consumers. Rice kernels when boiled presented a higher water uptake capacity (110% to 150%), compared to whole sorghum. Water uptake values at were higher (300 to 400 ml per 100 g) for short and medium grain varieties of the preferred types.

Precooked sorghum had slightly altered cooking and sensory properties in terms of color, texture and appearance of the final products. The formation of a gruel-like paste during cooking normally associated with white whole grain and longer cooking time, affected the appearance. The black and high tannin sorghum varieties evaluated yielded firm, separated kernels with darker color after cooking and the pericarp had some splitting that allowed water uptake easily. Evaluation of the pretreatment by a consumer panel is needed to rate sensory properties as acceptable or not, since sensory characteristics were evaluated just by the researcher.

Chemical composition changed after precooking. Protein, ash and fat were slightly reduced compared to the control, however precooking produced a nutritive sorghum with increased dietary fiber and high antioxidant potential. Almost half of the antioxidant activity was retained (67.8%) in comparison with control (22.7%) for the high Tannin varieties.

The application of precooking processes could make a significant contribution to reduction of cooking time in areas where sorghum is available and for US and European markets where “the need” for whole grain functional or nutraceutical foods is increasing. The black and high Tannin sorghums could produce specialty foods with unique flavor and texture and high antioxidant activity with all the benefits of whole grains.

APPLYING THE TECHNOLOGY OF PRECOOKING FOR PRODUCT DEVELOPMENT

The processing benefits of precooking were emphasized by cultivars with hard endosperm or intermediate hardness, because grain with soft endosperm was overcooked. However the precooking conditions must be adjusted for sorghum varieties with softer endosperm structure to improve the cooking properties**.** After pretreatment the softer grain, sumac, even if cooking time was the shortest, gave higher SSL during cooking (1.1%) which implies lower retention of nutritional components in the final product. This illustrates the impact that this technology could have on nutritional quality of grains to provide nutritious foods to people whose staple diet consists of mainly cereal products typically low in nutritive components.

Application of this technology to different raw materials other than rice or legumes is encouraged. Also precooked grain seems to have application other than preparation of rice-like products, for example like an ingredient for granola bars, desserts or side dishes like exotic mixed salads with other grains. The inclusion of whole boiled sorghum as an ingredient in some foods has been investigated and preliminary results were favorable (Appendix B)

FURTHER WORK

The cooking quality of sorghum and the effectiveness of precooking is a function of moisture content and time-temperature profile. By varying these parameters, e.g. increasing moisture content by soaking longer or decreasing residence time and heating, a completely different product could be obtained. Thus, these parameters should be investigated to limit energy requirements and yield a product with acceptable cooking and sensory properties, depending on the cultivar physicochemical characteristics. Besides, a trained panel should evaluate their impact on sensory properties.

In this study sorghum was cooked in excess water as is used in many parts of the world, but soluble solid losses leached from grain into the cooking broth. If this cooking water is discarded soluble vitamins minerals and phenolic compounds are lost. So, cooking quality parameters of sorghum grain cooked in limited water should be investigated.

A more precise and complete analysis of the nutritional quality of boiled whole sorghum is required with special attention to the retention of B-vitamins and minerals after cooking. A chemical Analysis of the composition of cooking broth of whole and cracked grain is required to determine the amount of phenolic compounds and other soluble material that are extracted during boiling The compounds in cooking broth could be used in the elaboration of other products or as an ingredient. Tea, food colorants etc. could be developed from this source.

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APPENDIX A

NUTRITIONAL QUALITY OF WHOLE SORGHUM

TABLE A-1. Nutrient composition of sorghum, millets and other cereals (per 100 g edible portion; 12 % moisture)

Food	**Protein (g)**	**Fat (g)**	**Ash (g)**	**Crude fibre (g)**	**Ca (mg)**	**Fe (mg)**	**Thiamin (mg)**	**Riboflavin (mg)**
Rice (brown)	7.9	2.7	1.3	1.0	33	1.8	0.41	0.04
Wheat	11.6	2.0	1.6	2.0	30	3.5	0.41	0.10
Maize	9.2	4.6	1.2	2.8	26	2.7	0.38	0.20
Sorghum	10.4	3.1	1.6	2.0	25	5.4	0.38	0.15
Pearl millet	11.8	4.8	2.2	2.3	42	11.0	0.38	0.21
Finger millet	7.7	1.5	2.6	3.6	350	3.9	0.42	0.19

Adapted from FAO/IAEA (2007)

Table A-2. Nutrient content of whole sorghum and its fractions (dry basis).

Kernel fraction	**% kernel weight**	**Protein (%)**	**Ash (%)**	**Oil (%)**	**Starch (%)**	**Niacin (mg/100g)**	**Riboflavin (mg/100 g)**	**Pyridoxine (mg/100g)**
Whole kernel	100	12.3	1.67	3.6	73.8	4.5	0.13	0.47
Endosperm	82.3	12.3	0.37	0.6	82.5	4.4	0.09	0.40
Germ	9.8	18.9	10.4	28.1	13.4	8.1	0.39	0.72
Bran	7 9	6.7	2.0	4.9	34.6	4.4	0.40	0.44

Adapted from FAO/IAEA (2007)

Table A-3. Chemical composition of whole and decorticated sorghum dishes* from Haiti and Africa

Variety and preparation	**Protein (N×6.25)**	**Ash (% w/w)**	**Fat (%w/w)**	**Crude fibre (% w/w)**	**Sugar (% w/w)**
Pitimi (whole grain boiled)	14.9	1.78	5.1	2.1	72.5
Pitimi decorticated (80% extraction)	10.1	0.87	2.7	0.8	74.3
Dabar, *ugali*, whole grain	11.3	1.56	4.1	2.2	69.9
Dabar, *ugali*, decorticated (79% extraction)	12.6	1.23	4.2	1.1	74.8

Source: FAO/IAEA (2007)

* **All data are expressed on a dry - matter basis.**

APPENDIX B

EXAMPLE OF A NUTRACEUTICAL PRODUCT DEVELOPED WITH WHOLE BOILED SORGHUM

(Report presented in AACC, 2006 Product Development Competition
San Francisco, CA. Authors: N. Alviola, A. Cardenas, V. Calderon,
D. Guajardo. Cereal Quality Lab,Texas A&M University.
(“Essential Grain” won second place in competiton)

Product description

“Essential Grain” is a ready to eat whole grain meal that is totally natural and a healthier alternative. It is made with whole brown glutinous rice, specialty cracked sorghum (Sumac) and barley, cooked in reduced fat milk and flavored with delicious condensed milk and natural spices like vanilla and cinnamon, without any preservative or artificial colorants. The different whole grain sources provide the product with a substantial amount of dietary fiber, antioxidants and B-glucans, besides other vitamins and minerals inherent in whole cereal grains that improve health (Table B-1). To add nutritional value and taste, the product is presented in six different flavors: vanilla (plain), raisins, blueberries, cranberries, mocha and chocolate and is conveniently packaged in a six-pack serving for customer “on-the-go” convenience.

A serving of “*Essential Grain”* (250 grams) contains 5 grams of dietary fiber, which represent 16.5 % of the Daily Value. Each serving has also an outstanding antioxidant activity with an ABTS value of 750 µmol TE and a substantial amount of B-glucans of 1.7 grams. Consumers are increasingly interested in whole grain foods with elevated levels of the above-mentioned components, because of their beneficial effects on health. (Trogh et al, 2005).

Consumer acceptability was performed on the product. Twenty untrained young adults panelists performed an informal sensory evaluation on each of the flavored and plain samples of “*Essential grain”*. The attributes of appearance, texture and flavor were acceptable to the panel.

Table B-1. Essential Grain Ingredients and Functionality

Ingredient	Main Functionality
Rice, sorghum and barley	Structure, color, source of antioxidants and dietary fiber
Reduced fat milk	Texture and source of calcium, Vitamin E
Condensed milk	Flavor, texture and color
Cinnamon, vanilla, mocha, chocolate	Flavor and color
Blueberries, cranberries	Source of antioxidants and natural flavor
Raisins	Source of minerals and potassium
Corn Starch	Thickener

Rationale

The United States Department of Agriculture (USDA) 2005. Dietary Guidelines for Americans (DHHS and USDA, 2005) recommends that the average sedentary American adult should consume at least 6 ounce-equivalent servings of grain products per day, including at least 3 servings of whole grains as a foundational element of all meals including snacks, breakfast and desserts. Numerous studies show that whole grain foods in diet would reduce the risk of many diseases because they contain not only dietary fiber but also other potentially beneficial components like phytochemicals including antioxidants and lignans (phytosterols).

“Essential Grain” is a nutraceutical and functional option for health-conscious consumers, because it is rich in antioxidants, B-glucans and dietary fiber that promote digestive health. Likewise, it may decrease the risk of cancer and heart disease and reduce LDL cholesterol. Nowadays, Americans are more conscious about the need to increase their grain consumption by 20-25%

(USDA, 2006). The Whole Grain Council (2006) established that whole grain foods including snacks and dessert would reach sales of $7.5 billions in 2009.

Target market

"Essential Grain" is primarily targeted to young adults (25+) who are looking for convenient, delectable and healthier alternatives for meals, snacks or deserts and who prefer natural wholesome foods .It can be enjoyed anytime as a breakfast meal, as a dessert or even as a snack! It is delicious hot or cold. For hot consumption, just open the lid and heat in a microwave on high for 1 to 1 1/2 minutes. If you prefer it cold, simple grab one from the fridge and enjoy it!

Essential Grain.
"The healthy alternative in any occasion".

VITA

Vilma Ruth Calderon de Zacatares received her B.A. in Biology from University of El Salvador in 1990. She got a Master of Science degree in Environmental Economy from Tropical Agriculture Higher Education and Research Center, (CATIE), Costa Rica in 2000.

Vilma has been working as a researcher for the National Center for Agriculture Technology (CENTA), El Salvador, since 1994. In January 2003 she started working for the International Sorghum & Millet Collaborative Research Support Program (INTSORMIL) as research assistant for the food technology laboratory. She entered the Food Science and Technology program at Texas A&M University in January 2005, and received her Master of Science degree in December 2007.

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