SPECIALTY SORGHUMS IN DIRECT-EXPANSION EXTRUSION

A Thesis

by

ALEJANDRO JOSÉ PÉREZ GONZÁLEZ

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 2005

Major Subject: Food Science and Technology

SPECIALTY SORGHUMS IN DIRECT-EXPANSION EXTRUSION

A Thesis

by

ALEJANDRO JOSÉ PÉREZ GONZÁLEZ

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

Approved by:

Chair of Committee,	Lloyd W. Rooney
Committee Members,	Ralph D. Waniska
	Mian N. Riaz
	Luis Cisneros-Zevallos
Chair of Food Science and Technology Faculty,	Rhonda Miller

December 2005

Major Subject: Food Science and Technology

ABSTRACT

Specialty Sorghums in Direct-Expansion Extrusion. (December 2005)

Alejandro José Pérez González,

B.S., Instituto Tecnológico y de Estudios Superiores de Monterrey

Chair of Advisory Committee: Dr. Lloyd W. Rooney

Whole-grain, high-fiber, or decorticated extrudates of excellent properties were made from white (nonwaxy, heterowaxy, waxy) sorghums or brown tannin-sorghums. Intact grains or prepared raw materials (cracked, cracked and sifted, decorticated) were extruded in a high-temperature, short-time (HTST) extruder. Waxy extrudates expanded less and were softer than those from nonwaxy or heterowaxy sorghums. Waxy extrudates had bigger air cells and thicker cell walls. Low moisture used in this type of extrusion and its interaction with the different amylose contents were the causes of the differences. Whole-grain extrudates from white sorghum had similar sensory acceptability to those from white decorticated sorghum. They had bland flavor and appearance and texture characteristic of whole-grain products. Extrudates from tannin sorghums were reddish brown due to their high levels of phytochemicals. The more expanded, softer products from whole-grain tannin sorghum were obtained when the grain was cracked and sifted. Decreased expansion was caused by higher levels of fiber and greater particle sizes (as in the extruded intact grain), and by reduced particle sizes (as in the cracked non-sifted grain). Expansion was correlated to smaller air cells with smooth walls. A simple enzymatic method was developed that isolates the “gritty” particles from whole-grain/high-fiber extrudates, which closely correlated with expansion. Gritty particles were fiber (bran) plus undegraded starchy material. Whole grain/high fiber extrudates from white and tannin sorghums are an excellent option for food processors because of their excellent taste, appearance and texture.

DEDICATION

To Pope John Paul II (1920-2005). *“Totus tuus”*.

ACKNOWLEDGMENTS

I thank God and the Holy Virgin Mary for guiding and watching my steps.

I thank my wife Angelina, who spells “love” to me in different ways every day.

I thank my father, Enrique A. Pérez Gárate, who taught me to hang out only with those smarter than me; my mother, Dolores González Cantú, who taught me that happiness is full of sacrifice.

I thank Dr. Lloyd Rooney, who taught me he who does not make mistakes has done nothing; Dr. Ralph Waniska, who not only showed me to think outside the box, but that there is no box; Cassandra McDonough, who showed me everything is about the structure of things, and minds. I will never forget their support. It was an honor to share these years with you.

I thank Dr. Sergio Serna, for helping me achieve and even improve upon this dream.

I thank Dr. Mian Riaz, for his unconditional support and encouragement; Dr. Luis Cisneros-Zevallos, for being a friend before a teacher.

I thank Pamela Littlejohn for her help with all those crucial things we take for granted.

I thank my friends at the Soil and Crop Sciences Department, the Cereal Quality Lab and the Food Science and Technology Graduate Program. I appreciate their help but most of all their friendship, especially Marc Barron, David Guajardo, Emilio Villarreal, Bolívar Cevallos, and Guisselle Cedillo.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE Page

FIGURE Page

CHAPTER I

INTRODUCTION

Sorghum, the fifth most important crop, is utilized for feed and food around the world. The projected worldwide production for 2010 is 63 million tons (NGSP 2005). Sorghum is resistant to dry and hot climates, so it has advantages over other crops in many areas. This crop has great genetic diversity which has allowed the development of many sorghum types of enhanced value. Specialty sorghums such as waxy, heterowaxy and tannin (high antioxidant) hybrids offer benefits for nutrition and/or processing (Rooney and Awika 2005).

Extrusion consists of forcing a mass in a sealed chamber towards a small opening. Cooking extruders convey a homogenized, heated and pressurized mass through a barrel, using a screw fitted inside towards a relatively small opening at the end. The material expands when exiting through a die, as there is a sudden release of pressure. It is a low cost, energy efficient, versatile process which produces a high quality product continuously without effluents (Harper 1981). Short barrel, high-temperature, short-time (HTST) extruders, produce all their heat by friction (they are autogenous), and are relatively inexpensive.

U.S. retail sales of extruded salted snacks are projected to be $1.5 billion in 2005 (8.5% annual growth). Total salted snacks retail sales will reach $23.9 billion with a growth of 5.7% annually (Packaged Facts 2002). Health concerns are reshaping the snack foods market in the United States and the world. Current trends include reduced consumption of fats and simple carbohydrates, increased fiber intake, and a preference for food with health-promoting compounds (nutraceuticals) (Sloan 2005).

Consumers continue to look for convenient foods, including snacks. According

---

This thesis follows the style and format of Cereal Chemistry.

to the Snack Foods Association (2004), 70% of American households purchase individual-portion snacks and 9 out of 10 Americans consume salted snacks regularly. Snacks are a great opportunity to deliver nutritional benefits.

Whole grains have an important role in the healthy foods market trend. Consumer awareness will continue to grow in the following years due to market and regulatory promotion. The USDA recently published the Dietary Guidelines for Americans and the new food pyramid (USDA 2005) that promote whole-grain foods. Increasing the consumption of total dietary fiber by consuming whole-grain foods improves human health through control of blood glucose levels, improved intestinal micro flora, increased fecal bulk, and decreased calorie consumption (Lupton and Turner 2000).

White sorghum has been successfully extruded decorticated (abrasively dehulled), cracked or as a whole grain (Acosta 2003). The bland flavor and white color of the finished product does not interfere with added coloring and flavorings. “Bongos” are a snack prototype made of whole-grain extruded sorghum which has excellent texture and flavor (Leal-Diaz et al 2002). Decorticated grits from waxy and heterowaxy sorghums produced more expanded and softer extrudates than those from nonwaxy sorghum, possibly due to greater gelatinization in the waxy and heterowaxy grains (Gomez et al 1988).

Tannin sorghum has been extruded with good results (Turner 2004). Fractions from this sorghum have greater *in vitro* antioxidant activity than most cereals and fruits, and may offer significant health benefits. There is epidemiological evidence suggesting that sorghum consumption reduces the risk of certain types of cancers in humans (Rooney and Awika 2004).

The technology used for the manufacture of whole-grain products is the same as used for traditional products. There is need to understand what occurs during processing, to achieve the desired physical and nutritional characteristics of the end-product.

The objective of this study was to assess the suitability of selected specialty sorghums for extrusion into whole-grain products. The specific goals were:

1) Determine the effect of amylose content and grain preparation method (decortication, cracking, or intact kernels) on the extrusion of waxy, heterowaxy and nonwaxy white sorghums;

2) Determine the effect of grain preparation (decortication, cracking with or without sifting, intact whole kernels) on the extrusion of tannin sorghum;

2) Determine the effect of different tempering conditions on the extrusion of tannin sorghum, and

4) Determine the effect of adding an emulsifier (rice bran extract) on the extrusion of tannin sorghum.

CHAPTER II

LITERATURE REVIEW

Extrusion

Extrusion is a food process in which ingredients are subjected to mixing, heating and shearing, and forced to flow through a die that forms and expands the ingredients (Rossen and Miller 1973). The most basic extruder consists of a shaft or "barrel" with a screw fitted inside, which forces the materials fed at one end towards the other side. The material is forced to exit the chamber through a die with small holes, located at the far end. Extrusion is a complex process in which many phenomena occur in a short period. Mixing, grinding, shearing, starch gelatinization and protein denaturation, expanding, shaping and dehydrating all take place. Several extruder designs exist. Selection of the most appropriate equipment for a given application depends on the raw materials, the product desired, and costs (capital, labor, energy).

The least versatile, most simple and inexpensive to acquire is the single-screw, "dry" extruder. This equipment is also known as short-temperature short-time (HTST); short-barrel; high-shear, or collet extruder. It consists of a relatively short barrel with a length to diameter (L/D) ratio of 4 or less. The screw has three sections (as any other extruder): the feeding section conveys the material downstream, the compression section shears, heats and kneads the mass into a continuous dough, and the metering section shears and heats the dough further, as it delivers it to the die exit. Throughout the barrel there are grooves that prevent slip at the walls. The screw has shallow flights of decreasing pitch as it advances forward, so the shear is gradually increased (Harper 1981). The dry extruder is also called an autogenous extruder (Rossen and Miller 1973), because all the heat comes from the viscous dissipation of the mechanical energy (shear) applied. The product formulation and extruder configuration can be changed to adjust the process (Riaz 2001). The correct formulation (with an optimum equipment configuration) will result in the appropriate phenomena inside the extruder and in a product with the desired attributes.

The common raw material for expanded snacks is corn meal. Due to its composition, ratio of vitreous to floury endosperm, and particle size it makes a light, highly expanded, crunchy and soft product, at the optimal extruding conditions. Many variations exist to this basic recipe. The main ingredient factors affecting the characteristics of the end-product are:

Starch

It is the main component of the finished product and provides the underlying structure (Guy 2001). Starch granules are gelatinized and dispersed during extrusion, resulting in the formation of a continuous phase of the melt inside the extruder. Average molecular weight is decreased, which allows for optimum formation and stability of air cells at the die exit. Both amylose and amylopectin are needed to give the best expansion characteristics (Huber 2001).

Fiber

Fibrous materials such as bran are part of the dispersed phase of extrudates, embedded in the starchy continuous phase (Guy 2001). Fiber is chemically unaltered by the process, and it affects expansion of the product (Huber 2001). Fibrous fragments disrupt the starchy film of air cell walls, reducing their formation and swelling, and altering air cell size.

Water

Water is the main plasticizer in extrusion. It is needed for starch gelatinization and dispersion of ingredients. It aids in the formation of a viscous fluid that is conveyed and cooked. Air cell creation and expansion by evaporation at the die exit also depend on the optimum moisture content of raw materials.

Additives

Specific effects of flavoring or coloring agents depend on their reactions with other ingredients, but all will dilute the mix. Additives used for increasing expansion and cell wall formation/swelling are called nucleating agents and include sodium bicarbonate and calcium carbonate. Monoglycerides are commonly used in commercial operations (Guy 2001) and act as surfactants (lubricants). Emulsifiers from rice bran have been shown to produce corn meal extrudates of lower bulk density, lighter structure, softer texture and more evenly distributed air cells compared to regular corn puffs (Barron et al 2003)

Particle size

Particle size of raw materials has a profound effect on extrusion performance (Acosta 2003). Desrumaux et al (1998) found that for a given composition, increasing the average particle size of corn grits results in harder extrudates, with large air cells and decreased density.

Sorghum

Sorghum originated as a human crop about 2000 years ago in Asia and Africa (Rooney and Serna-Saldivar 2000). It is the fifth most important crop behind rice, maize, wheat and barley. Production is 63 mmt and area planted is 41 million hectares (NGSP 2005). Sorghum has advantages because it is tolerant to drought and is adapted to tropical and dry conditions.

Africa and Asia have the most acreage dedicated to sorghum in the world (about 24 million hectares), and account for roughly half of the production. About 35% of sorghum crop is used for food. The rest is utilized for feed or industrial uses (Rooney and Awika 2004). Sorghum is used in Asia, Africa, and Central America in numerous foods including tortillas, porridges, thick beers, European beers, flat breads, and couscous.

The sorghum kernel is a naked caryopsis with typical dimensions of about 4.5mm x 2.5mm x 2.0mm. It consists of the three basic anatomical parts germ, endosperm and pericarp. The pericarp (about 6% of kernel weight) is the outer layer and contains fiber and little if any starch. The endosperm (84% of kernel weight) contains mostly starch and protein, and has typically hard (vitreous) and soft (floury) areas in varying proportions. The germ is the true seed and has mainly oil and protein. It accounts for 10% of the kernel weight.

Specialty sorghums

There is great genetic diversity in sorghum. The world Sorghum Collection in India has more than 22000 selections (Rooney and Serna-Saldivar 2000). Within the last seven decades, breeders around the world have incorporated numerous traits in hybrids. Sorghum has spread in the Western Hemisphere and many hybrids/varieties offer additional advantages to growers and processors.

Waxy and heterowaxy sorghums have a decreasing amount of amylose in their starchy fraction. The normal proportion (similar in most cereals) is 75% amylopectin and 25% amylose. Heterowaxy sorghums have about 17% and waxy 0% amylose. Amylose, a long, non-branched glucose polymer, is part of the non-crystalline areas of starch granules and plays an important role in many cereal products, as it is related to the initial retrogradation or “setting”. Amylopectin, a highly branched polymer of glucose, forms the crystalline structure of starch granules. Its retrogradation after cooking (and gelatinization) and dispersion is slower than that of amylose. It is related to “staling”, or cereal products (due to long-term retrogradation). Amylopectin is easier to digest by amylases. It also has a lower gelatinization temperature. The texture of most cereal-based products depends on the balance between amylose and amylopectin, and their state of gelatinization-retrogradation. Advantages can be obtained by varying the amylose to amylopectin proportions in the raw materials.

Phytochemicals have increasing popularity because of their antioxidant activity and other possible health benefits. All sorghums contain certain amounts of phytochemicals including phenolics (phenolic acids and flavonoids), sterols and policosanols. Phenolic acids in sorghum are derivatives of benzoic or cinnamic acid. Among the flavonoids the most important are tannins and anthocyanins. Genetics and environment play an important role in the amount of phenolic compounds present in the grain. Based on extractable tannin in the grain, sorghums are classified as types I, II or III (Rooney and Serna-Saldivar 2000). Type I sorghums are “tannin free” such as the white food-type, and type III are “tannin” such as brown sorghums. Tannin sorghums are characterized by the presence of a pigmented testa underneath the pericarp (Rooney and

Awika 2004). Tannins in sorghum are condensed tannins with trace amounts of tannic acid or hydrolysable tannins. Epidemiological (Chen et al 1993) and in-vitro (Grimmer et al 1992) studies have linked tannin sorghum and anti-carcinogenic activity. Tannin sorghums may also be useful to fight obesity, as it is well known that they decrease feed efficiency in animals (Rooney and Awika 2004).

Extrusion of sorghum

Sorghum has been extruded successfully for research and commercial purposes. White sorghums are used in Japan to make a highly expanded, soft snack with added flavors that appeal to that market (Rooney 1996). "Bongos" is a prototype snack made from whole-grain white sorghum, with excellent texture and taste (Leal-Diaz et al 2002). Waxy sorghum grits were extruded (Gomez et al 1988) and decreasing amounts of amylose increased expansion, decreased bulk density, and increased enzyme-susceptible starch ratio and water solubility. Grits from waxy sorghum (12.2% amylose) extruded at 17% moisture produced the most expanded, lightest extrudates with the most uniform distribution of small thin-walled air cells. These characteristics were due to greater starch gelatinization in the low-amylose extrudates.

Turner (2004) extruded tannin sorghum and compared it to white sorghum and corn meal. Tannin sorghum has a thick pericarp which contains some starch, an intermediate-hardness endosperm and a thick pigmented testa layer underneath the pericarp. The tannin sorghum produced extrudates with lower expansion and similar bulk density than extrudates from white sorghums. The feed rate was lower and specific mechanical energy (SME) was higher for the tannin sorghum as compared to white sorghum.

Whole grains in extrusion

The use of whole grains affects the quality of products normally made from refined-endosperm ingredients (Camire 2004). Sensory attributes like texture, expansion, appearance, color and taste are usually negatively affected. Nutritional attributes such as antioxidant activity, fiber, mineral, vitamin and calorie content are usually improved. It is the challenge of the food technologist to develop foods that meet market requirements in both fronts. In direct-expansion extrusion, increased fiber dilutes the starch and protein, decreasing their gelatinization, denaturation and dispersion. Extra fiber forms part of a dispersed phase that results in a tenderer product (Fulcher and Rooney-Duke 2002). The bran fragments affect the formation and expansion of air cells at the die exit, as they "puncture" the incipient bubbles. Expansion is decreased and air cells are not uniform. Extrudates usually have a darker color and altered appearance when made from whole-grains. Particle size of the fibrous material used affects extrusion (Von Fulger 1988). Corn bran of particle size up to 100 microns improves extrudate characteristics as opposed to regular corn bran (up to 840 microns).

The effect of fiber on the final product depends on the changes the fibrous material undergoes during extrusion. Wang et al (1993) found that extrusion decreased dietary fiber and increased soluble fiber of whole-wheat flour and wheat bran. These changes were due to disruption of bonds between fiber molecules, which caused smaller molecule size.

The texture of a puffed product depends on the structure attained at the die exit. Structure is determined by size of air cells and thickness of air cell walls; both parameters are closely related (Barrett 2003). Barrett and Peleg (1992) found that a corn extrudate of increased density (less expanded) had a smaller cell size, thicker cell walls, and hence a greater proportion of solid phase per unit volume. These extrudates were firmer (or "crunchier") than their more expanded counterparts, because their cell walls were thicker and harder to break.

Expansion depends on gelatinization and dispersion of the starch in the extruder. Starch forms an even, continuous phase or "film", that retains air cells as they expand. The capacity to form this continuous phase is related to the "fragmentation" (reduction of molecular size) of the starch fraction during extrusion (Gomez and Aguilera 1983). This alteration of the carbohydrate fraction affects the digestibility and solubility of extrudates. Mercier and Feillet (1975) prepared extrudates from cornstarch using various compositions and extruder parameters and found that the extrudates with greater expansion had higher starch solubility and enzyme digestibility. Changes that the increased fiber in whole-grain products imparts to extrudate structure (cell size and cell wall thickness) must be determined. It is also necessary to assess the effect of fiber and oil on the continuous phase formed by carbohydrates and protein.

CHAPTER III

AMYLOSE CONTENT AND GRAIN PREPARATION METHOD EFFECTS ON EXTRUSION OF WHITE SORGHUMS

Justification

The effects of varying amounts of amylose on the extrusion of maize and sorghum materials have been studied (Gomez et al 1988; Mercier and Feillet 1975). This work has been done with refined flours or starches at moderate to high moisture contents (18-45%). There remains the question if un-refined (whole grain or high fiber) or refined materials extruded at lower moisture contents will have the same behavior. The objective of this study was to determine the effect of amylose content and grain processing method (decortication, cracking, or intact kernels) on the low-moisture extrusion of waxy, heterowaxy and nonwaxy white sorghums.

Materials and methods

Grain characterization

Composition of sorghums was determined by Near Infrared Reflectance (NIR) with a Perten PDA 7000 (Perten Instruments, Reno, NV). Density was measured using a gas-comparison pycnometer (Multipycnometer, Quantachrome, Syosset, NY). Test weight was determined with a Winchester Bushel Meter. Thousand-kernel weight (TKW) was performed by weighing 100 kernels from each sample and multiplying by 10. Hardness index was evaluated with a Tangential Abrasive Dehulling Device (TADD) using a 20 g sample and 3.5 min abrasion time. Hardness and diameter of 300 kernels was determined with a single kernel hardness tester (SKHT, model SKCS 4100, Perten Instruments, Reno, NV). The color of grains was measured with a colorimeter (model CR-310, Minolta, Osaka, Japan), using CIE L*a*b* color scale. The parameters reported are L*, a*, b*, and chroma. The Clorox bleach test for presence of a pigmented testa was based on the method used by FGIS-GIPSA. Measurements were done in duplicate. Five kernels of each hybrid were also dissected and endosperm appearance evaluated.

Raw materials preparation

The sorghum hybrids white waxy (AArg1*RTx2907) white heterowaxy (ATx631*RTx2907), and nonwaxy white food-type (ATx631*RTx436), grown in College Station TX in 2003 were utilized. Commercial corn meal was used as a control (Cargill Inc., Minneapolis, MN 2005). Grains were extruded intact or prepared for extrusion by two methods: decortication or cracking and sifting (Fig. 1). Grain was decorticated in 4-kg batches for 90 s (nonwaxy and heterowaxy) or 100 s (waxy) in a PRL mini-dehuller (Nutama Machine Co., Saskatoon, Canada). The bran (~8% original grain weight) was removed with a KICE grain cleaner (Model 6DT4-1, KICE Industries Inc., Wichita KS). Grains were cracked into 1/2 - 1/4 pieces in an attrition mill of 1.5 HP (Glen Mills Inc., Maywood NJ). Fines were separated with a U.S. standard #18 sieve (1.001 mm).

Particle size distribution

Particle size distributions were measured on 50 g samples of each raw material, with the standard sieves US #10, 20, 30, 40, 60, 80, and 100. Results were reported as % of the starting material retained above each sieve.

Tempering

Distilled water was added to the intact whole kernels or processed grains to be extruded, to reach 14% moisture. Water incorporation was done by placing the raw material with the added water inside rigid plastic bottles (1 gal). The bottles were attached to a tumbler rotating at 34 rpm. The tumbler was stopped when the water was completely distributed as assessed visually (1-4 h). Equilibration was done afterwards in closed containers at 21ºC during 24 h.

Extrusion

Extrusion was performed in a single-screw HTST extruder (model MX- 300I, Maddox Inc, Dallas, TX). Length/diameter ratio is 4; the unit had two flow plates and a die with 4, 1/8 inch (3.175 mm) holes. The extruder was pre-heated to 325ºF and the preheat system turned off just before running raw materials through the extruder. The screw speed was set to 341 rpm. 3-5 Kg of corn meal tempered to 14% moisture was

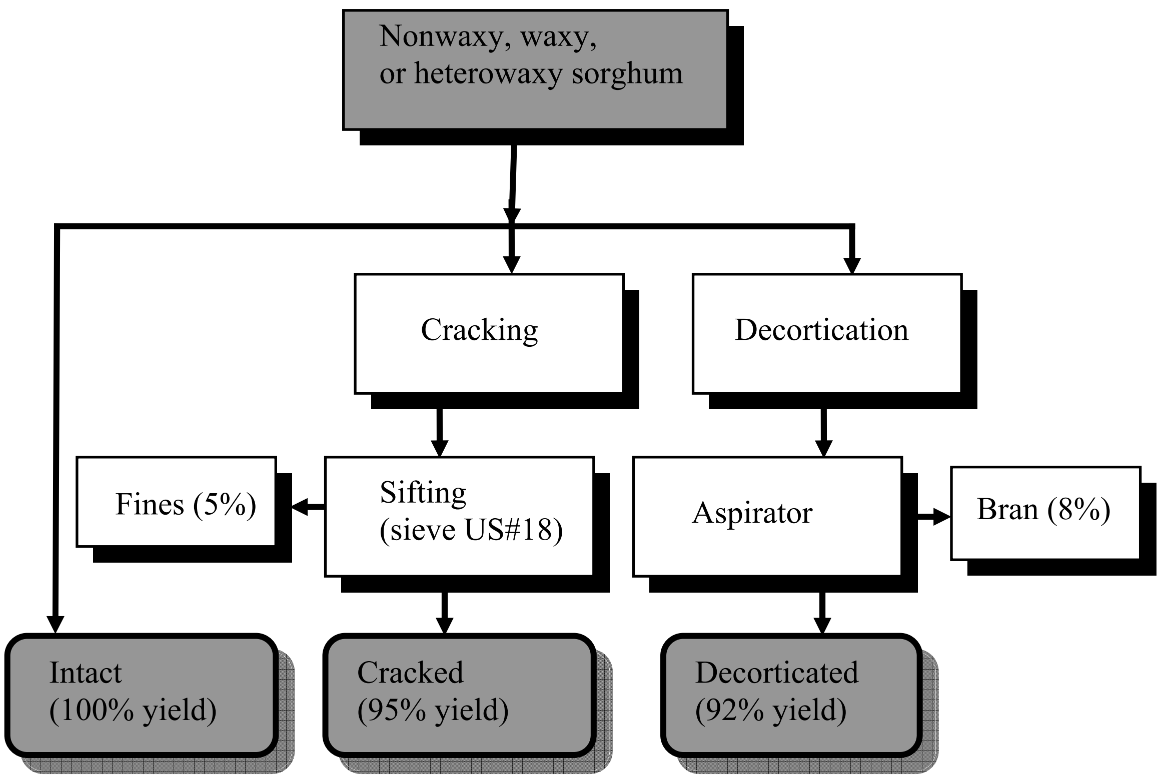

Fig. 1. Flow chart for raw materials preparation from the white sorghum hybrids.

processed to stabilize the process before running the experimental samples. The electrical current (amperage) and extruder die temperature were recorded during processing from the extruder display. The nominal mechanical power applied by the extruder was calculated using the power formula for three-phase motors:

$$\text{Power (kW)} = \sqrt{3} * \text{Current (Amp)} * \text{Voltage (KV)} * \text{PF} * \text{Eff}$$

PF is the power factor of the motor (80%), and Eff is the motor efficiency (93%). The voltage is 460 V. Specific Mechanical Energy was calculated by dividing Power by the feed rate. The extrudates obtained were dried at 100°C for 30 min in a tray convection oven and stored in zipper plastic bags at -20ºC until analyzed. Treatments were extruded in duplicate.

Expansion ratio and bulk density

Bulk density of extrudates was calculated by filling a tared, 6 L container with extrudates and weighing it. Weight was divided by volume. Two measurements were taken per treatment. Expansion ratio was calculated according to Gomez et al (1988). Diameter was measured on 25 extrudates with an electronic caliper, and each value divided by the die-hole diameter (1/8" or 3.175 mm).

Moisture

Moisture content of the extrudates before and after the drying step were measured by a modified oven method (extrudates were not ground, AACC 44-19) in duplicate.

Texture

The texture of the extrudates was tested using a Texture Analyzer model TA.HD*i* (Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, UK) with a 250 Kg load cell, and fitted with a five-blade Kramer shear cell. The test was performed on 8, 10 g samples for each treatment. Parameters recorded were shear force (total force to process the sample) and peak force.

Structure

Macrostructure

Extrudates from selected treatments were broken radially by hand to minimize artifacts. Pictures of the resulting cross-sections were taken with a digital camera (Coolpix 995, Nikon Inc., Mellvile, NY).

Microstructure

Cross-sections of extrudates from selected treatments were analyzed by electron microscopy. Extrudates were mounted on aluminum stubs with conductive adhesive and viewed with an Environmental Scanning Electron Microscope (ESEM, model E-3, Electroscan Corp., Wilmington, MA) with an accelerating voltage of 20 kV.

Gritty particles

One intact extrudate was weighed and placed in a 100-ml conical bottom tube with 25ml of a solution of Tris-maleate buffer (pH 6.9), containing 10 IU/ml porcine α-amylase (EC 3.2.1.1) and 4mM of $CaCl_2$. The tube was capped and shaken horizontally for 4 h in an Eberbach 6000 reciprocating shaker (185 oscillations/min). The resulting product was filtered through Whatman filter paper no. 41 (pore size 20-25 microns), with the aid of first 80 ml water and then 20 ml methanol. Filter papers were dried at 21°C for 24 h. The dry product retained by filtration (gritty particles) was reported as % of original extrudate weight (d. b.). Three replicates were done per sample.

Sensory evaluation

Sensory evaluation of selected treatments was conducted by 32 untrained panelists between the ages of 18 and 59 years, who were students, faculty and staff of Texas A&M University. Evaluation was done with a 9-point hedonic scale (1=dislike extremely, 9= like extremely) for appearance, flavor, crunchiness, texture, and overall acceptability (Appendix A). Extrudates were pre-coated with 26% (w/v) vegetable oil and seasoned with 16% (w/v) Kernel Season´s Nacho Cheddar seasoning (Kernel Season´s L.L.C., Highland Park, IL) prior to evaluation.

Statistical analysis

Grain characterization, extruder parameters and sensory evaluation

Means were analyzed with ANOVA and separated by Duncan's test (α=0.05). The statistical software SPSS v. 11.5 (SPSS Inc., Chicago, IL) was utilized.

Extrudate characteristics

A full factorial design was used to determine interactions between independent variables (grain preparation method and amylose content). Main effects were analyzed for significance (α=0.05). The statistical software SPSS v. 11.5 (SPSS Inc., Chicago, IL) was utilized.

Results and discussion

Grain characterization

The normal (nonwaxy) sorghum had typical values for physical properties (Table I). This grain had a high proportion of hard endosperm, according to the hardness index from the SKHT and a high yield in the TADD. This correlated with its density, test weight, and TKW. The waxy sorghum was quite hard and had a slightly lower density and test weight than the nonwaxy. The heterowaxy sorghum had even lower density and test weight, and was softer than the other two sorghums, as shown by the TADD yield and the SKHT hardness index. Nonwaxy sorghum was lighter in color (higher L value) than the waxy and heterowaxy grains. Dissection of kernels showed the typical floury and vitreous endosperm sections in the nonwaxy grain, and the opaque appearance of the waxy endosperm (Fig. 2). The heterowaxy kernels were a mixture of these appearances. No tannins were detected in any of the samples by the Clorox bleach test. Each of the grains would be a typical white food-grade, tan-plant sorghum.

Raw materials preparation and particle size distribution

Pictures of prepared raw materials are presented in Fig. 3. For the three sorghum hybrids, the greatest particle size was that of the intact grains, in which all material was retained above sieve US#10 (Table II). The decorticated grains had 1-5% passing

Table I

Composition and physical characteristics of the white sorghum hybrids[a]

	Nonwaxy	Heterowaxy	Waxy	LSD
Protein (% d.b.)	8.4 c	13.3 a	12.7 b	5.7
Starch (% d.b.)	76.7 a	71.5 b	69.9 c	10.8
% decorticated grain yield (TADD)	86.0 a	79.1 c	84.6 b	1.0
Hardness index (SKHT)	84.5 b	72.9 c	87.5 a	2.3
Average kernel diameter (mm)	2.5 b	2.7 a	2.5 b	0.1
Thousand kernel weight (g)	30.7 c	34.4 a	32.2 b	0.2
Density (g/cm3)	1.38 a	1.34 c	1.36 b	0.003
Test weight (lb/bu)	62.5 a	60.9 a	61.1 a	1.7
Clorox bleach test	Negative (tannin free)	Negative (tannin free)	Negative (tannin free)	--
Color				
L	61.9 a	57.4 b	58.3 b	2.5
a	3.5 c	4.6 b	5.3 a	0.2
b	19.3 b	18.5 c	20.9 a	0.7

[a] Values followed by the same letter within a row are not significantly different ($p<0.05$).

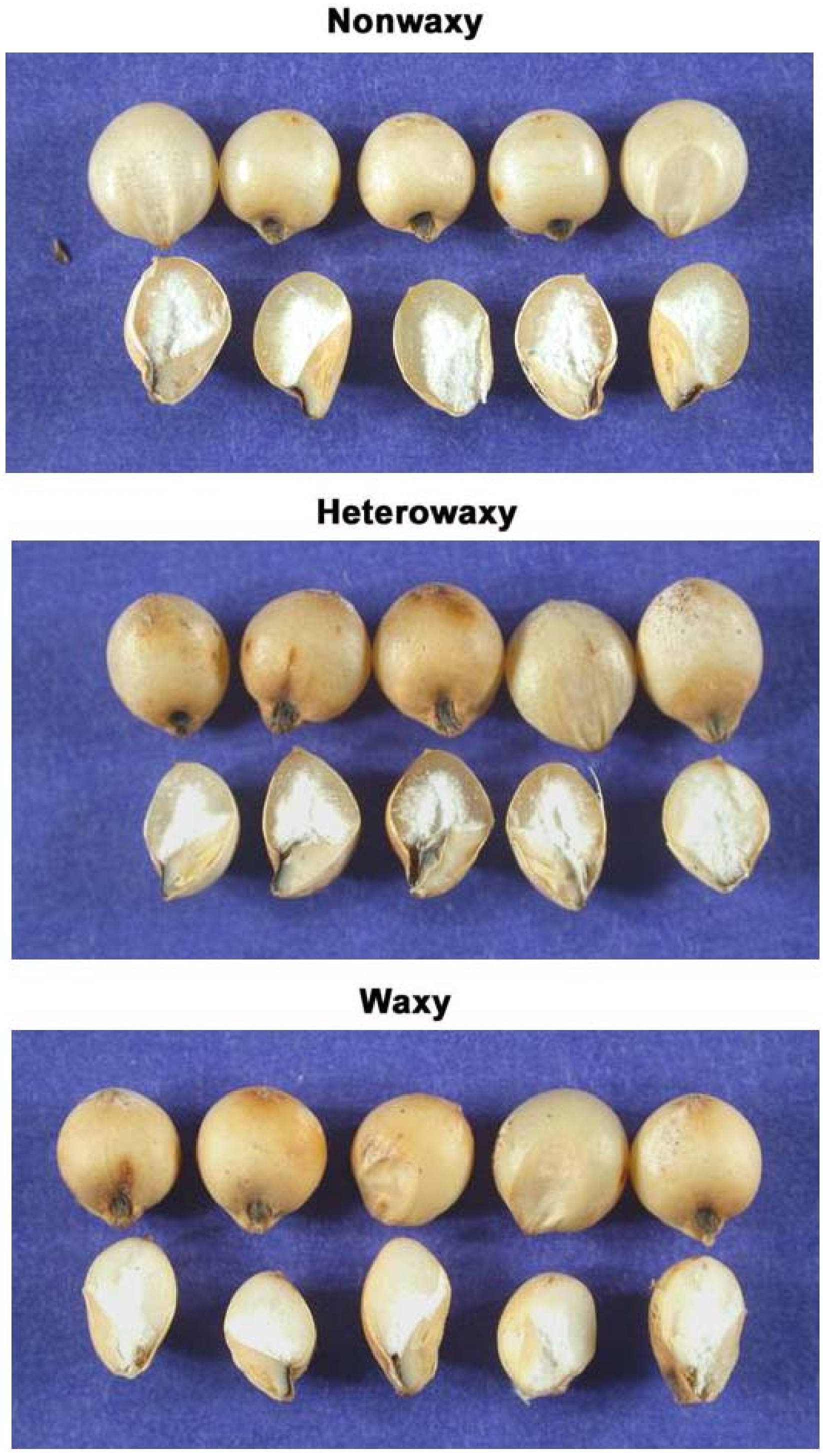

Fig. 2. Kernels of the white sorghum hybrids intact and dissected.

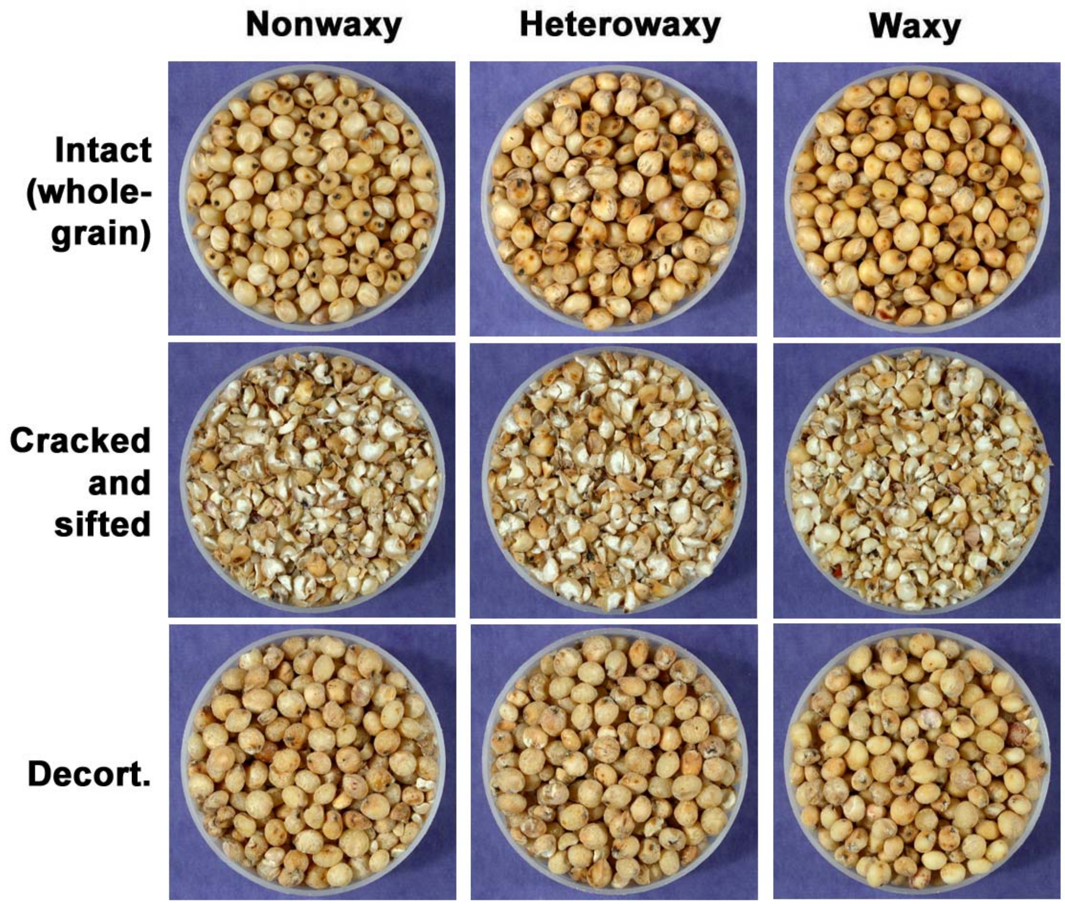

Fig. 3. Raw materials for extrusion of the white sorghum hybrids.

Table II

Particle size distribution of the raw materials from the white sorghum hybrids[a]

	Grain preparation	Sieve US#10 (2000 µm)	Sieve US#20 (850 µm)	Pan (<850 µm)
Nonwaxy	Intact	100.0 a	0.0 b	0.0 a
	Cracked and sifted	67.1 b	32.8 a	0.13 a
	Decorticated	97.0 a	2.9 b	0.0 a
Heterowaxy	Intact	99.9 a	0.1 b	0.0 a
	Cracked and sifted	70.0 b	29.9 a	0.07 a
	Decorticated	95.0 a	4.9 b	0.02 a
Waxy	Intact	99.9 a	0.1 b	0.0 a
	Cracked and sifted	68.0 b	31.9 a	0.06 a
	Decorticated	98.5 a	1.4 b	0.04 a
LSD		25.0	10.4	10.5

[a] Values followed by the same letter within a column are not significantly different ($p<0.05$).

Table III

Extrusion parameters of the white sorghum hybrids[a]

	Grain preparation	Temperature (F)	Power (kW)	Feed rate (kg/h)	SME (kJ/kg)
Nonwaxy	Intact	311.0 a	18.2 b,c,d	167.4 a,b	391.3 b,c
	Cracked and sifted	324.5 a	18.7 a,b,c,d	155.4 b	432.6 a,b
	Decorticated	311.5 a	20.6 a,b	168.7 a,b	440.1 a,b
Heterowaxy	Intact	310.0 a	17.7 c,d	161.2 a,b	395.8 c
	Cracked and sifted	328.5 a	18.3 b,c,d	156.6 a,b	420.6 b,c
	Decorticated	309.5 a	21.2 a	162.4 a,b	469.7 a
Waxy	Intact	318.0 a	17.3 d	170.1 a	365.7 c
	Cracked and sifted	314.7 a	19.3 a,b,c,d	161.2 a,b	431.6 a,b
	Decorticated	319.0 a	20.3 a,b,c	170.1 a	429.7 a,b
LSD		25.0	2.5	12.5	56.4

[a] Values followed by the same letter within a column are not significantly different ($p<0.05$).

through sieve US#10 but above US#20. The cracked and sifted grains had the smallest particles, with about 30% passing through US#10 and being retained by US#20.

Extrusion

All raw materials were extruded successfully, yielding products of acceptable appearance (Fig 4). Observed extrusion parameters are presented in Table III.

SME was lowest for the intact grains, followed by the cracked and decorticated sorghums, respectively (Fig. 5). This trend was possibly due to decreased fiber and oil content in cracked and decorticated grains. Turner (2004) reported that white sorghum had a total dietary fiber (TDF) of 6.3%. In the same study it was reported that cracking and sifting of white sorghum causes a loss of ~10% total dietary fiber, resulting in a TDF of 5.7%. Bran from decorticated white sorghum has 40% TDF (Turner 2004), so TDF for decorticated white sorghum is ~3.1%. There were no differences between the mean Specific Mechanical Energy (SME) of the three grain types (Fig 6).

Expansion ratio and bulk density

Decorticated sorghums had the greatest expansion ratio and the lowest bulk density (Figs. 7 and 8). Fiber (bran) interferes with expansion by “puncturing” air cells and hindering their growth at the end of the extruder (Guy and Horne 1988). Bran pieces also dilute the starch and protein and decrease their gelatinization, denaturation and dispersion (Fulcher and Rooney-Duke 2002). Chinnaswamy and Hanna (1991) observed that extrudates from native corn starch had about equal apparent amounts of amylose and amylopectin. Degradation of amylopectin to less branched derivatives during extrusion had been previously observed (Gomez et al 1983). Chinnaswamy and Hanna (1991) also detected that adding different cellulose fibers to starch extruded at 14% moisture decreased expansion. The added-fiber extrudates had fewer low-molecular weight linear molecules than the extruded native starch. The authors speculated that fiber reduces starch degradation in the extruder. Linear, low-molecular weight starch molecules (such as amylose in extruded nonwaxy materials) may have a higher tendency to retrograde and give strength to the extruding melt, supporting expansion and preventing air cell collapse.

Fig. 4. Extrudates from the raw materials of the white sorghum hybrids.

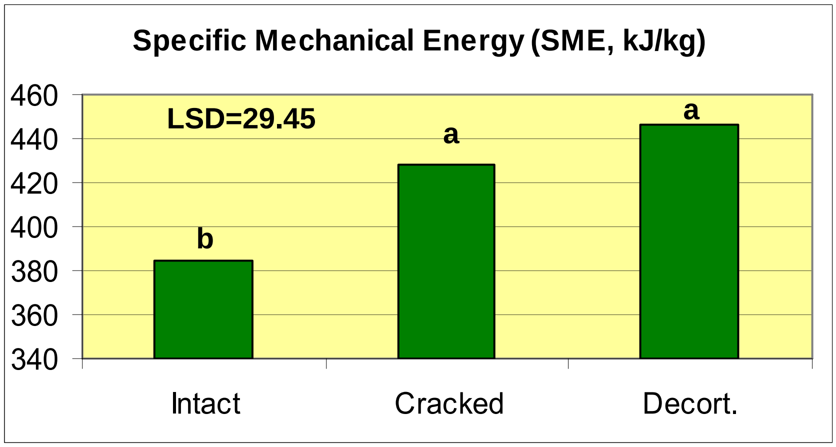

Fig. 5. Specific mechanical energy (SME) for raw materials prepared from the white sorghum hybrids as affected by preparation method. Bars represent means of treatments within each level of the factor. Values with the same letter are not significantly different at α=0.05.

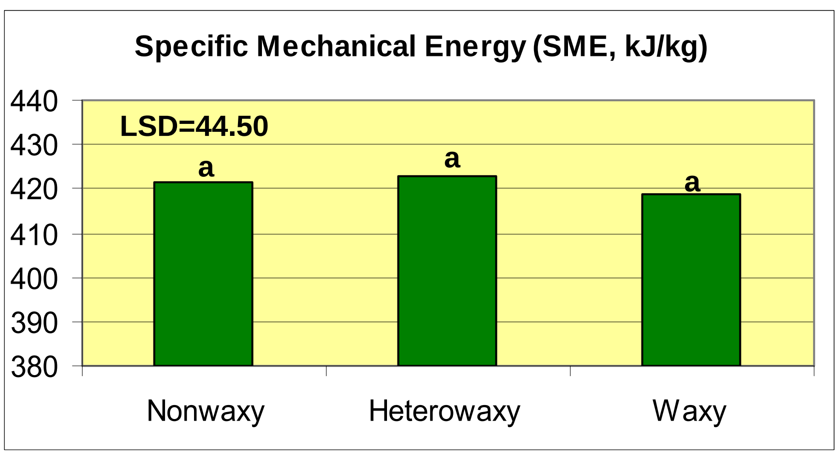

Fig. 6. Specific mechanical energy (SME) for raw materials prepared from the white sorghum hybrids as affected by amylose content. Bars represent means of treatments within each level of the factor. Values with the same letter are not significantly different at α=0.05.

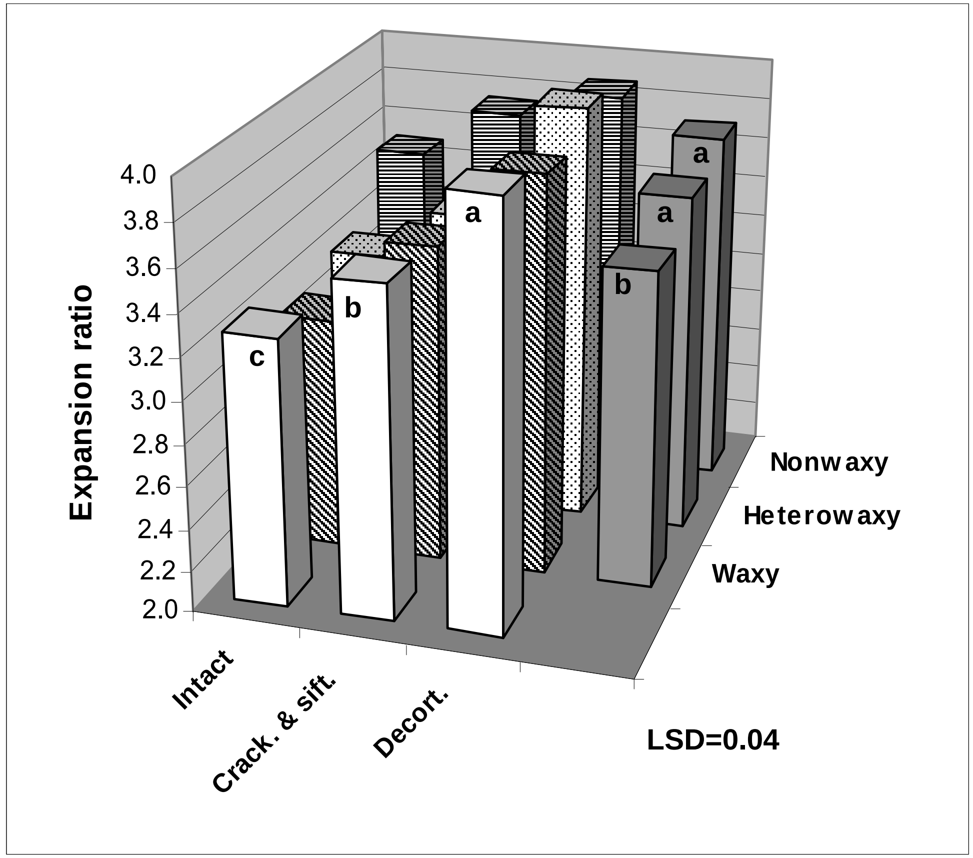

Fig. 7. Expansion ratio of extrudates from the white sorghum hybrids. Solid white or gray bars represent means for each level of either factor. Values with the same letter within a factor are not significantly different at α=0.05.

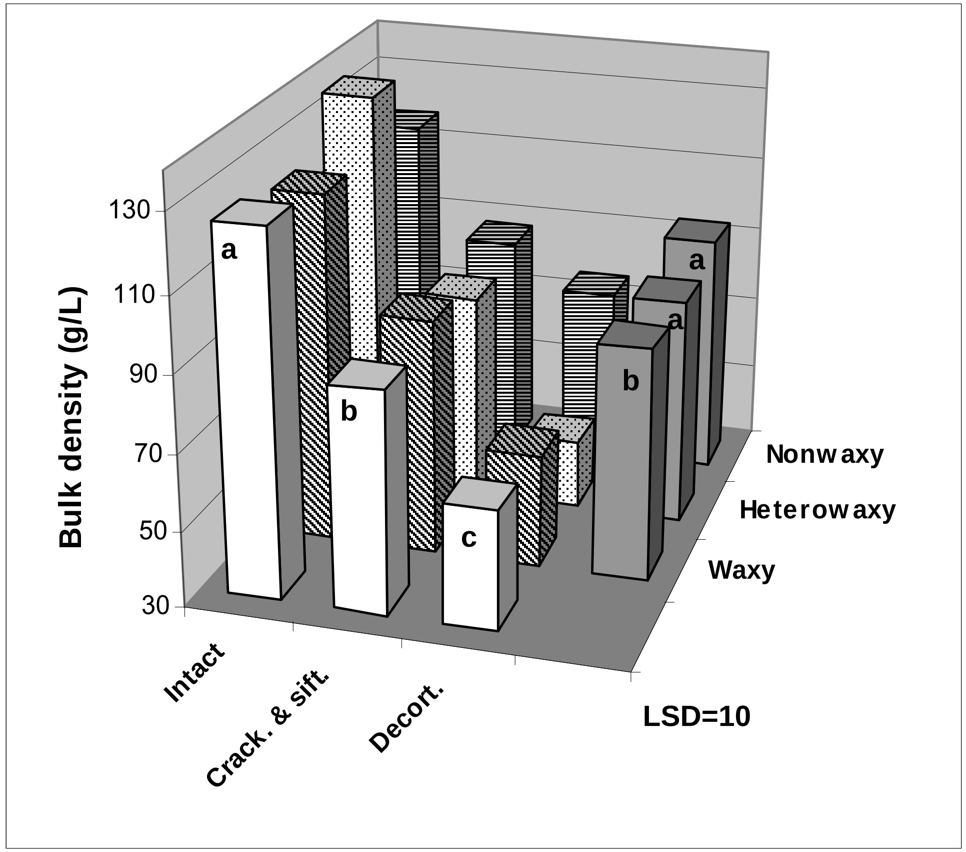

Fig. 8. Bulk density of extrudates from the white sorghum hybrids. Solid white or gray bars represent means for each level of either factor. Values with the same letter within a factor are not significantly different at α=0.05.

The most expanded extrudates from intact or cracked sorghums were produced from nonwaxy grain; the most expanded extrudates from decorticated sorghum were from heterowaxy grain (Fig. 7). The sorghum hybrid with the least expansion for all raw material types was the waxy. Amylose and amylopectin are needed for developing good extrudate properties (Huber 2001). Matz (1976) advised an amylose content of 5-20% for obtaining extrudates of good crispness and texture. The combination of the amylose and amylopectin provide the "film" structure in the continuous phase of the extrusion melt or "dough". Amylose retrogrades fast as amylose interactions are quicker than amylopectin interactions (Hoseney et al 1978); amylose is responsible for setting of many starchy products, which may include extruded snacks. The waxy extrusion melts lacked films of retrograded amylose, which would have given them strength and prevented collapse of the extrudate structure upon setting after expansion.

Gomez et al (1988) extruded decorticated sorghum meals at 18, 32 or 45% moisture at 150°C and observed higher expansion for the waxy (12% amylose) as compared to the normal (27% amylose) and heterowaxy (22% amylose) meals. Waxy materials also expanded more than nonwaxy ones in studies by Mercier and Feillet (1975) and Bhattacharya and Hanna (1987). In those cases the extrusion moisture was 18-25% and temperature was 135-160°C.

In contrast, Chinnaswamy (1993) reported that extrusion (14% moisture, 140°C) of corn starches containing 10% amylose yielded the least expanded extrudates compared to those with 25, 50, or 70% amylose. In those experiments the most expanded extrudates were from 50% amylose starch.

Starch in extruded cereals forms helical non-covalent associations with lipids, called amylose-lipid complexes (Mercier et al 1978). The configuration of these complexes can be either "E" or "V" type. Only E-type complexes are formed when extrusion moisture of cereal starch is 12-15% at extrusion temperatures >70°C. V-type complexes are formed at extrusion moisture contents >16%. V-type complexes were observed in the experiments by Gomez et al (1988), and may have formed because of the relatively high extrusion moisture. E-type complexes have more space between helices

(1.5 nm) than the V-type (1.4 nm), and their occurrence is correlated to increased expansion and starch water solubility (Mercier et al 1978). It is possible that the amylose has greater mobility in E- than in V-type configuration, and is available for other interactions besides those with lipids. Amylose in E-type complexes could hydrate, rearrange and retrograde, supporting expansion as discussed above.

In the present experiments (extrusion moisture 14%, average temperature 158°C), as in those by Chinnaswamy and Hanna (1993) (14% moisture, 140°C), conditions were favorable for formation of E-type complexes. This configuration allowed the amylose to retrograde and support expansion. The extruding melts from waxy materials had possibly retrograded structures, but not enough for supporting greater expansion than in the other hybrids.

As for the reason why V-type complexes are favored by increased moisture content, it may relate to starch molecular mobility and the effect of water as plasticizer. Increased water content plasticizes the starch, lowering its gelatinization temperature or "Tm". At the moisture contents (18-45%) of some of the experiments cited above, Tm of amylose may have been reached or surpassed, causing extensive dispersion and lipid-complexation. Plasticizer was more limited in the experiments at 14% moisture. Tm may have not been reached. Amylose did not disperse as much, and it may have rearranged only to the E-type complex, or even stayed in an amorphous, hydratable phase.

Moisture

The moisture of extrudates before and after drying are presented in Table IV. The dried waxy extrudates had the greatest mean moisture content. It is known that amylopectin has more tendency to interact with water than amylose due to its molecular structure. Interactions of water with the starch in waxy extrudates may have been more prevalent than in the lower-amylopectin extrudates.

Texture

Decorticated grain produced extrudates with the lowest shear force (softest) across grain types (Fig. 9). It is known that fiber content increases hardness or "crunchiness" of extrudates (Guy 2001). The interaction between the factors tested was significant (p=0.032), so the effect of preparation method on texture was not the same for the three grain types.

Across all grain preparation methods, the softest extrudates were produced with the waxy sorghum. Waxy raw materials make products that are tenderer than their higher amylose counterparts (Gomez et al 1988, Chinnaswamy and Hanna 1988a). Barrett and Peleg (1992) found that cell size and expansion could not entirely predict the texture of extrudates, as changes in the starch and cell walls are also important. The high amylopectin content of the waxy grain causes a weak continuous phase in the melt inside the extruder that does not support growth of air cells at the die exit and may also affect starch modifications. It has been proposed (Bhattacharya and Hanna 1987) that the starch in waxy extrudates is more gelatinized (due to lower gelatinization temperature), and has weaker intra-molecular interactions. Amylose has quicker molecular ssociations that may cause setting of the product and development of crunchy texture. Low amylose content contributes to a softer, less crunchy product. Retrograded amylose could not be formed that gave strength to the extrusion melt. In the present study, this phenomenon was accentuated by the presence of bran and oil. Fiber may have hindered degradation of amylopectin to less-branched derivatives, as described by Chinnaswamy and Hanna (1991). These linear, low-molecular weight derivatives would have given some strength to the extrusion melt through retrogradation. Thus, bran punctured the film of the waxy extrusion melt to a higher degree than that of its higher amylose counterparts, and oil may have also made this film weaker.

Structure

Macrostructure

The greater expansion of intact nonwaxy sorghum correlated with bigger air cells than in the heterowaxy and waxy extrudates. Extrudates from intact waxy grain had small cells when compared to nonwaxy extrudates (Fig. 10). Air cells and tunnels could not be formed as much and/or they collapsed at the die exit when waxy or heterowaxy sorghums were extruded. Barrett and Peleg (1992) observed that corn starch extrudates with the greatest expansion had larger air cells compared to less expanded products. The

Table IV

Moisture content of extrudates from the white sorghum hybrids[a]

	Grain preparation	Moisture before drying	Moisture after drying
Nonwaxy	Intact	5.8 a	2.9 d
	Cracked and sifted	5.4 a	2.3 f
	Decorticated	4.8 a	2.0 g
Heterowaxy	Intact	5.6 a	3.0 d,c
	Cracked and sifted	4.5 a,b	2.5 e
	Decorticated	3.1 b	2.3 f
Waxy	Intact	6.2 a	3.3 b
	Cracked and sifted	5.8 a	3.7 a
	Decorticated	5.9 a	3.1 c
LSD		1.5	0.1

[a] Values followed by the same letter within a column are not significantly different ($p<0.05$).

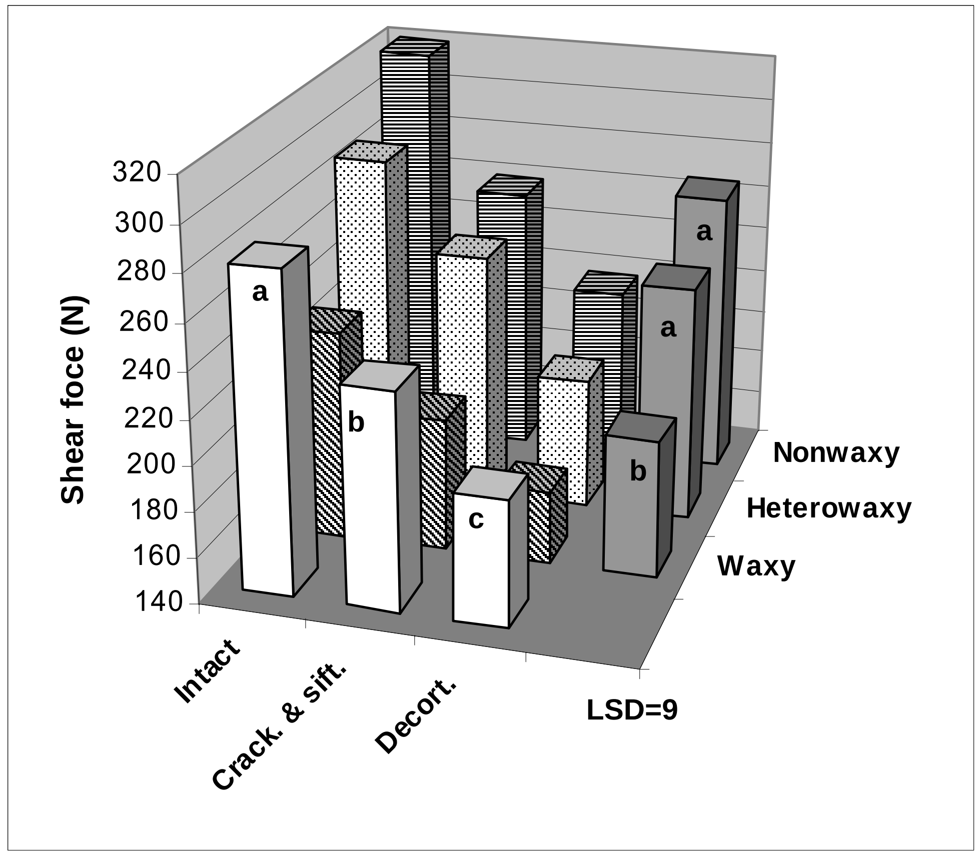

Fig. 9. Shear force of extrudates from the white sorghum hybrids. Solid white or gray bars represent means for each level of either factor. Values with the same letter within a factor are not significantly different at α=0.05.

structure of the densest extrudates was more “filled in” and had thicker air cell walls.

Among the extrudates from cracked and sifted, or decorticated grains, those from waxy sorghum had bigger air cells and tunnels. The most expanded decorticated sorghum was the heterowaxy, and the least was the waxy. The former had smaller air cells than the latter (Fig. 10); air cells could not propagate as much in the waxy melt, resulting in fewer, larger cells.

Microstructure

Intact waxy extrudates had thicker cell walls, with wrinkled appearance, as compared to those from intact nonwaxy extrudates (Fig. 11). The extruding melt was not strong enough to support the propagation of thin-walled air cells, so there were fewer cells with thick walls. These walls did not have the strength of retrograded amylose films, and they collapsed after the initial expansion at the die exit. The wrinkled appearance in surfaces of cell walls from waxy extrudates is evidence of this collapse.

Decorticated waxy extrudates had fewer air cells with thicker cell walls than decorticated heterowaxy extrudates (Fig. 12). In the latter, there was enough amylose to retrograde and form a strong film, which supported expansion and prevented collapse at the die exit.

The waxy extrudates were the softest across grain preparation methods (Fig. 9), even though they thicker cell walls. Softness was not correlated to thinner cell walls.

Gritty particles

Extrudates from decorticated grains had fewer enzyme-resistant (gritty) particles than the extrudates from cracked or intact sorghums (Fig. 13). There was a negative correlation (R^2=0.94) between expansion ratio and gritty particles (Fig. 14). Fewer gritty particles mean that the extrudate had less non-starch material (mainly fiber, oil) and that starch was more digestible in α-amylase. Gomez et al (1988) reported that the most expanded extrudates from either nonwaxy, heterowaxy or waxy sorghum meals had the greatest enzyme-susceptibility and water solubility indices. Extrusion causes the dispersion of starch and protein and their gelatinization and denaturation, respectively.

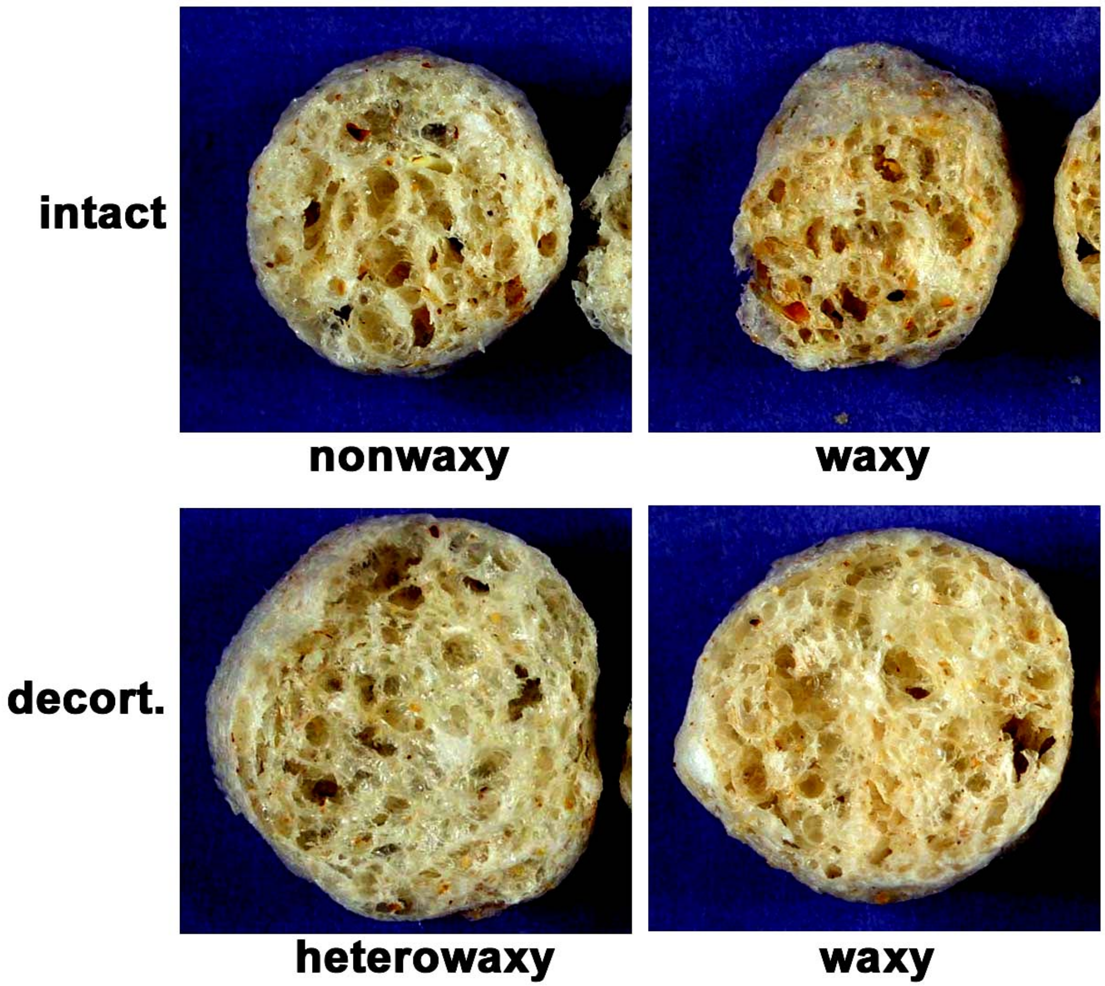

Fig. 10. Cross-sections of extrudates from the white sorghum hybrids.

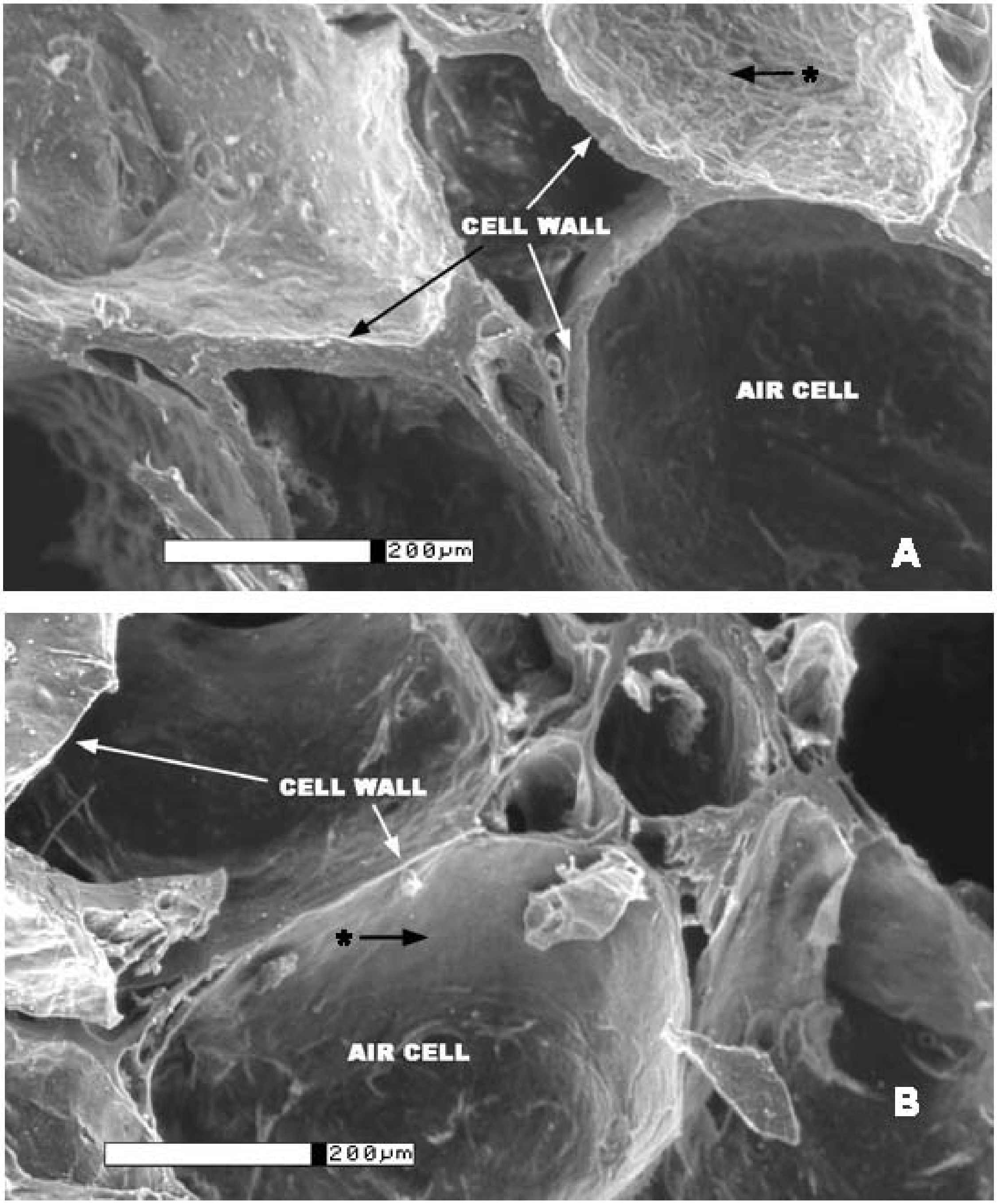

Fig. 11. ESEM images of extrudates from waxy (A) and nonwaxy (B) sorghums extruded intact. * Indicates cell wall surface differences.

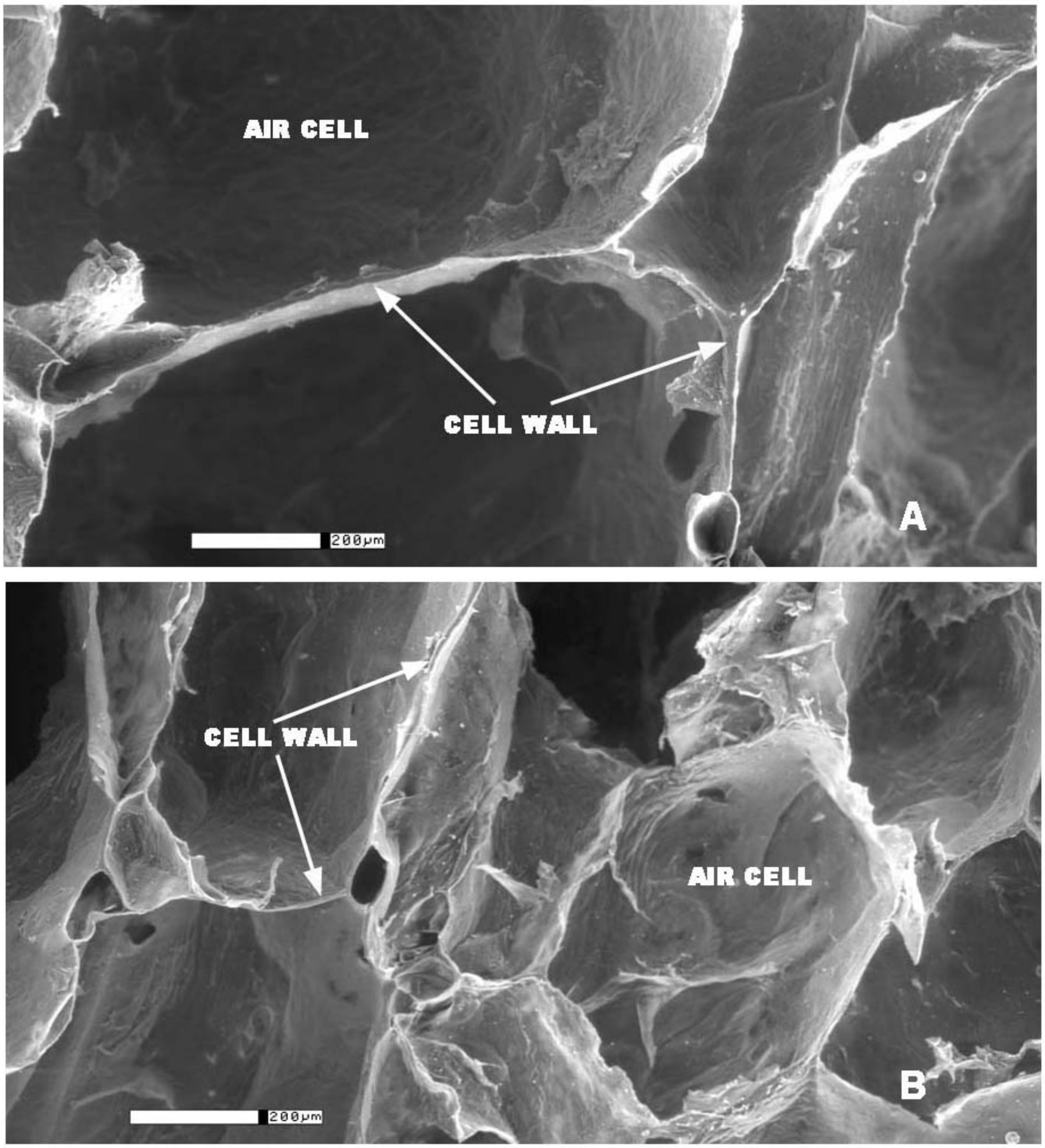

Fig. 12. ESEM images of extrudates from waxy (A) and heterowaxy (B) sorghums extruded after decortication.

Starch in extrudates becomes available for digestion as it is degraded and its interactions with protein are diminished. Increased molecular degradation may also promote air cell formation and growth. The most expanded extrudates from the present study had greater degradation of starch, which caused less gritty particles. Starch degradation is greatest when extruding conditions of low temperature, low moisture content and high RPM (similar to those used in the present experiments) were utilized (Wen et al 1990).

Effects of fiber on the starch molecules may also have contributed to the correlation between expansion and grittiness. Chinnaswamy and Hanna (1991) observed that fiber may affect degradation of starch inside the extruder by affecting velocity gradient of the melt.

The amount of gritty particles, however, could not predict all significant differences in expansion ratio. There were no differences ($p>0.05$) in gritty particles within the extrudates from decorticated grains, although they had different expansions. The differences in starch composition may be part of the explanation, as it is widely know that amylopectin is more amylase-susceptible than amylose (Frei et al 2003; Goddard et al 1984; Svihus et al 2005). Mercier and Feillet (1975) found that extrudates from starch with 1% amylose were more easily digested by α-amylase than extrudates from starches with 15, 30, 46 and 61% amylose. In the present study, although the waxy sorghum was the least expanded among the decorticated grains, its high amylopectin content caused the extrudates to be as digestible as the extrudates from nonwaxy and heterowaxy decorticated sorghums, resulting in similar grittiness. The significance of the grittiness assay presented may be greatest for “high fiber” of “whole grain” extrudates, or within a given grain type.

Sensory evaluation

Extrudates from whole-grain sorghum (from intact grain) had the same overall acceptability as those from decorticated sorghum (Fig. 15). Both products were “liked” by the panel. The biggest difference among the two was the flavor. The crunchy texture and gritty appearance of the whole-grain product were not disliked.

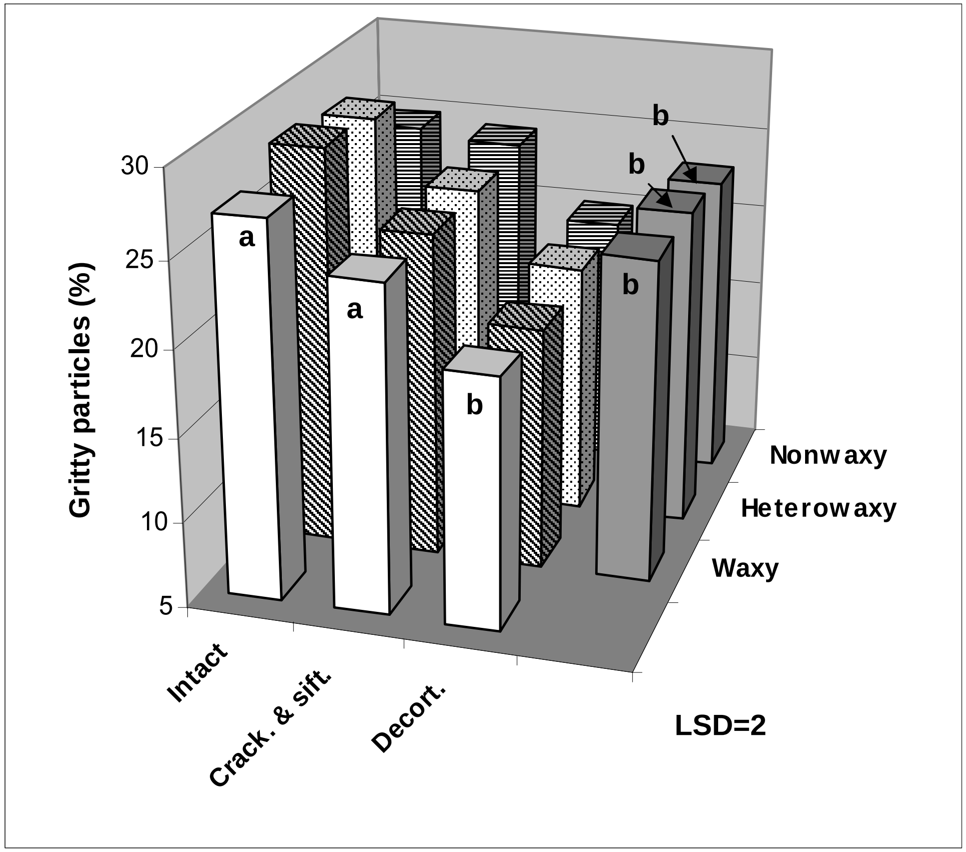

Fig. 13. Gritty particles of extrudates from the white sorghum hybrids. Solid white or gray bars represent means for each level of either factor. Values with the same letter within a factor are not significantly different at α=0.05.

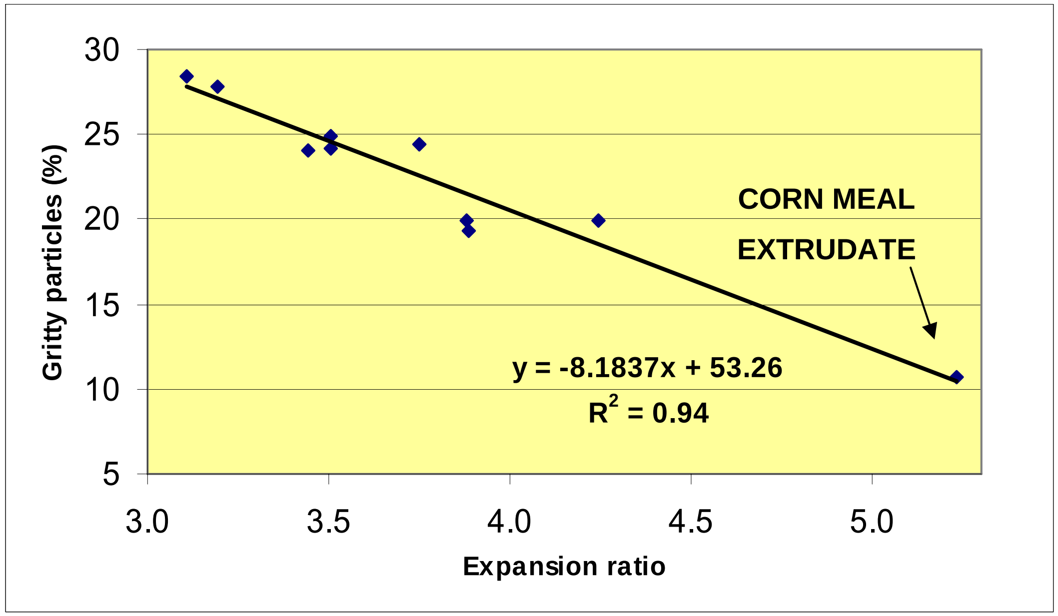

Fig. 14. Correlation between gritty particles and expansion ratio of extrudates from the white sorghum hybrids and corn meal.

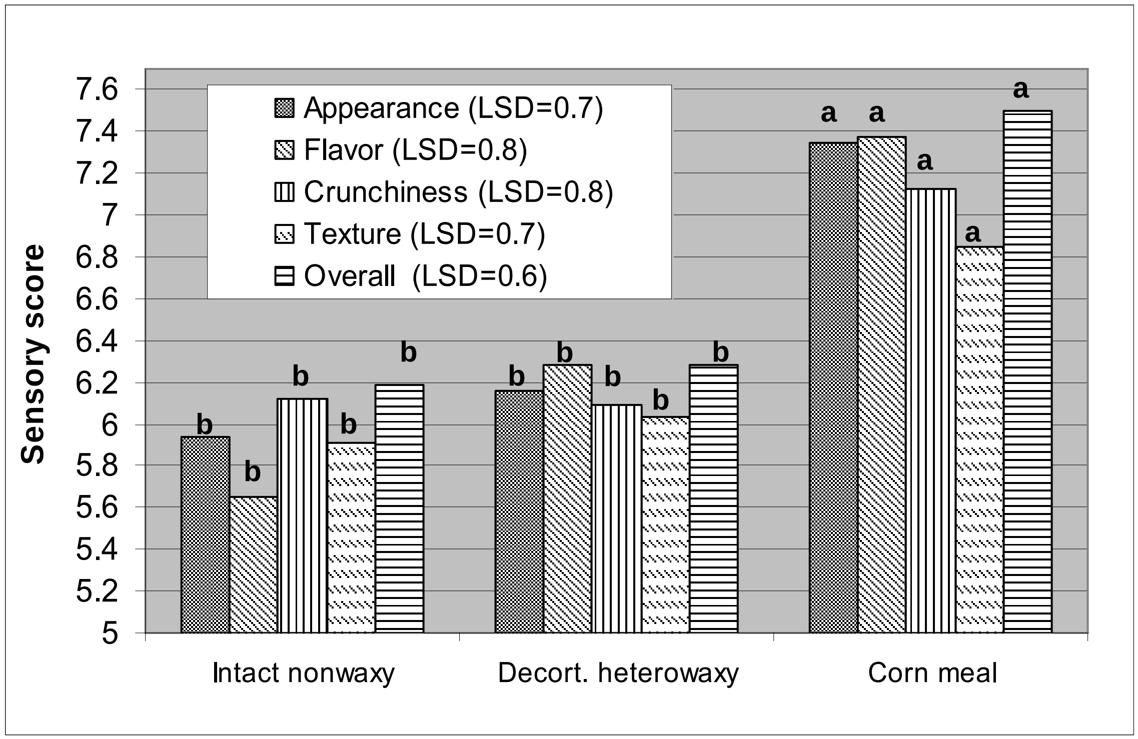

Fig. 15. Sensory evaluation of extrudates from the white sorghum hybrids and corn meal.

CHAPTER IV

GRAIN PREPARATION, TEMPERING, AND RICE BRAN EXTRACT EFFECTS ON EXTRUDATES OF TANNIN SORGHUMS

Justification

Tannin sorghums have been extruded successfully (Turner 2004). Their antioxidant components may offer advantages for making nutraceutical extruded products. Standard tempering conditions such as used for extruding white food-type sorghums have been used. Tannin sorghum kernels are smaller, softer and have a thicker pericarp than white sorghums. These characteristics may give them different hydration characteristics. Thus, one objective of this study was to optimize the tempering moisture content and equilibration time for tannin sorghum raw materials.

Rice brain extract is used in extrusion for increasing expansion, decreasing bulk density and to make a more stable process (Hammond 2000). Expansion of whole-grain cereals is known to decrease expansion and affect product consistency (Fulcher and Rooney-Duke 2002). Thus, an objective of the present study was to evaluate the effect of rice bran extract on the extrusion of tannin sorghum.

Materials and methods

Grain characterization

The procedures described in Chapter III were followed.

Raw materials preparation

The sorghum hybrids “Tannin” (CSC3xR28, College Station 2001) and “Sumac” (College Station 2003) were utilized (tannin sorghum for experiments 4.1 and 4.2, Sumac sorghum for experiment 4.3). Commercial corn meal was used as a control (Cargill Inc., Minneapolis, MN, 2005). Grain was extruded intact or prepared for extrusion by cracking, cracking and sifting, or decortication (Figs. 16 and 17). Grain was decorticated in 4-kg batches for 210 s as described in Chapter III. The bran (~18%

original grain weight) was removed as described in Chapter III. Grains were cracked with or without the sifting step, as described in Chapter III.

Particle size distribution

Particle size distribution of raw materials was measured as described in Chapter III.

Tempering

Distilled water was added to the intact whole kernels or processed grains to reach the desired extrusion moisture (Fig. 16). Water incorporation was done as described in Chapter III.

Experiment 4.1

Intact or prepared grains were tempered at 14 or 16% moisture. Equilibration was done afterwards at 21ºC for 24 h.

Experiment 4.2

Intact grains were tempered at 14, 15 or 16% moisture. Equilibration was done at 21°C for 24 h. Grain tempered at 14% was also equilibrated for 48 or 72 h.

Experiment 4.3

Intact or prepared grains were tempered at 14% moisture. Equilibration was done at 21ºC for 24 h (Fig 17).

Extrusion

Extrusion was performed (in duplicate unless otherwise stated) and extruding parameters recorded as described in Chapter III.

Expansion ratio and bulk density

Bulk density and expansion ratio were measured as described in Chapter III.

Moisture

Moisture contents of the extrudates before and after the drying step were measured as described in Chapter III.

Texture

The texture of the extrudates was tested as described in Chapter III.

Structure

Macrostructure

Experiments 4.1 and 4.2

Pictures of selected extrudates were obtained as described in Chapter III.

Microstructure

Experiment 4.1

The microstructure of extrudates from selected treatments was analyzed as described in Chapter III.

Gritty particles

Experiments 4.1 and 4.2

Gritty particles of extrudates were determined as described in Chapter III.

Sensory evaluation

Experiment 4.1

Sensory evaluation was conducted as described in Chapter III.

Statistical analysis

Means were analyzed with ANOVA and separated by Duncan's test (α=0.05). The statistical software SPSS v. 11.5 (SPSS Inc., Chicago, IL) was utilized.

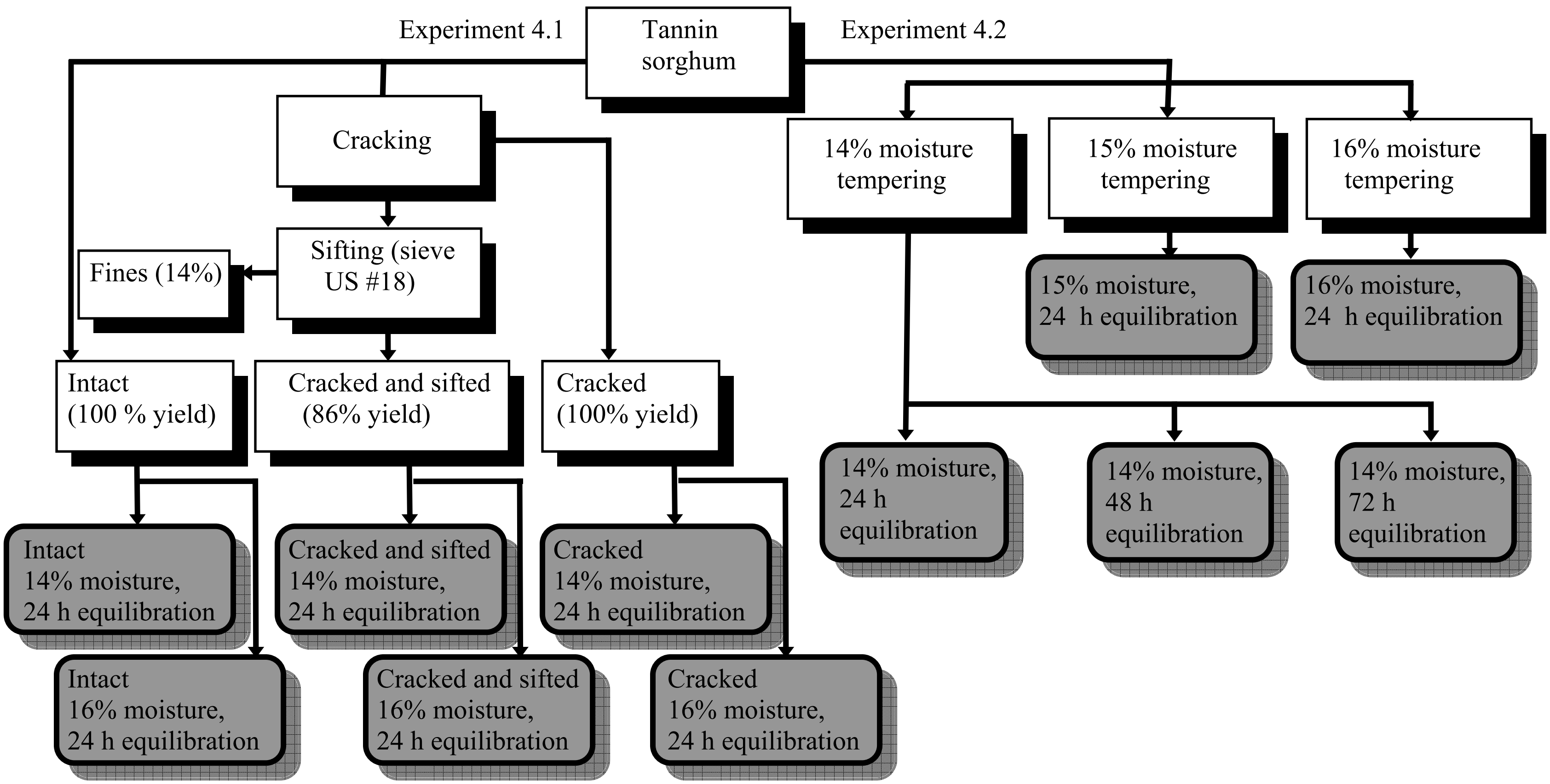

Fig. 16. Flow chart for raw materials preparation from tannin sorghum and their tempering.

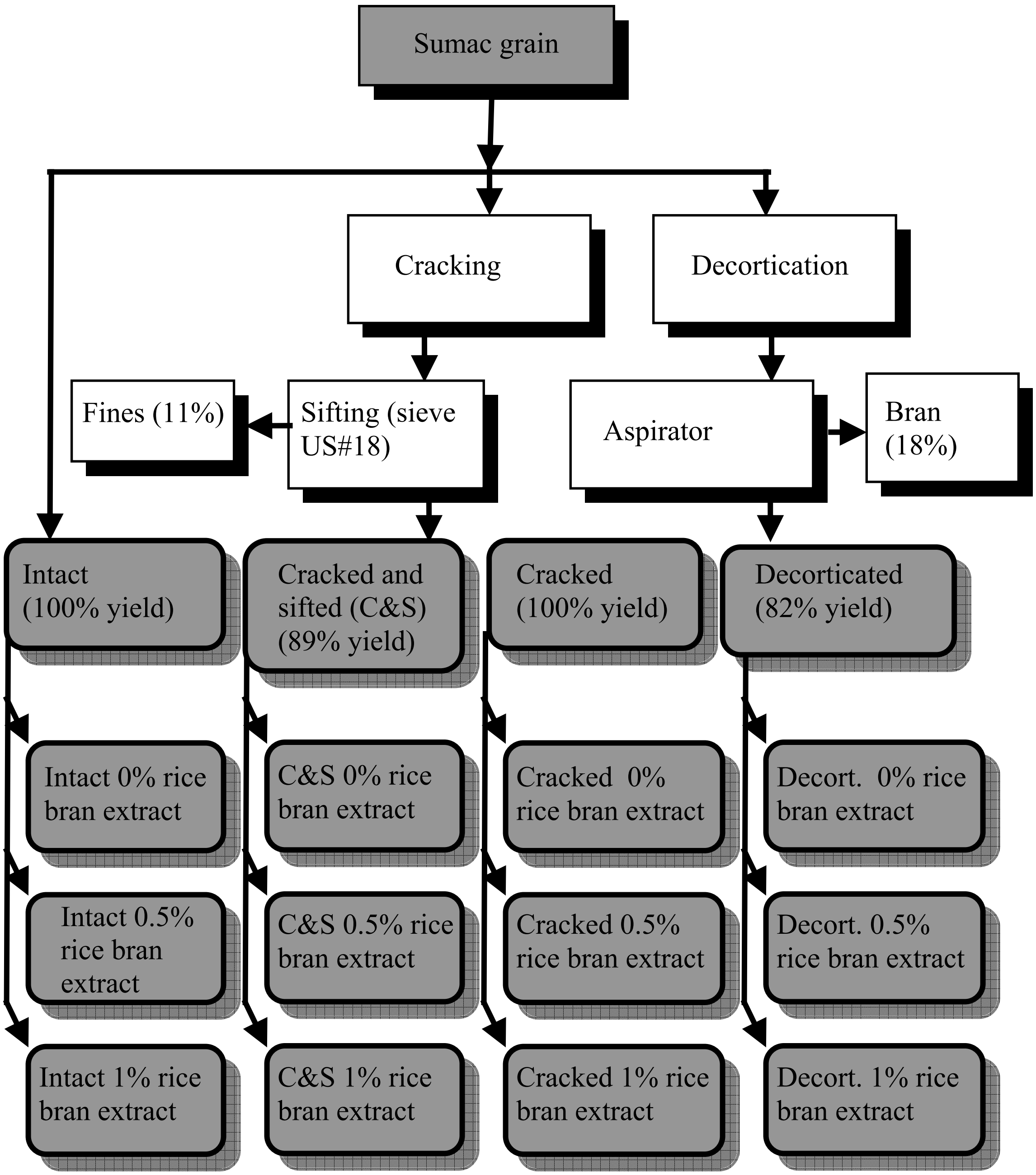

Fig. 17. Flow chart for raw materials preparation from Sumac sorghum.

Results and discussion

Grain characterization

The tannin sorghums utilized had typical values for physical properties (Table V). The kernels were small, relative to white food-type sorghum (see Table I in Chapter III). Kernels of Sumac grain were even smaller than the tannin grains. Dissection of kernels of tannin sorghum revealed a high proportion of soft endosperm and a thick pericarp which contains starch (Fig. 18). Dissected Sumac kernels showed a very soft endosperm and a thick pericarp without starch (Fig. 19). These characteristics caused a high percent removal in the TADD and the low hardness index from the SKHT, which indicated the sorghums were soft. Density and test weight were similar to those of white food-type sorghum. The pigmented testa layer was detected by the Clorox bleach method in both grain types.

Raw materials preparation and particle size distribution

Pictures of prepared raw materials are presented in Figs. 20 and 21. For the two types of grain, the greatest particle size was that of the intact grains, in which all material was retained above sieve US#10 (Tables VI and VII). The cracked and sifted grains had all the material retained above sieve US#20; the cracked not sifted had about 8% passing though sieve US# 20 in both cases. The decorticated Sumac grain had about 5% material passing through sieve US#10 and retained above sieve US#20.

Table V

Physical characteristics of the tannin and Sumac sorghums

	Tannin sorghum CSC3xR28	Sumac sorghum
Protein (% d.b.)	11.5	11.5
Starch (% d.b.)	69.3	69.8
TADD, % decorticated grain yield	76.7	79.3
Hardness index (SKHT)	76.5	64.3
Average kernel diameter (mm)	1.9	1.8
Thousand kernel weight (g)	22.6	15.6
Density (g/cm^3)	1.3	1.3
Test weight (lb/bu)	59.1	60.8
Color		
L	41.2	36.9
a	13.5	9.3
b	12.9	8.3
Clorox bleach test	Positive	Positive
Tannins (mg CE/g dry matter)*	8.1	13.7
Phenols (mg GAE/g d.m.)*	12.4	19.6
Anthocyanins (mg LE/g d.m.)*	4.3	2.9

* From Awika (2003).

Fig.18. Kernels of the tannin sorghum grain intact and dissected in experiments 4.1 and 4.2.

Fig. 19. Kernels of the Sumac sorghum grain intact and dissected in experiment 4.3.

Fig. 20. Raw materials for extrusion of tannin sorghum in experiments 4.1 and 4.2.

Fig. 21. Raw materials for extrusion of Sumac sorghum in experiment 4.3.

Table VI

Particle size distribution of raw materials from tannin sorghum in experiments 4.1 and 4.2[a]

Grain preparation	Sieve US#10 (2000 µm)	Sieve US#20 (850 µm)	Sieve US#30 (600 µm)	Sieve US#40 (425 µm)	Sieve US#60 (250 µm)	Sieve US#80 (180 µm)	Sieve US#100 (150 µm)	Pan (<150 µm)
Intact	100.0 a	0.0 b	0.00 b	0.00 b	0.00 b	0.00 a	0.00 a	0.00a
Cracked and sifted	48.7 b	51.2 a	0.09 b	0.03 b	0.01 b	0.00 b	0.00 a	0.00a
Cracked not sifted	45.9 b	45.7 a	3.82 a	2.11 a	1.46 a	0.62 a	0.37 a	0.08a
LSD	11.5	12.1	0.35	0.40	0.85	0.13	0.10	0.10

[a] Values followed by the same letter within a column are not significantly different ($p<0.05$).

Table VII

Particle size distribution of raw materials from Sumac sorghum in experiment 4.3[a]

Grain preparation	Sieve US#10 (2000 µm)	Sieve US#20 (850 µm)	Sieve US#30 (600 µm)	Sieve US#40 (425 µm)	Sieve US#60 (250 µm)	Pan (<250µm)
Intact	99.9 a	0.1 b	0.00 b	0.00 b	0.00 b	0.00 b
Cracked and sifted	24.1 b	75.6 a	0.1 b	0.1 b	0.01 b	0.00 b
Cracked not sifted	16.5 b	75.3 a	3.1 a	2.3 a	1.7 a	0.9 a
Decorticated	95.3 a	4.5 b	0.2 b	0.0 b	0.0 b	0.0 b
LSD	6.3	5.4	0.3	0.1	0.3	0.6

[a] Values followed by the same letter within a column are not significantly different ($p<0.05$).

Extrusion

All raw materials were extruded successfully, making products of acceptable appearance (Figs. 22, 23 and 24). Pigments naturally present in the outer layers of these sorghums gave the extrudates an even brownish red color, especially in the "whole grain" treatments. This appearance was expected and product is considered acceptable as a specialty. Observed extrusion parameters are presented in Tables VIII in experiment 4.1, IX in experiment 4.1 and X (experiment 4.3).

Experiment 4.1

SME was similar for all treatments with the exception of cracked and sifted grain tempered to 14% moisture. SME of this raw material was higher than that of its counterpart tempered at 16% moisture. Decreasing feed water content results in greater SME during extrusion (Bhattacharya and Hanna 1987). Decreased extrusion moisture can also lead to higher temperatures and power consumption (Miller 1990). In the present case there were no statistical differences in temperature and power but the tendencies corresponded to this explanation. So, a reduced hydration of the raw material tempered at 14% moisture may have been the cause of its higher SME.

Cracked and sifted sorghum tempered at 14% moisture, had a greater SME than intact or cracked grains extruded at the same moisture. Garber et al (1997) reported that for a given corn meal extrusion moisture, maximum SME was reached at particle sizes of 0.7 mm. Particle sizes below or above this caused lower SME values. In the present case the cracked and sifted grain had also a middle particle size as compared to the grain just cracked or the intact grain (Table VI).

Experiment 4.2

SME was lowest for the grain tempered at 16% moisture for 24 h; the material received less energy input compared to the other treatments. An increase in moisture in the extrusion feed can lead to a higher melt specific heat, reduced viscosity and reduced power consumption (Miller 1990); and SME (Bhattacharya and Hanna 1987).

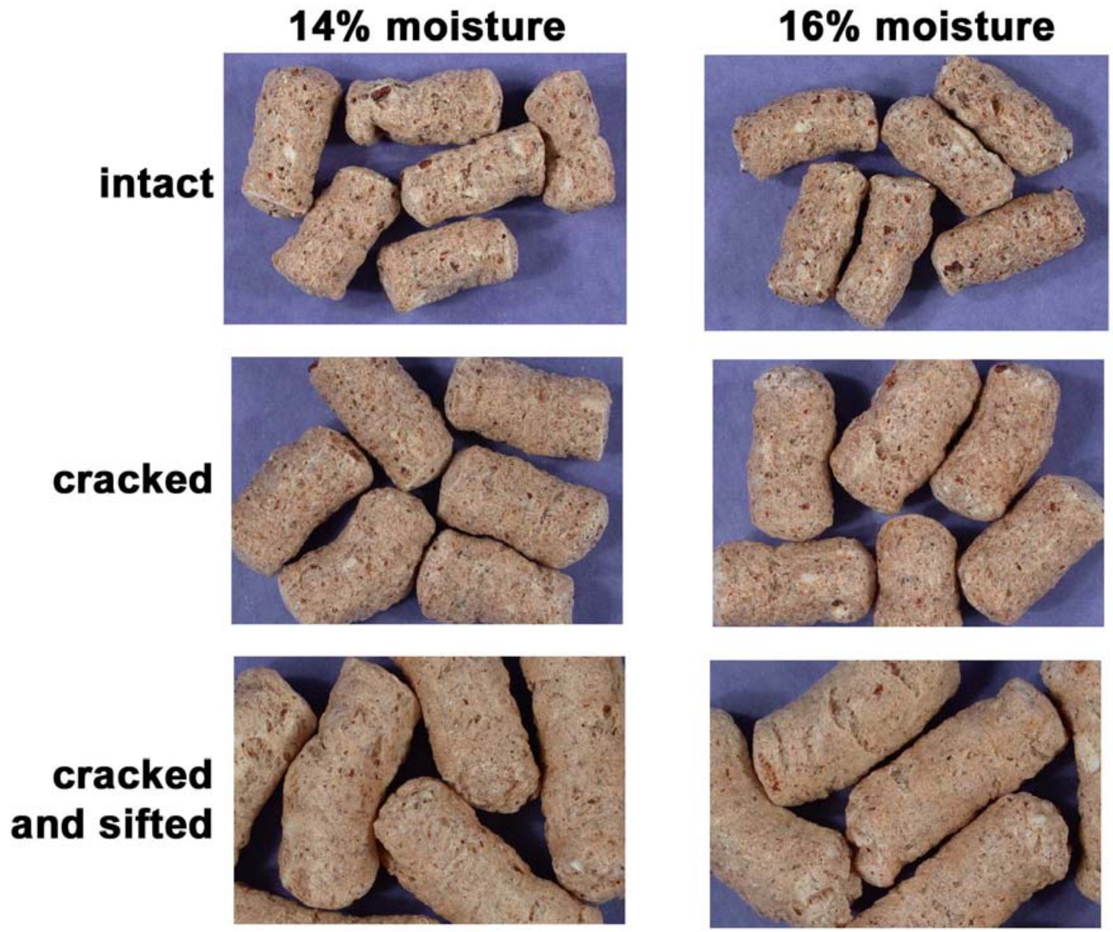

Fig. 22. Extrudates from experiment 4.1.

Table VIII

Extrusion parameters of tannin sorghum raw materials in experiment 4.1[a]

	Treatment (% moisture, preparation)	Temperature (F)	Power (kW)	Feed rate (kg/h)	SME (kJ/kg)
Tannin sorghum	14% intact	313.0 a	18.2 b,c	180.0 a	364.8 b
	14%, cracked	316.5 a	18.4 b,c	186.5 a	360.9 b
	14%, cracked and sifted	309.0 a	22.4 a	162.6 a	495.4 a
	16% intact	299.0 a	16.9 c	175.9 a	345.8 b
	16%, cracked	318.5 a	18.1 b,c	170.9 a	382.7 b
	16%, cracked and sifted	330.0 a	20.2 a,b	186.3 a	397.7 b
LSD		48.9	2.5	59.5	91.9

[a] Values followed by the same letter within a column are not significantly different ($p<0.05$).

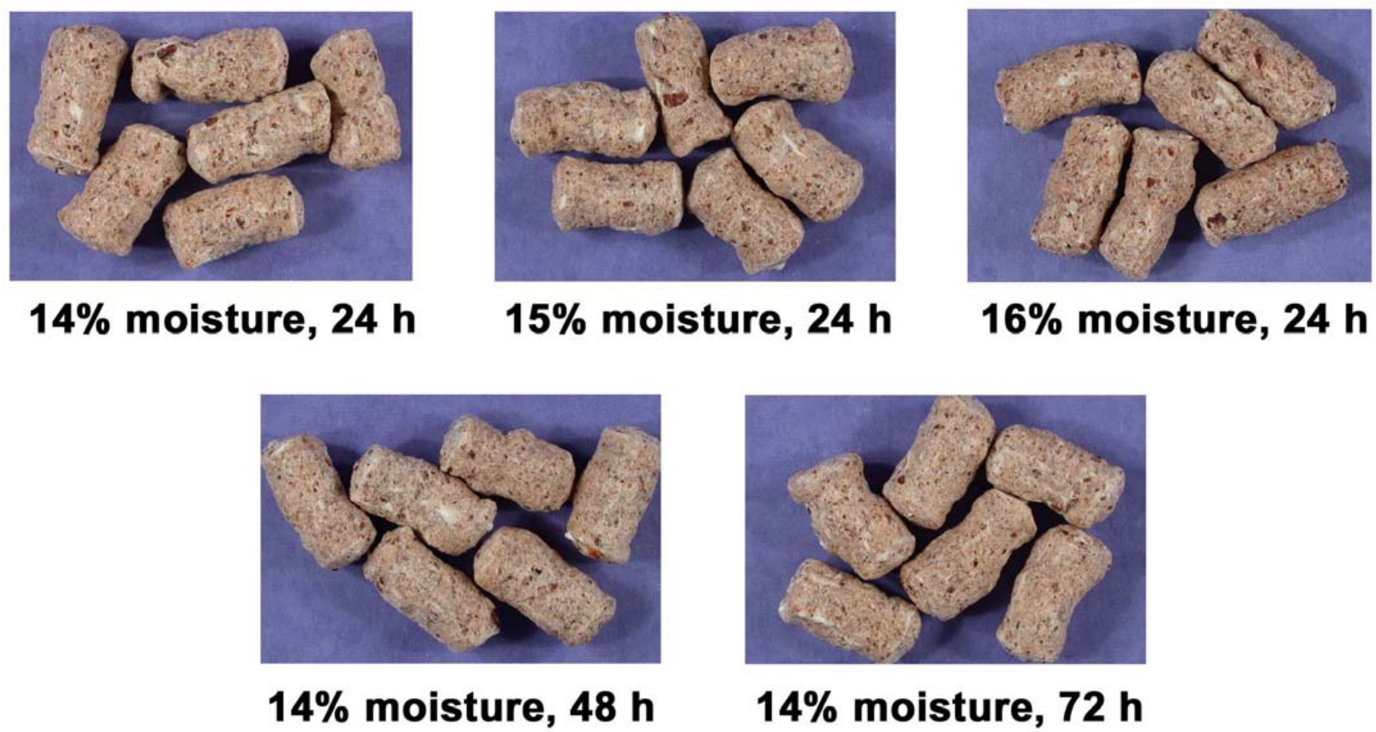

Fig. 23. Extrudates from experiment 4.2.

Table IX

Extrusion parameters of tannin sorghum raw materials in experiment 4.2[a]

	Treatment (% moisture, tempering time)	Temperature (F)	Power (kW)	Feed rate (kg/h)	SME (kJ/kg)
Tannin sorghum CSC3xR28	14%, 24 h	322.5 a	18.2 a,b	180.0 a	364.8 a,b
	15%, 24 h	308.0 a	17.7 a,b	172.8 a	369.8 a,b
	16%, 24 h	299.0 a	16.9 a	175.9 a	345.8 b
	14%, 48 h	289.5 a	18.9 b	174.2 a	391.4 a
	14 %, 72 h	303.0 a	18.8 a,b	174.2 a	387.7 a
LSD		81.3	1.8	13.7	38.1

[a] Values followed by the same letter within a column are not significantly different ($p<0.05$).

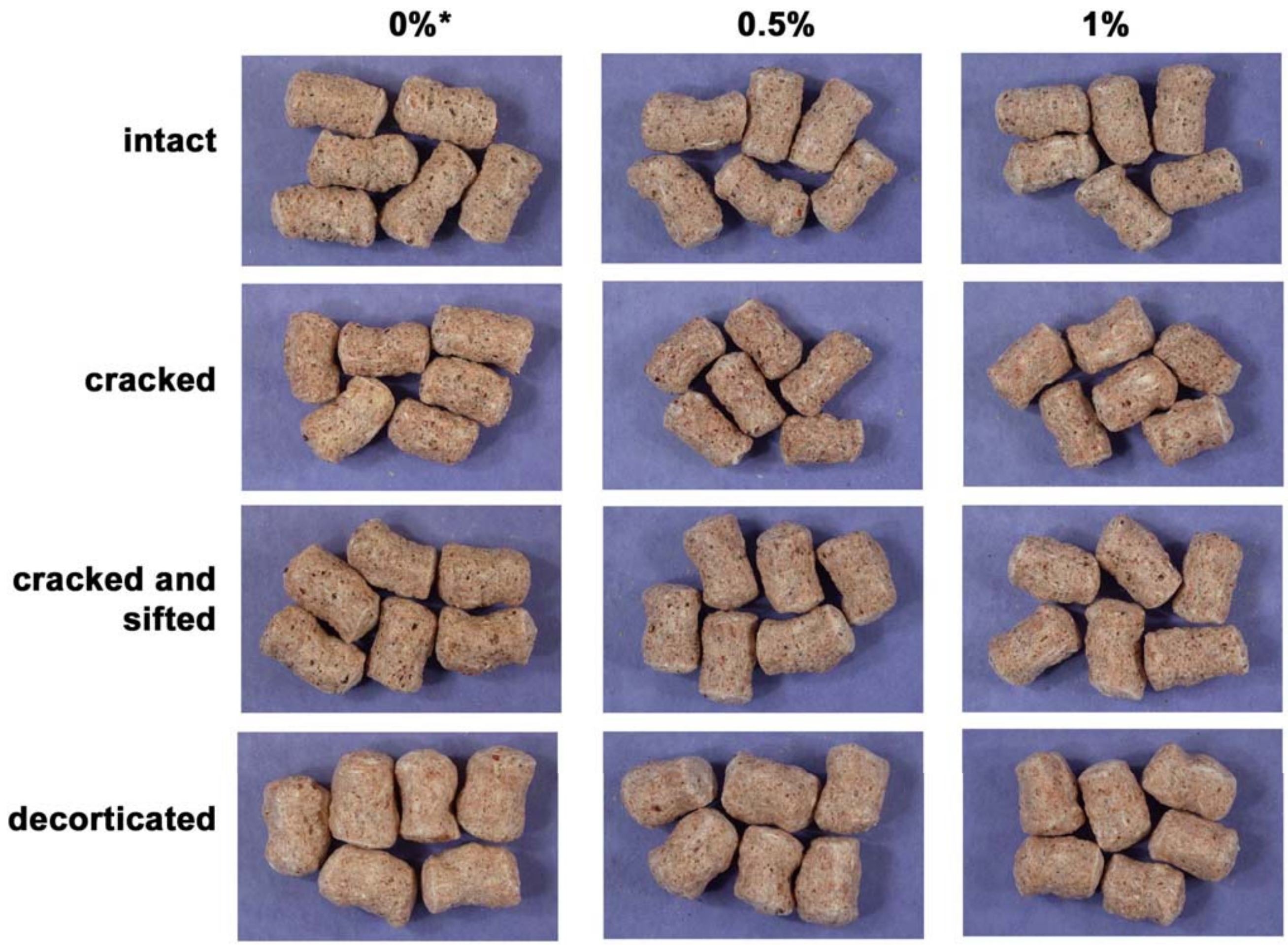

Fig. 24. Extrudates from experiment 4.3. * Level of rice bran extract addition.

Table X

Extrusion parameters of Sumac sorghum raw materials in experiment 4.3[a]

Grain preparation	% rice bran extract	Temperature (F)	Power (kW)	Feed rate (kg/h)	SME (kJ/kg)
Intact	0%	335	17.8	168.8	380.6
	0.5%	327	17.8	163.6	391.2
	1%	296	17.8	166.2	386.6
Cracked	0%	327	15.9	161.2	354.8
	0.5%	293	16.2	163.6	357.3
	1%	309	15.9	163.6	350.8
Cracked and sifted	0%	NA	NA	158.8	NA
	0.5%	315	17.0	158.8	385.6
	1%	320	17.4	161.2	389.2
Decorticated	0%	299	18.0	174.2	372.4
	0.5%	325	17.1	171.4	359.8
	1%	304	17.4	171.4	364.7

[a] Values from a single extrusion run

Experiment 4.3

Among grain preparation methods, SME was lowest for the cracked grain; this means the cracked material received less energy input compared to the other treatments. The smaller particle size (Table VII) may explain the difference, as the other raw materials had higher average particle size. Particles that are too fine can lead to early gelatinization in the extruder and low melt viscosity (Matz 1976).

Expansion ratio and bulk density

Experiment 4.1

At either moisture content (14 or 16%), expansion ratio and bulk density were significantly affected by preparation method (Figs. 25 and 26). The least expanded, most dense extrudates were those from intact grains. They were followed by the cracked, and by the cracked and sifted grain, respectively. The particle sizes of the raw materials may hold the explanation. According to Chauhan and Bains (1985), the larger the particles the greater the expansion. There is a limit to this relationship, as Guy and Horne (1988) reported that wheat flour particles larger than 0.5 mm produced incompletely melted particles in the final product. Also Anderson et al (1969) found that corn grits greater than 1.2 mm did not degrade properly in single-screw extrusion. Garber et al (1997) reported that greater longitudinal expansion and specific volume were reached with middle-sized corn grits (0.94 mm) than with extruded flours (0.50 mm) or large grits (1.6 mm). One of the factors that probably determine the optimum particle size of the raw material is its proper hydration. Hydration of rice particles before extrusion is faster with decreasing particle size (Yeh et al 1992). In the present study, fines in the cracked grain probably took up most of the tempering water before the larger particles could be hydrated. Particle size may also affect expansion by altering the “timing” of raw material degradation in the process. Matz (1976) suggested an optimum corn meal size of 0.4 mm for extrusion, because it retarded gelatinization until just before discharge through the die. Smaller particles were gelatinized too soon causing excessive degradation and low melt viscosity. The more uniform, mid-sized particles of cracked and sifted sorghums had the best hydration during tempering, and degradation during extrusion.

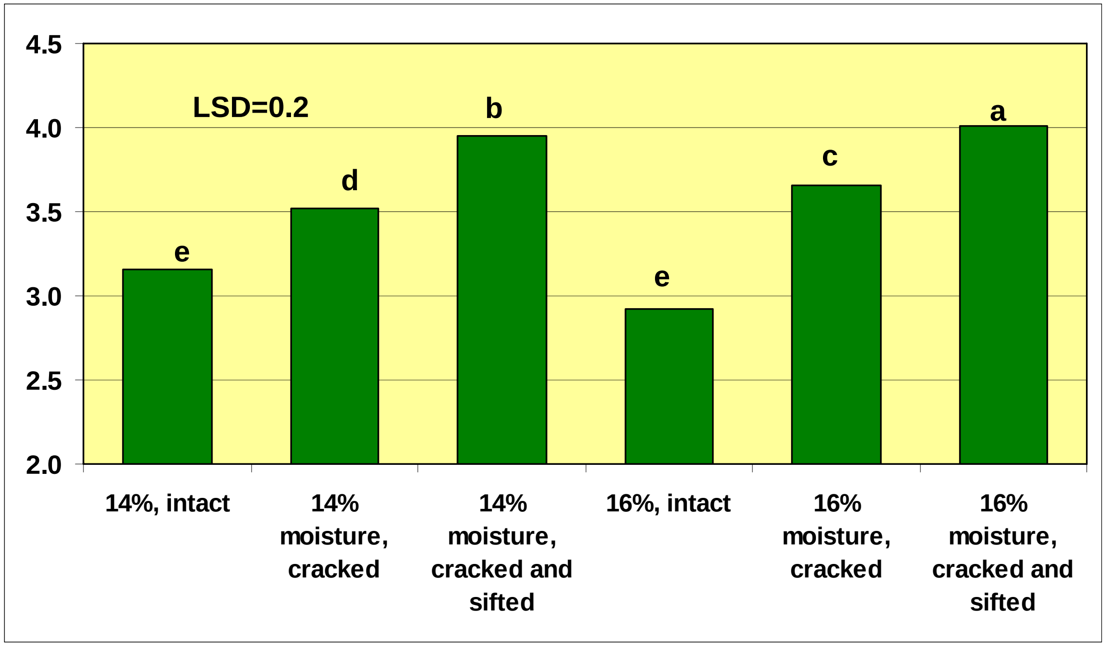

Fig. 25. Expansion ratio of extrudates from tannin sorghum in experiment 4.1. Values with the same letter are not significantly different at α=0.05.

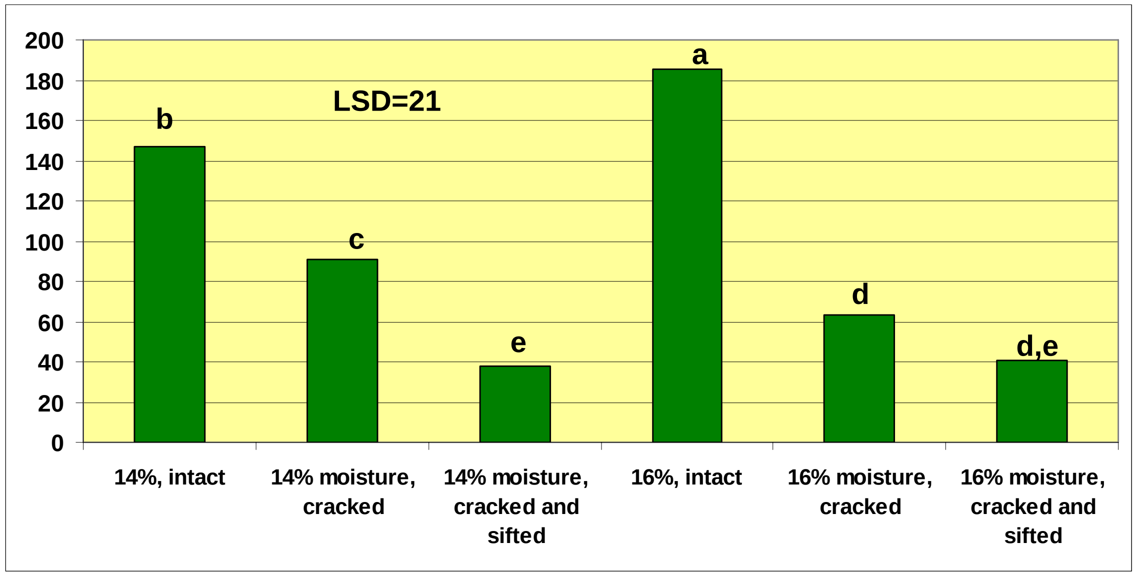

Fig. 26. Bulk density (g/L) of extrudates from tannin sorghum in experiment 4.1. Values with the same letter are not significantly different at α=0.05.

Expansion and SME of cracked grain extruded at 16% moisture were greater than at 14% moisture. It has been reported that expansion or “puffing” can increase with moisture. Miller (1990) explained that in “undergelatinized” systems, extruding melt viscosity can increase with water, with the concomitant rise in temperature, pressure, and expansion. The sorghum tempered at 16% moisture had more water available to hydrate all particles, including the fines. Fines (a result of the grinding process) may require a high amount of water because of their high surface area and fiber content. Turner (2004) reported that these fines had 17% TDF, as their removal decreased that of the cracked grain by 1%. In the case of materials tempered at 14% moisture, the fines may have taken up too much water quickly, hindering hydration of bigger particles.

The difference in optimum extrusion moistures for “intact” and “cracked” sorghum is noteworthy. According to Harper (1981), the moisture of the extruding melt significantly affects viscosity, expansion and product texture. A different amount of water was needed for particle hydration, melt lubrication, development of viscosity, and steam generation at the die exit.

Experiment 4.2

Expansion ratio was lowest and bulk density highest for intact grains tempered at 16 instead of at 14% moisture (Figs. 27 and 28). There was “excess” water in the former case, which was not absorbed by this raw material entirely. The additional water also decreased energy input into the extruding material (SME in Table IX). In ranges above 13-15%, increasing moisture can lower expansion in extrusion (Garber et al 1997; Alvarez-Martinez et al 1988; Chinnaswamy 1993; Guy and Horne 1988). Lower moisture content may increase shear rate inside the extruder, possibly increasing gelatinization and expansion (Chinnasamy and Hanna 1988b).

.

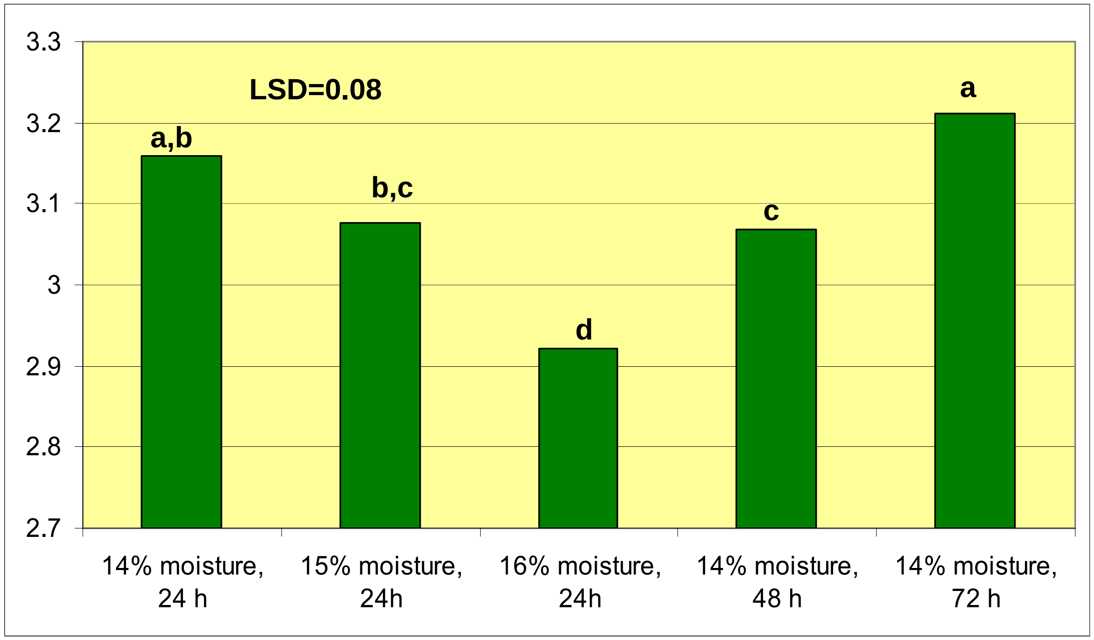

Fig. 27. Expansion ratio of extrudates from tannin sorghum in experiment 4.2. Values with the same letter are not significantly different at α=0.05.

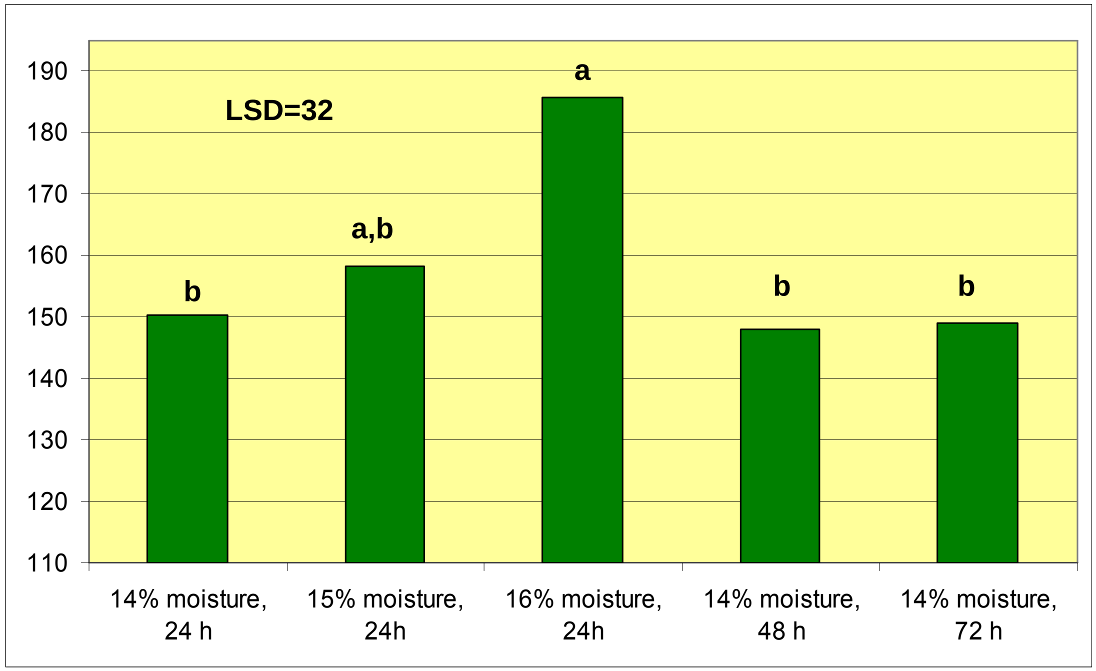

Fig. 28. Bulk density (g/L) of extrudates from tannin sorghum in experiment 4.2. Values with the same letter are not significantly different at α=0.05.

Within the grains tempered at 14% moisture, lowest expansion was for those tempered for 48 h. Hsieh et al (1989) found an effect of tempering time on expansion of rice cakes. At some tempering moisture contents, however, no effect of tempering time on specific volume was detected by the authors

Experiment 4.3

Among grain preparation methods, the least expanded extrudates were the "whole-grain" products (those from grains processed intact or just cracked) (Fig. 29). Starch is the foremost component on which expansion depends, and whole grains have an average of 400% volume increase upon expansion, as compared to 500% for pure starches (Horn 1977). The second most expanded extrudates (after those from decorticated grain) were from the cracked and sifted grain. Turner (2004) demonstrated that cracking and sifting results in a decrease in total dietary fiber, as the fines removed have about 17% TDF. Decorticated sorghum, obviously, has the least amount of fiber among the four prepared grain types, and hence produced the most expanded extrudates.

Addition of 1% rice bran extract decreased expansion compared to 0.5% or no addition (Fig. 30). The rice bran extract has emulsifying properties (Hammond 1994). Addition of emulsifiers such as monoglycerides results in decreased degradation of starch in HTST extrusion (Kervinen 1981). Amylose-lipid complexes may decrease the solubility of the starch (Mercier et al 1980).

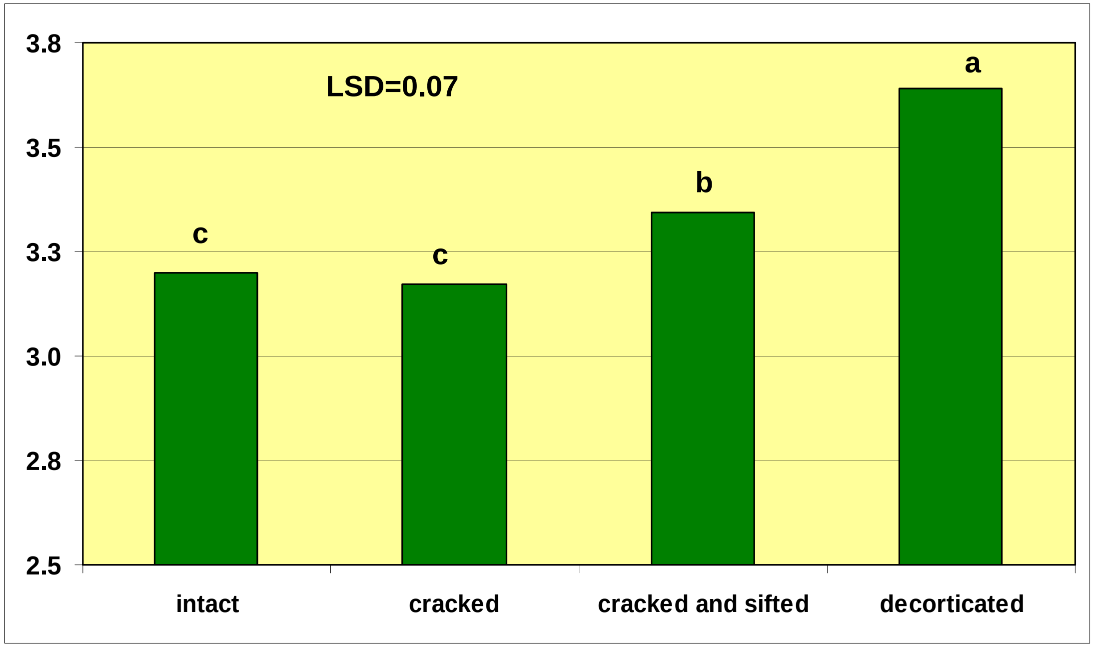

Fig. 29. Expansion ratio of extrudates from Sumac sorghum as affected by preparation method in experiment 4.3. Values with the same letter are not significantly different at =0.05.

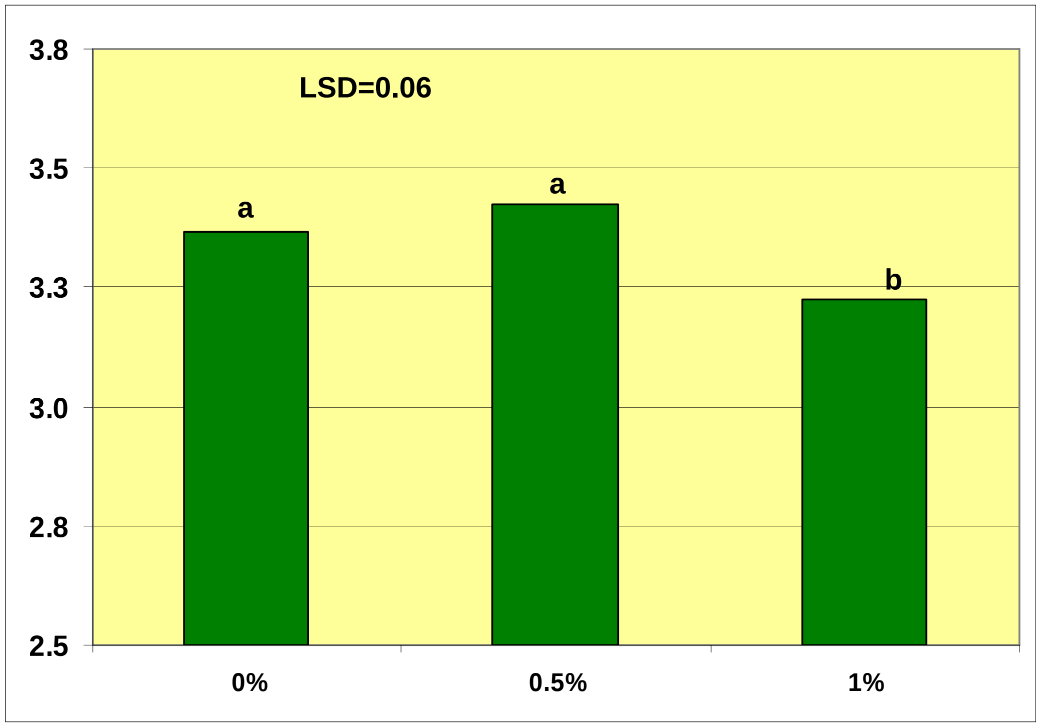

Fig. 30. Expansion ratio of extrudates from Sumac sorghum as affected by % addition of rice bran extract in experiment 4.3. Values with the same letter are not significantly different at α=0.05.

Moisture

Experiment 4.1

There were differences in the moisture before drying, but moistures after drying were similar (Fig. 31). Moisture before drying was lowest for cracked and sifted sorghums, at either tempering moisture content. The trend throughout was the lower the extrudate moisture content right after extrusion, the greater its expansion. The homogeneous, middle-sized particles in cracked and sifted grain caused better water distribution than in the intact or cracked grains. Particles were more evenly transformed into a continuous matrix in the melt. Addition of water reduces interactions and plasticizes the dry polymers from raw materials, helping to transform them into deformable, plastic fluids (Guy 2001). Water was more easily and uniformly released as steam.

Experiment 4.2

Among the grains equilibrated for 24 h, the highest moisture after extrusion was that of the grain tempered at 16% moisture (Fig. 32). More water was retained in the extrudates after extrusion than at 14 or 15% extrusion moisture. This treatment had water in excess to that needed for the hydration of the raw material. This resulted in increased lubrication and decreased shear inside the equipment. Expansion was possibly more related to expansive effects of the "dry" phase than due to moisture (steam flashing) effects, as described by Padmanabhan and Bhattacharya (1989).

Within the grains tempered at 14% moisture, water content after extrusion was lowest for those equilibrated at 72 h. The increased time may have caused water to be more distributed, leading to more steam flashing at the die exit. However, this was not correlated with a high expansion ratio. Changes in the rheology of the extruding melt may have prevented greater expansion. Miller (1985) explained that water can increase the elasticity of the extruding melt, causing it to shrink more easily upon cooling after extrusion.

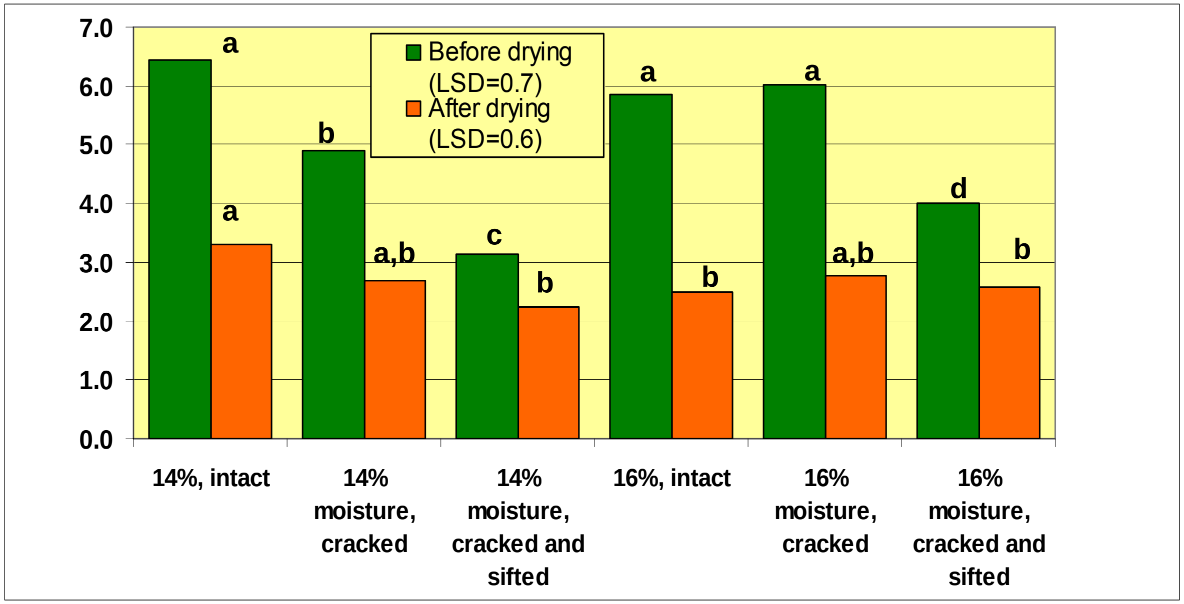

Fig. 31. Moisture (%) of extrudates from tannin sorghum before and after drying in experiment 4.1. Values with the same letter are not significantly different at α=0.05.

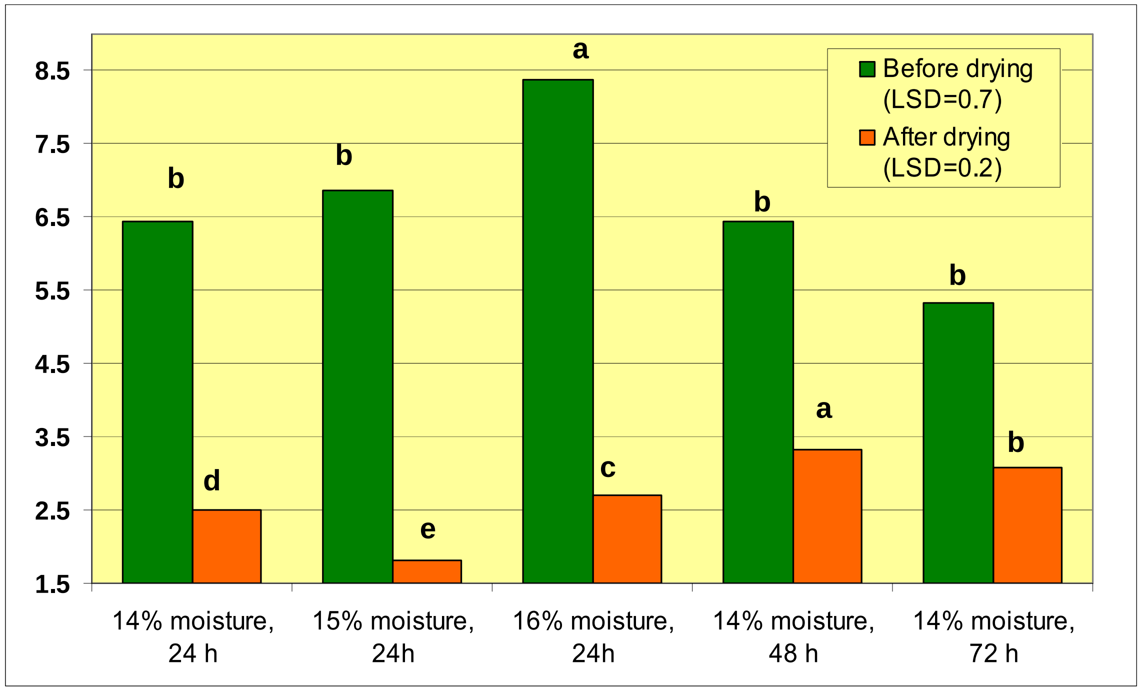

Fig. 32. Moisture (%) of extrudates from tannin sorghum before and after drying in experiment 4.2. Values with the same letter are not significantly different at α=0.05.

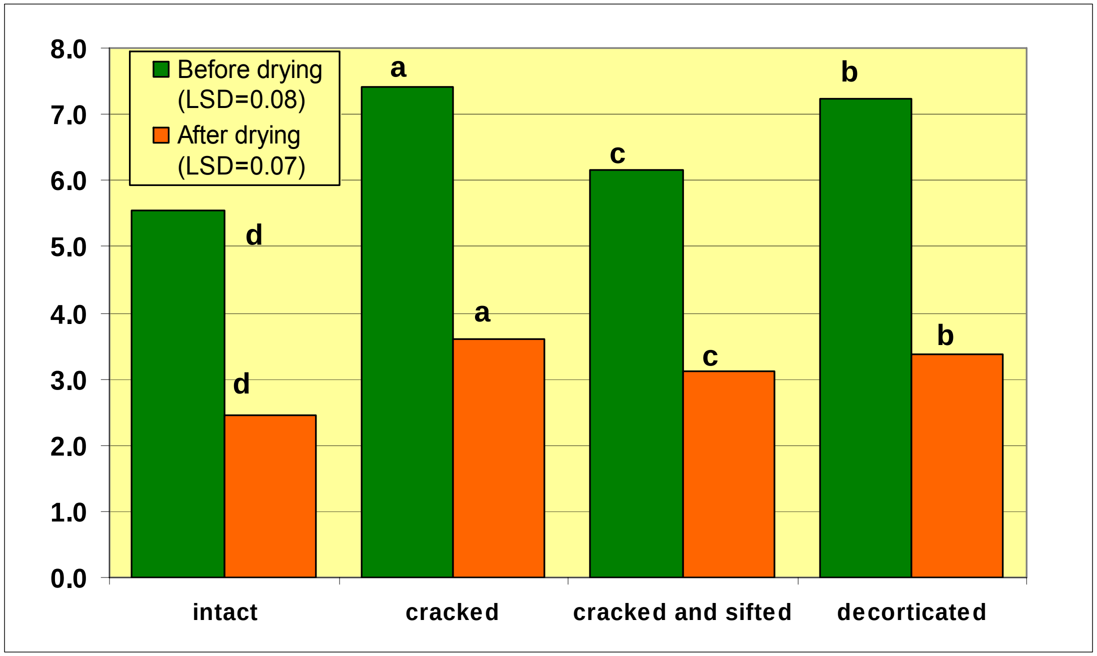

Fig. 33. Moisture (%) of extrudates from Sumac sorghum before and after drying as affected by preparation method in experiment 4.3. Values with the same letter are not significantly different at α=0.05.

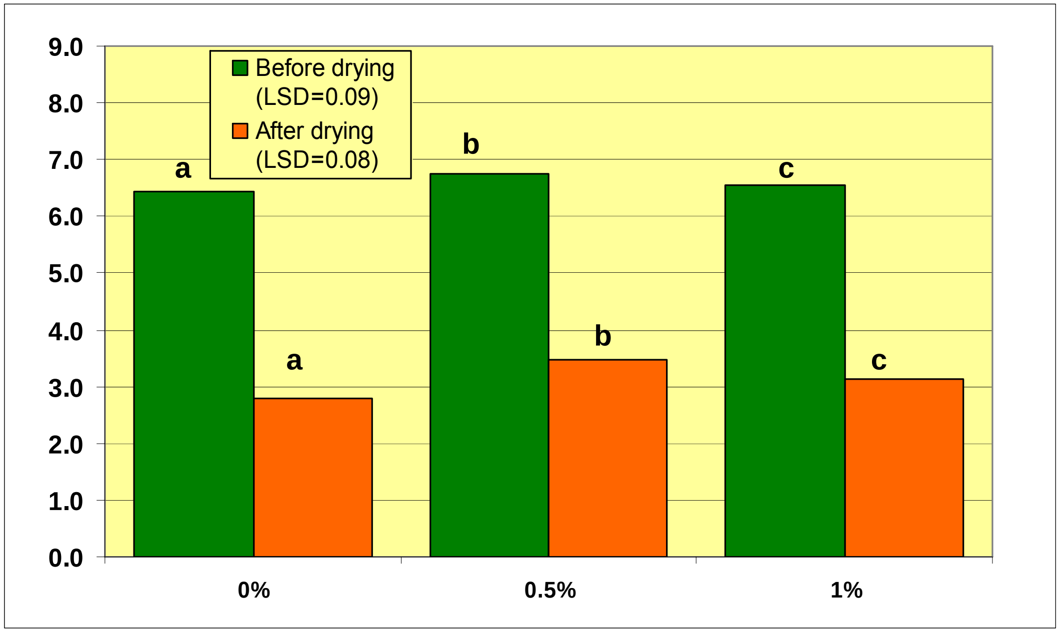

Fig. 34. Moisture (%) of extrudates from Sumac sorghum before and after drying as affected by % rice bran extract addition in experiment 4.3. Values with the same letter are not significantly different at α=0.05.

Experiment 4.3

The highest moisture after extrusion was that of the extrudates from cracked grain, as compared to extrudates from grains prepared by the other methods (Fig. 33). This was correlated with expansion. The high hydration of the fines in the cracked grain may have caused uneven distribution of moisture and less steam flashing at the die exit. Small particles tend to hydrate faster than larger particles (Chauhan and Bains 1985).

Extrudates from raw materials with no added rice bran extract had the least moisture after extrusion (Fig. 34).

Texture

Experiment 4.1

At 14 or 16% moisture, the greater the expansion the softer the extrudates (lower shear force, Fig. 35). Acosta (2003) found that extrudates from coarse whole-sorghum meal expanded more, and were less "stiff" than extrudates from whole sorghum (un-ground) and fine whole-sorghum meal. Also Garber et al (1997) found that extrudates from a corn meal with particle size of 0.4 mm had greater expansion and lower breaking strength than extrudates from coarser or finer corn meal. In the present experiments the most expanded (and softest) extrudates were from cracked and sifted grain.

Extrudates from cracked grain tempered at 16% moisture were softer than those from cracked grain tempered at 14% moisture (Fig. 35). This correlated with a lower expansion of the latter. A better distribution and total amount of water for that particular raw material, resulted in better starch transformation into a continuous phase for the treatment tempered at 16%. This resulted in good film formation inside the extruder due to optimum viscosity and lubrication. Increasing the water content within certain ranges, increases softness in expanded pet foods (Miller 1985), corn grits (Lanay and Lisch 1983) and wheat flours (Faubion and Hoseney 1982).

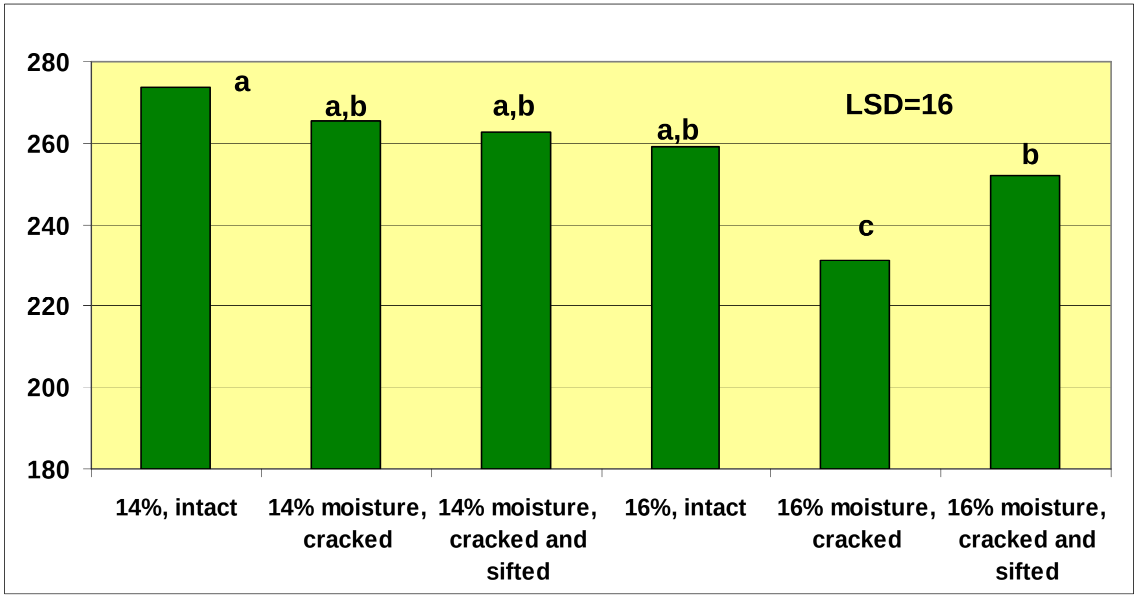

Fig. 35. Shear force (N) of extrudates from tannin sorghum in experiment 4.1. Values with the same letter are not significantly different at α=0.05.

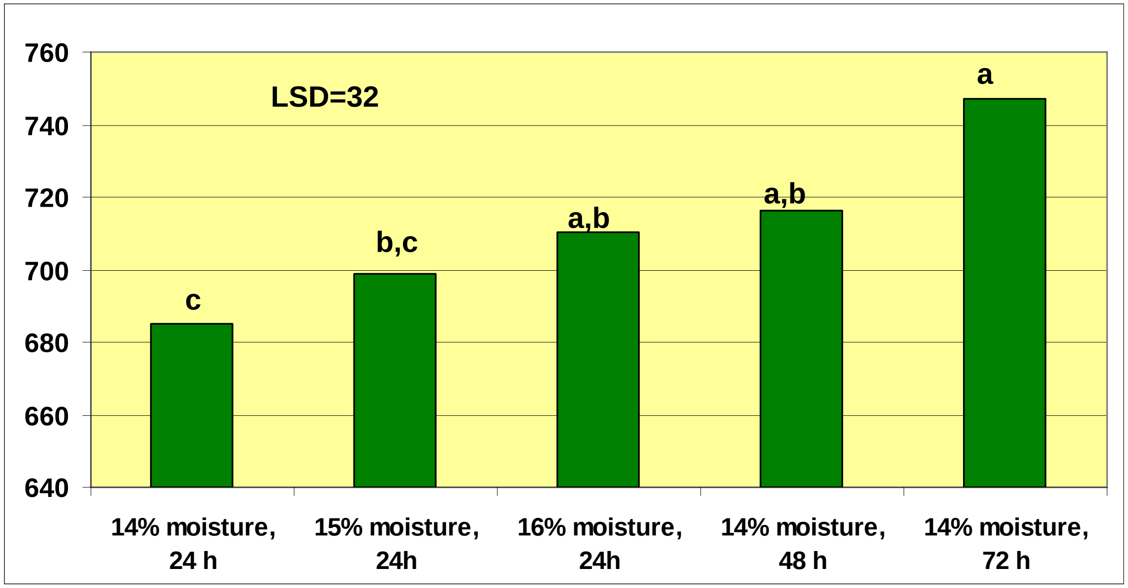

Fig. 36. Peak force (N) of extrudates from tannin sorghum in experiment 4.2. Values with the same letter are not significantly different at α=0.05.

Experiment 4.2

Extrudates from grain tempered at 16% moisture for 24 h had a higher braking peak force (were firmer) than those tempered at 14% for 24 h (Fig. 36). This correlated with their difference in expansion. Extrudate expansion depends on air cell growth. The more expanded an extrudate, the greater its cells and the thinner its cell-walls. Thinner and weaker cell walls of the more expanded extrudates result in a softer texture (Barrett and Peleg 1992).

Extrudates from sorghums tempered at 14% moisture had a lower peak force when the grains were equilibrated for 24 h rather than for 48 h (Fig.36). Increased peak force correlated with a decreased expansion.

Experiment 4.3

Intact and cracked grains resulted in the firmest extrudates (Fig. 37). As was discussed above, these raw materials are “whole grains” and hence have higher fiber content than the other raw materials. They also have the most extreme particle sizes in the experiments (low for cracked grains, high for intact grain), a fact that limits their expansion.

Rice bran extract made the extrudates firmer (Fig. 38). Hammond (2000) added rice bran extract to make expanded rice crisps firmer. It has been observed that emulsifiers complex with starch in extrusion, causing reduction in dispersion and gelatinization and SME dissipation (Singh et al 1988). Zones of unaltered starch may disrupt the continuous phase of gelatinized starch, decreasing the strength of air cell walls.

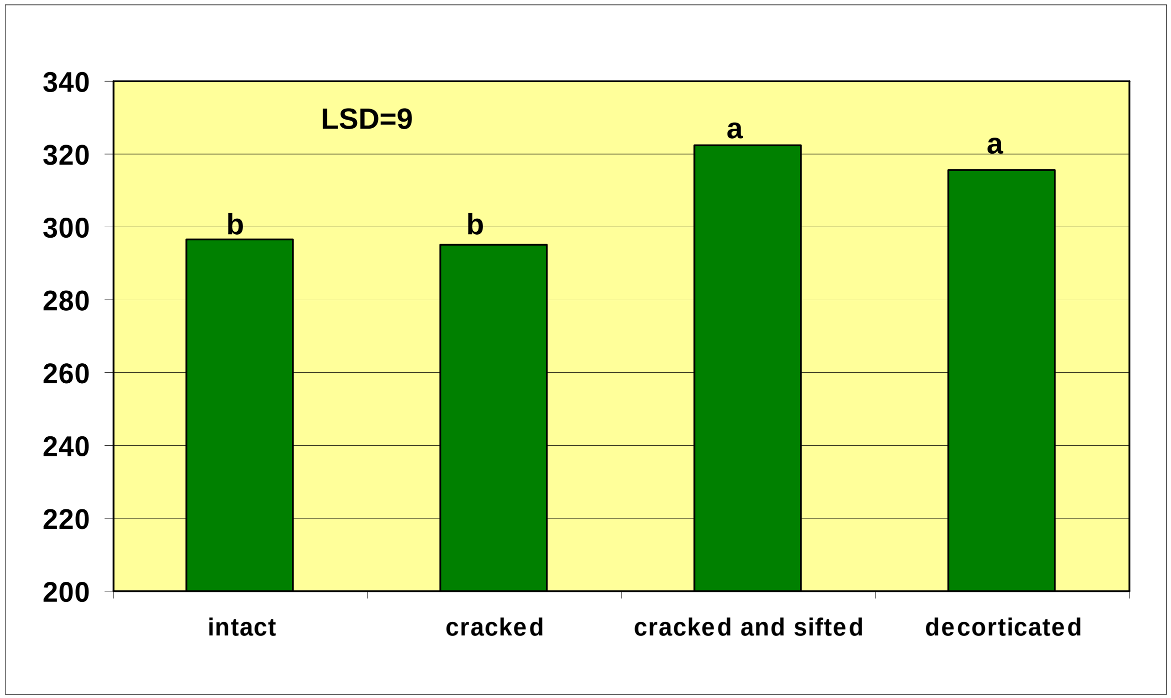

Fig. 37. Shear force (N) of extrudates from Sumac sorghum as affected by preparation method in experiment 4.3. Values with the same letter are not significantly different at α=0.05.

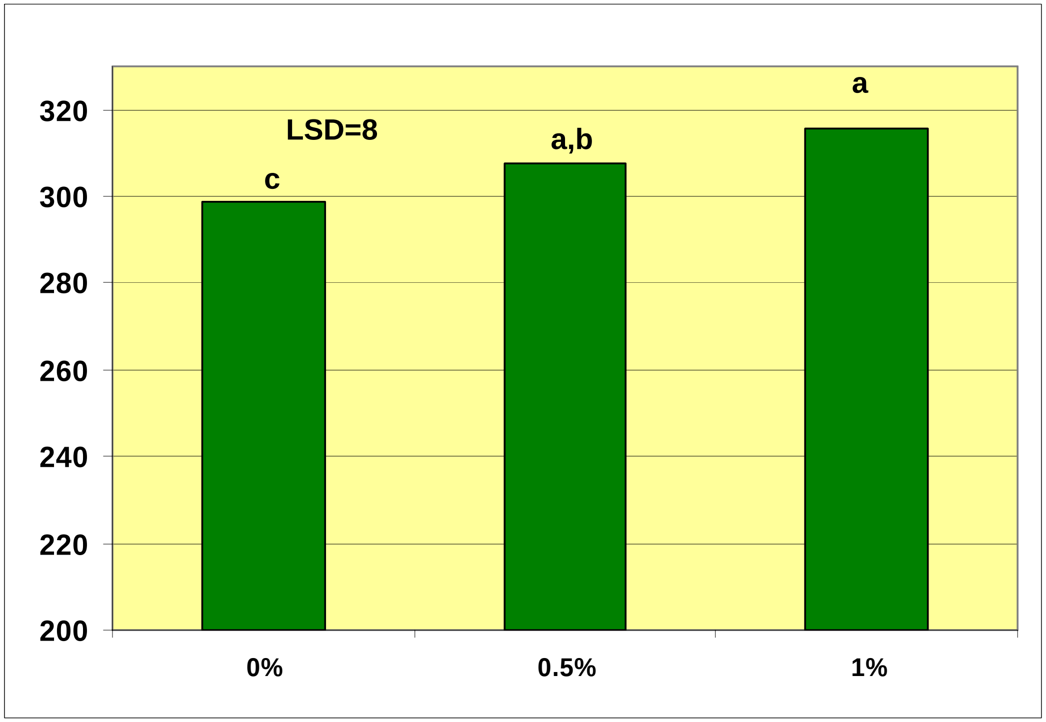

Fig. 38. Shear force (N) of extrudates from Sumac sorghum as affected by % rice bran extract addition in experiment 4.3. Values with the same letter are not significantly different at α=0.05.

Structure

Macrostructure

Experiment 4.1

Extrudates from intact grains had the biggest air cells, followed by extrudates from cracked, and cracked and sifted grains (Fig. 39). This correlated with microstructure (Fig. 40).

Experiment 4.2

Extrudates from grains equilibrated at 72 h had smaller and more evenly distributed air cells than those equilibrated for either 24 (Fig. 41) or 48 h. Possibly the more uniform water distribution in the former caused a more even steam flashing thorough the extruding melt matrix at the die exit. This was not translated into a grater expansion due to the high elasticity of the melt, which also resulted from its hydration and led to shrinking upon cooling or "setting" (Miller 1985).

Microstructure

Experiment 4.1

Results from macrostructure observations were confirmed by microscopy analysis (Fig. 40), which also showed that the bigger the air cells the thicker their walls and the more ragged their surface.

Barrett and Peleg (1992) observed that corn starch extrudates with the greatest expansion had the biggest air cells. The structure of the densest extrudates was more "filled in" and had thicker air cell walls. In the present case, however, the less expanded extrudates had large air cells and tunnels with a harsh appearance and uneven distribution. Padmanabhan and Bhattacharya (1989) explained that expansion in extrusion is governed by material ("elastic") and moisture effects. Material effects are related to the release of pressure from the "dry" phase of the extrusion melt; moisture effects relate to the flashing of water into steam. Moisture effects are responsible for the production of evenly distributed bubbles; material effects cause a few, large and middle-sized bubbles. The expansion of the intact and cracked grains may have been more dependent on material effects than on moisture effects. This is supported by the fact that their extrudates retained more water through the process than the cracked and sifted grain, indicating less steam flashing off during expansion. Faubion and Hoseney (1982) found that wheat flour extrudates of poor expansion had air cells of non-uniform size and that their location in the cross-sections of the extrudates was quite random. They observed that the biggest cells had non-smooth cell walls which indicate failure before setting. In the present experiments, the incipient bubbles were likely punctured by the bran particles as described by Guy and Horne (1988), so their growth was not uniform and their cell walls appear ragged.

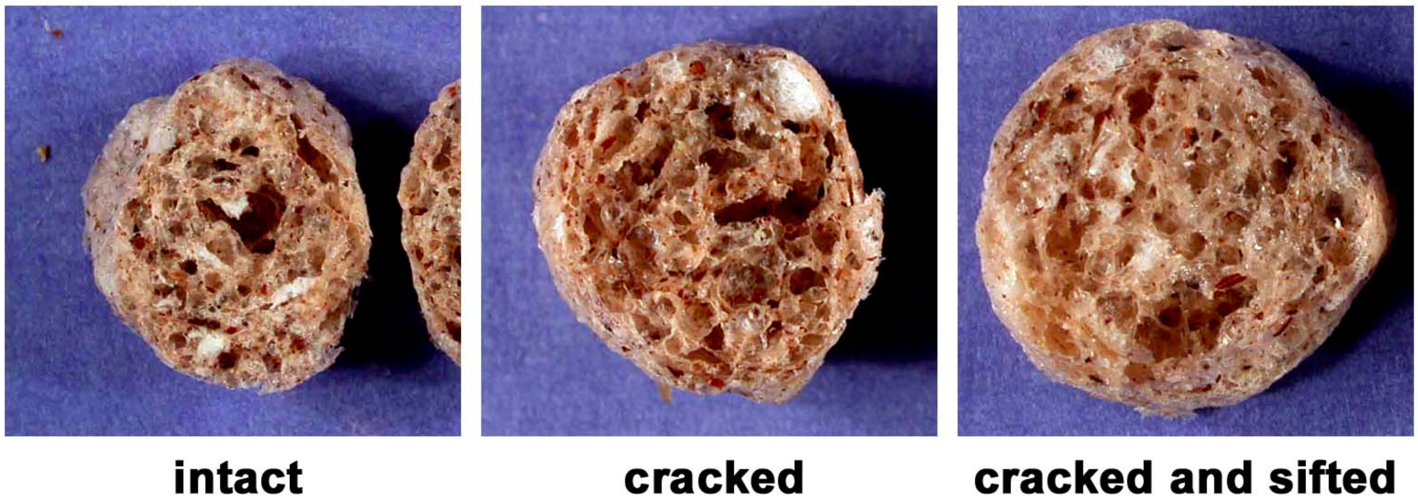

Fig. 39. Cross-sections of extrudates from tannin sorghum in experiment 4.1.

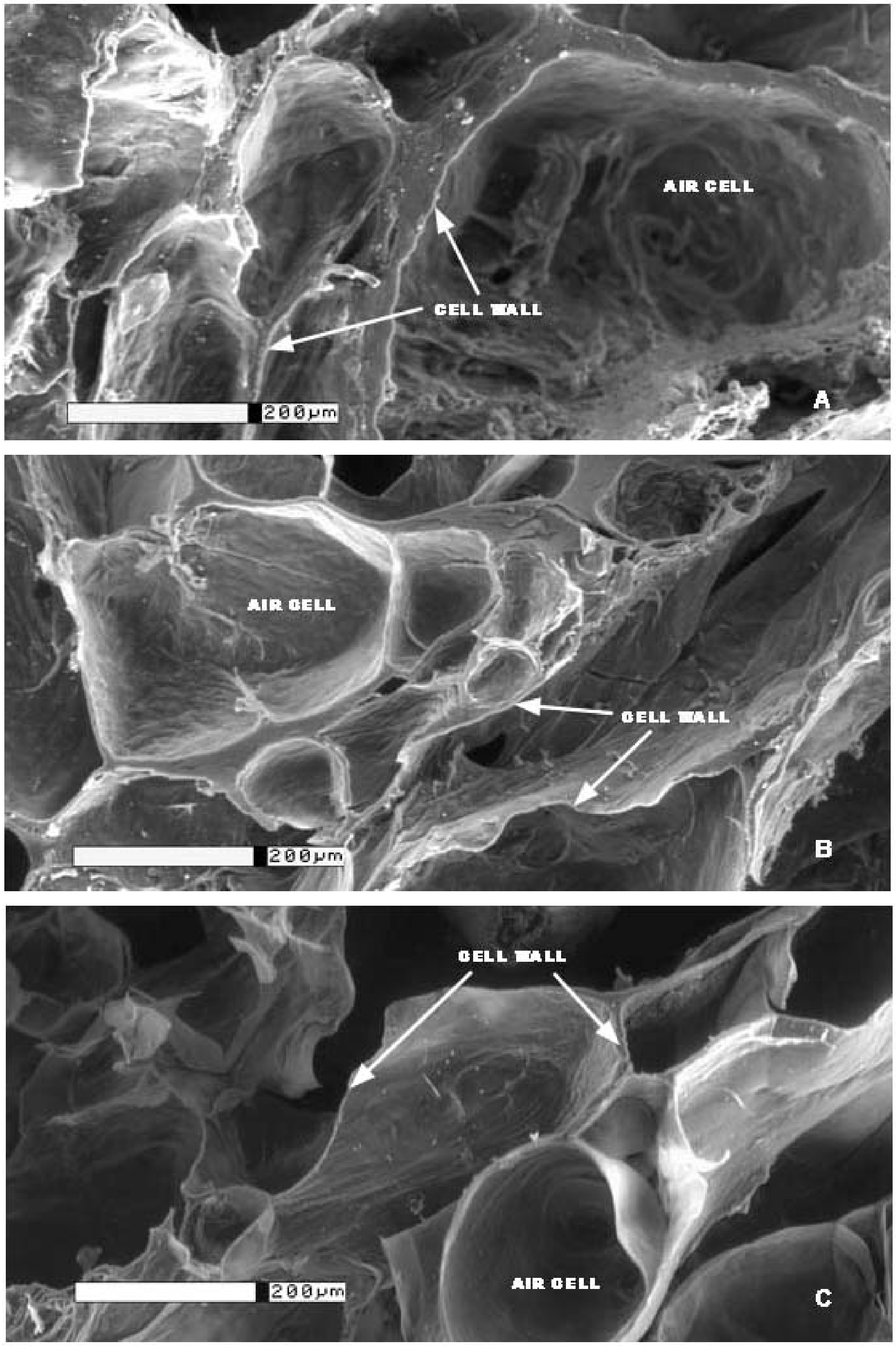

Fig. 40. ESEM images of extrudates from tannin sorghum extruded intact (A), cracked (B), and cracked and sifted (C) in experiment 4.1.

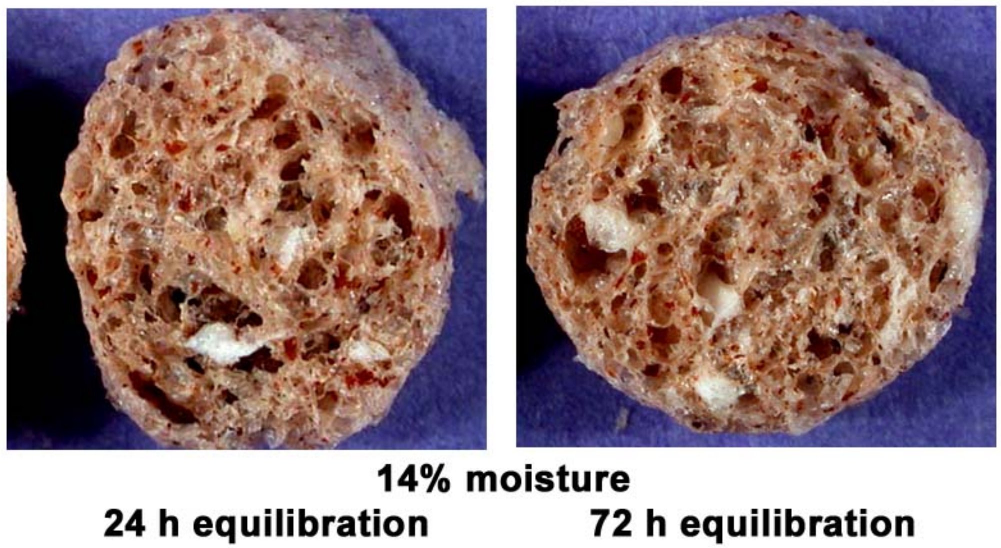

Fig. 41. Cross-sections of extrudates from tannin sorghum in experiment 4.2.

Gritty particles

There was a negative correlation between expansion ratio and gritty particles (Figs. 42 and 43). Fewer gritty particles depended on less bran (fiber) particles in the extrudates. Cracked and sifted grains have a TDF of 10%, versus 11% for the other two raw material types (Turner 2004).

Less grittiness also means a starchy fraction more digestible in α-amylase. It was observed by Gomez et al (1988) that the most expanded extrudates from sorghum meal s were also more enzyme-susceptible. The more expanded extrudates had greater degradation of endosperm pieces and starch, which caused recovery of less gritty particles. Extrusion causes the dispersion of starch and protein and their gelatinization and denaturation, respectively. Starch becomes available for digestion as it is degraded and its interactions with protein are diminished. An elastic continuous phase (or "film") of aligned starch-derived molecules is formed, which supports air cell formation and growth (Alvarez-Martinez et al 1988). Starch degradation is greatest when extruding conditions of low temperature, low moisture content and high RPM (similar to those used in the present experiments) are utilized (Wen et al 1990).

Effects of fiber on the starch molecules may have contributed to the correlation between expansion and grittiness. Chinnaswamy and Hanna (1991) observed that fiber affects degradation of starch inside the extruder by affecting velocity gradient of the melt.

Experiment 4.1

Extrudates from cracked and sifted grains had fewer gritty particles than extrudates from cracked or intact sorghums, at either moisture content (Fig. 44). Within the intact or cracked grains, expansion was negatively correlated with grittiness. In the

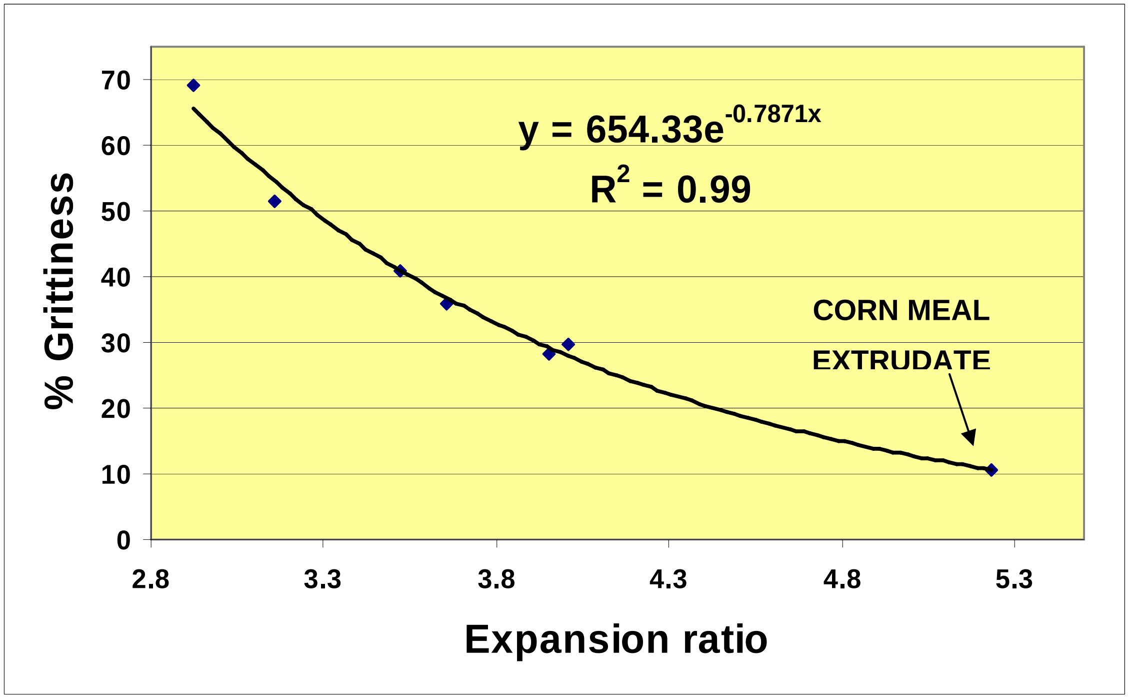

Fig. 42. Correlation between gritty particles and expansion ratio of extrudates from tannin sorghum and corn meal in experiment 4.1.

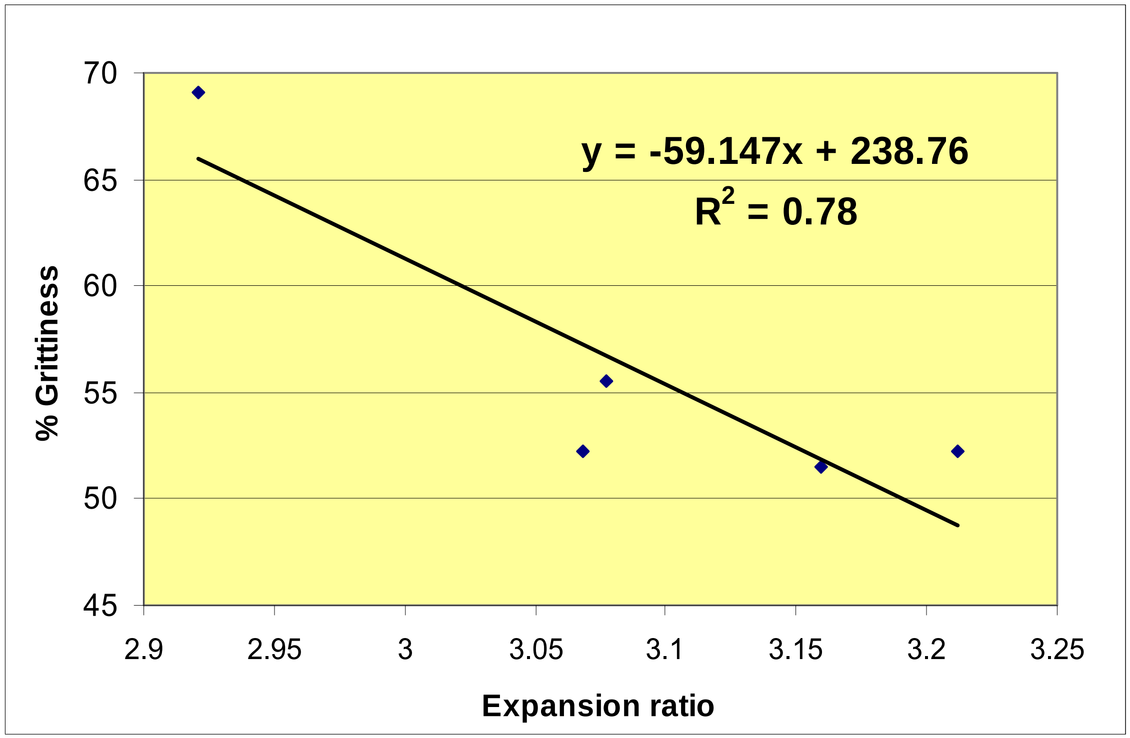

Fig. 43. Correlation between gritty particles and expansion ratio of extrudates from tannin sorghum in experiment 4.2.

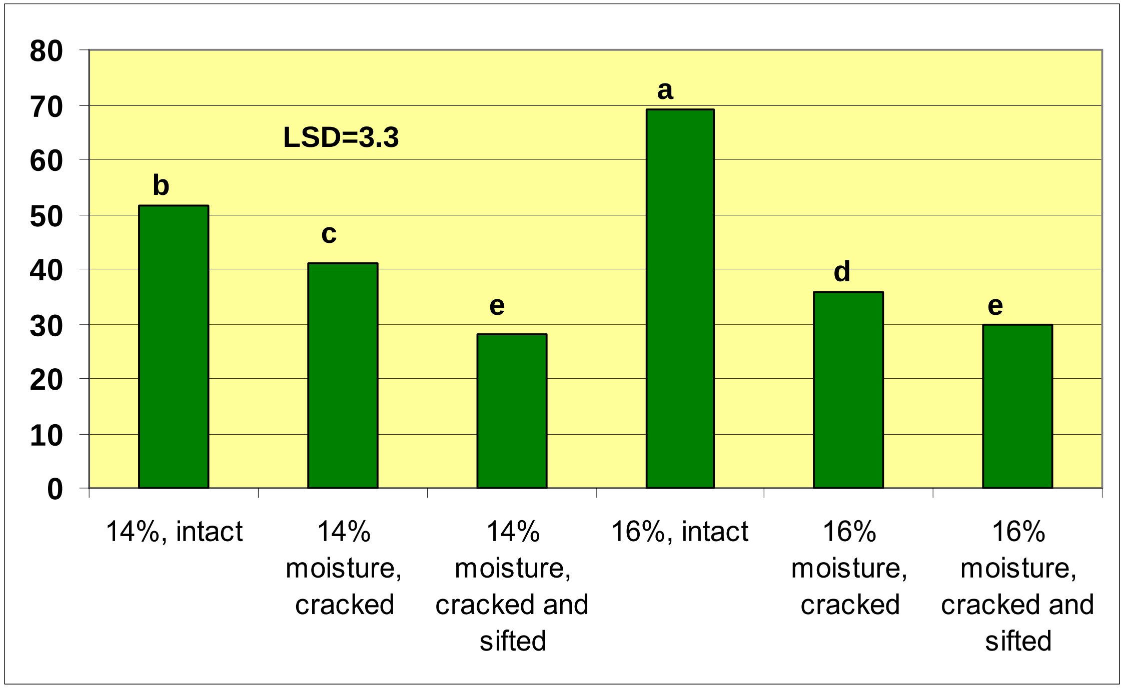

Fig. 44. Gritty particles of extrudates from tannin sorghum in experiment 4.1. Values with the same letter are not significantly different at α=0.05.

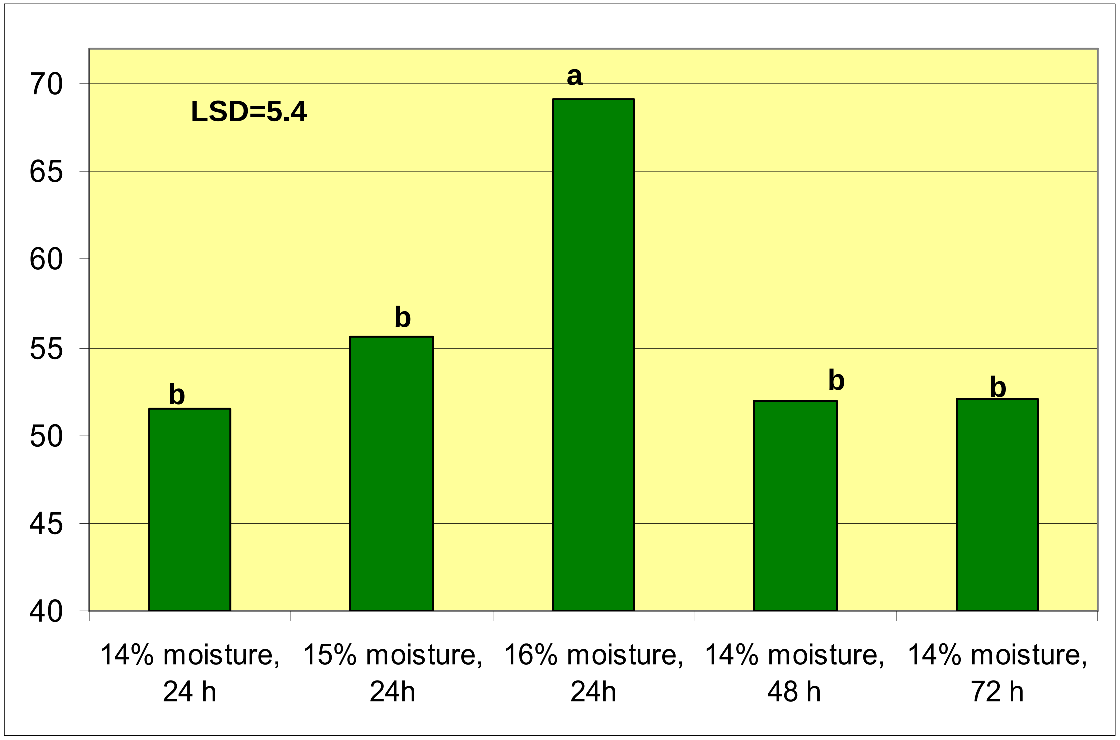

Fig. 45. Gritty particles of extrudates from tannin sorghum in experiment 4.2. Values with the same letter are not significantly different at α=0.05.

more expanded extrudates, pieces of raw materials were more transformed. A more uniform melt was created, which allowed greater starch fragmentation, viscosity and temperature development.

Experiment 4.2

The highest grittiness was that of extrudates from sorghum tempered at 16% moisture and equilibrated for 24 h (Fig. 45). All raw materials had the same dry composition including bran (fiber) content, so differences in grittiness came entirely from changes in the starchy fraction as described above.

Sensory evaluation

Experiment 4.1

Extrudates from tannin sorghums prepared by the three methods did not show differences in the attributes tested, except in texture (Fig. 46). Extrudates from cracked and sifted sorghum received a higher texture score than those from intact sorghum. The lowest scores of all the tannin extrudates were for appearance, possibly due to their dark color.

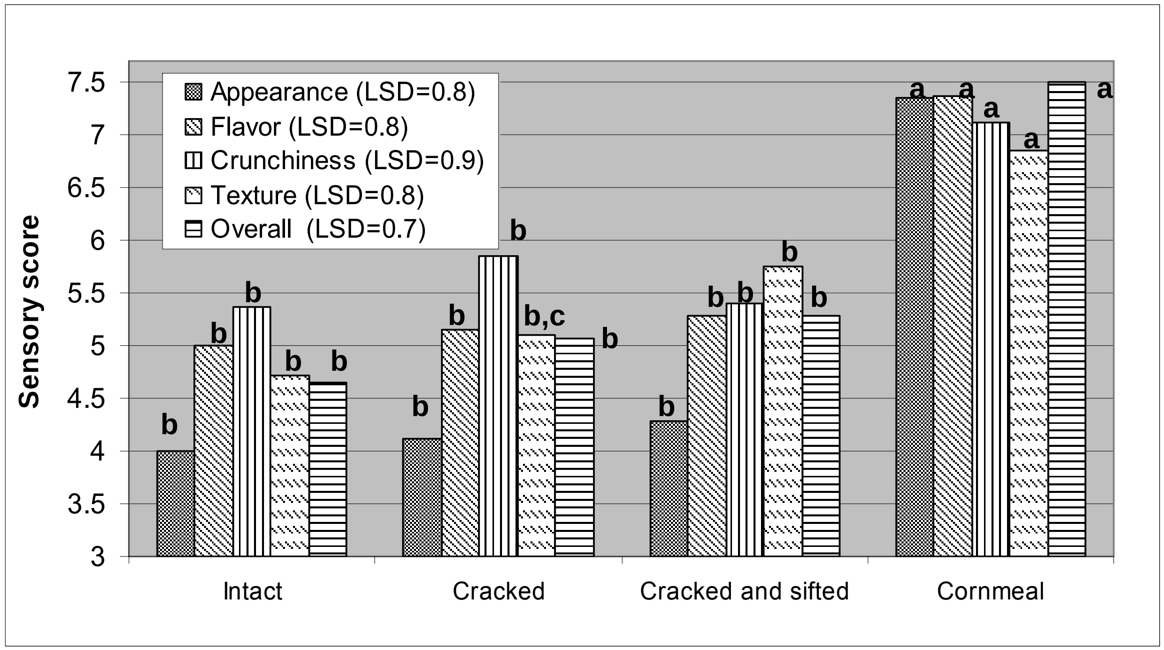

Fig. 46. Sensory evaluation of extrudates from tannin sorghum in experiment 4.1

CHAPTER V

SUMMARY AND CONCLUSION

White sorghums

Whole-grain and high-fiber extrudates of excellent quality were obtained from the white sorghums hybrids nonwaxy, heterowaxy and waxy. Extrudate characteristics were affected by grain preparation method (intact grains, cracked and sifted, or decorticated), amylose content and their interaction.

Waxy sorghum produced less expanded but softer extrudates than the raw materials with higher amylose contents. This property could help improve the structure of whole-grain/high-fiber extruded products, which because of their high fiber and oil content tend to be crunchier than regular products.

Results were conflicting with some published reports that waxy raw materials expand more than nonwaxy or heterowaxy ones. Differences were due to the lower moisture content used in the present experiments.

A practical method was developed to measure grittiness in extrudates, which allows the quantification of bran particles plus undegraded starchy material of whole-grain or high-fiber extrudates. Grittiness was correlated to expansion.

Tannin sorghums

Good extrudates were made from tannin sorghums. There is possibility of taking advantage of their nutraceutical properties in extruded products. Simple grain preparation procedures (cracked with or without sifting) can enhance the quality of the finished product by reduction in particle size and/or fiber.

Cracked non-sifted tannin sorghum (100% yield of original grain) makes very good whole-grain extrudates. Their reddish brown appearance may be an advantage in specialty products.

Optimum tempering for intact tannin sorghum is at 14% moisture, with 24 h equilibration. Longer equilibration times had no advantage in expansion, but brought changes in structure of extrudates.

Cracking and sifting did not offer an advantage (in expansion or texture) over extruding Sumac sorghum intact, for making whole-grain extrudates. Rice brain extract at 1% makes less expanded, crunchier extrudates.

The grittiness method developed also correlated to expansion of tannin extrudates and may offer a valuable tool for testing whole-grain or high-fiber products.

LITERATURE CITED

Acosta, D. 2003. White food-type sorghum in direct-expansion extrusion applications. M.S. thesis. Texas A&M University.

Alvarez-Martinez, L., Kondury, K.P. and Harper, J.M. 1988. A general model for expansion of extruded products. J. Food Sci. 53: 609-615.

Anderson, R.A., Conway, H.F., Pfeifer, V.F and Griffin, E.L. Jr. 1969. Gelatinization of corn grits by roll-cooking and extrusion cooking. Cereal Sci. Today 14: 4-12.

Awika, J.M. 2003. Antioxidant properties of sorghum. PhD dissertation. Texas A&M University.

Barrett, A.H. and Peleg, M. 1992. Extrudate cell structure-texture relationships. J. Food Sci. 57(5): 1253-1257.

Barrett, A. H. 2003. Characterization of macrostructures in extruded products. Pages 369-386 in: Characterization of Cereals and Flours: Properties, Analysis, and Applications. Kaletunc, G. and Breslauer, K.J., eds. Marcel Dekker, Inc.,New York.

Barron, M., McDonough, C., and Rooney, L.W. 2002. The effects of a rice based emulsifier on extruded corn meal. AACC meeting, Montréal, Québec, Canada.

Bhattacharya, M. and Hanna, M.A. 1987. Textural properties of extrusion-cooked corn starch. Lebensm.-Wiss. u.-Technol. 20: 195-201.

Camire, M.E. 2004. Technological challenges of whole grains. Cereal Foods World 49(1): 20-22.

Chauhan G.S., and Bains, G.S. 1985. Effect of granularity on the characteristics of extruded rice snack. J. Food Tech. 20: 305-309.

Chen, F., Cole, P., Mi, Z.B. and Xing, L.Y. 1993. Corn and wheat flour consumption and mortality from esophageal cancer in Shanxi, China. Int. J. of Cancer 53: 902-906.

Chinnaswamy, R. and Hanna, M.A. 1988a. Relationship between amylose content and extrusion-expansion properties of corn starches. Cereal Chem. 65(2): 138-143.

Chinnaswamy, R. and Hanna, M.A. 1988b. Optimum expansion-cooking conditions for maximum expansion of corn starch. J. of Food Sci. 53(3): 834-840.

Chinnaswamy, R. and Hanna, M.A. 1991. Physicochemical and macromolecular properties of starch-cellulose fiber extrudates. Food Structure 10: 229-239.

Davidson, V.J., Paton, D., Diosday, L.L., and Larocque, G. 1984. Degradation of wheat starch in a single screw extruder: characteristics of extruded starch polymers. J. Food Sci. 49: 453-458.

Desrumaux, A., Bouvier, J.M. and Burri, J. 1998. Corn grits particle size and distribution effects on the characteristics of expanded extrudates. J. Food Sci. 63(5): 857-863.

Faubion, J.M. and Hoseney, R.C. 1982. High-temperature short-time extrusion cooking of wheat starch and flour. I. Effect of moisture and flour type on extrudate properties. Cereal Chem. 59(6): 529-533.

Frei, M., Siddhuraju, P. and Becker, K. 2003. Studies on the in vitro starch digestibility and the glycemic index of six different indigenous rice cultivars from the Philippines. Food Chemistry 83: 395-402.

Fulcher, R.G. and Rooney-Duke, T.K. 2002. Whole-grain structure and organization: implications for nutritionists and processors. Pages 9-46 in: Whole Grain Foods in Health and Disease. Marquat, L., Slavin, J.L. and Fulcher, R., eds. American Association of Cereal Chemists, Minneapolis, MN.

Garber, B.W., Hsieh, F. and Huff, H.E. 1997. Influence of particle size on the twin-screw extrusion of corn meal . Cereal Chem. 74(5):655-661.

Goddard, M.S., Young, G. and Marcus, R. 1984. The effect of amylose content on insulin and glucose responses to ingested rice. The American Journal of Clinical Nutrition 39: 388-392.

Gomez, M.H. and Aguilera, J.M. 1983. Changes in the starch fraction during extrusion-cooking of corn. J. Food Sci. 48: 378-381.

Gomez, M.H., Waniska, R.D., Rooney, L. W. and Lusas, E. W. 1988. Extrusion-cooking of sorghum containing different amounts of amylose. J. Food Sci. 53: 1818-1822.

Grimmer, H.R., Parbhoo, V. and McGarth, R.M. 1992. Antimutagenicity of polyphenol-rich fractions from *Sorghum bicolor* grain. Journal of Agricultural and Food Chemistry 59: 251-256.

Guy, R. and Horne, A.W. 1988. Extrusion and co-extrusion of cereals. Pages 331-349 in: Food Structure- Its Creation and Evaluation. J.M.V. Blanshard and J.V Mitchell, eds. Butterworths, London.

Guy, R. 2001. Raw materials for extrusion cooking. Pages 5-28 in: Extrusion Cooking: Technologies and Applications. Guy, R., ed. Woodhead Publishing Ltd., Cambridge, England.

Hammond, N. 1994. Functional and nutritional characteristics of rice bran extracts. Cereal Foods World 39(10): 752-754.

Hammond, N. 2000. Use of rice bran extract as a processing aid. U.S. patent no. 6, 054, 149.

Harper, J. M. 1981. Extrusion of Foods, Vol I. CRC Press, Inc., Boca Raton, FL.

Hiseh, F., Huff, H.E., Peng, I.C. and Marek, S.W. 1989. Puffing of rice cakes as influenced by tempering and heating conditions. J. Food Sci. 54(5): 1310-1312.

Hoseney, R.C., Lineback, D.R. and Seib, P.A. 1978. Role of starch in baked foods. The Bakers Digest. 52: 11-16.

Horn, R.E. 1977. Extrusion cooking systems. Paper 77-3522, American Society of Agricultural Engineers. St. Joseph, MO.

Huber, G. 2001. Snack foods from cooking extruders. Pages 315-367 in: Snack Food Processing. Lusas, E.W. and Rooney, L.W., eds., CRC Press, Baca Raton, FL.

Jackson, D.S., Gomez, M.H., Waniska, R.D. and Rooney, L.W. 1990. Effects of single-screw extrusion on starch as measured by aqueous high-performance size-exclusion chromatography. Cereal Chem. 67(6): 529-532.

Launay, B., and Lisch, J.M. 1983. Twin screw extrusion cooking of starches: behavior of starch pastes, expansion and mechanical properties of extrudates. J. Food Eng. 2: 259-280.

Leal-Diaz, A., Maranphal, N. and Silva, L. 2002. Bongos: the cool snack. AACC meeting, Montréal, Québec, Canada.

Lupton, J.R. and Turner, N.D. 2000. Dietary fiber. Pages 143-154 in: Biochemical and Physiological Aspects of Human Nutrition. Stipunak, M. H, ed. W.B. Saunders Company, Philadelphia, PA.

Matz, S.A. 1976. Snack Food Technology. AVI Publishing Co., Westport, CT.

Mercier, C. and Feillet, P. 1975. Modification of carbohydrate components by extrusion-cooking of cereal products. Cereal Chem. 52(3): 283-297.

Mercier, C., Charbonniere, R., Gallant, D. and Guilbot, A. 1978. Structural modification of various starches by extrusion cooking with a twin-screw French extruder. Pages 153-181 in: Polysaccharides in Food. Blanshard, J.M.V. and Mitchell, J.V., eds. Butterworths, London.

Miller, R.C. 1990. Unit operations and equipment IV. Extrusion and extruders. Pages 135-194 in: Breakfast Cereals and How They Are Made. Fast, R.B., and Caldwell, E.F., eds. AACC, St. Paul, MN.

National Grain Sorghum Producers (NGSP). 2005. Sorghum: the global grain of the future. http://www.sorghumgrowers.com/.

Packaged Facts. 2002. The U.S. market for salted snacks. Marketresearch.com http://academic.marketresearch.com/.

Padmanabhan, M. and Bhattacharya, M. 1989. Extrudates expansion during extrusion cooking of foods. Cereals Foods World 34: 945-949.

Riaz, M. N. 2001. Selecting the right extruder. Pages 29-50 in: Extrusion Cooking: Technologies and Applications. Guy, R., ed.. Woodhead Publishing Ltd., Cambridge, England.

Rooney, L.W. 1996. Attributes of improved quality sorghums for value-added marketing. Pages 112-124 in: ASTA Proceedings of The 51^{st} Annual Corn and Sorghum Research Conference. Chicago, IL.

Rooney, L. W. and Serna-Saldivar, S. O. 2000. Sorghum. Pages 149-176 in: Handbook of Cereal Science and Technology. Kulp, K. and Ponte, J. G., eds. Marcel Dekker, New York..

Rooney, L.W. and Awika, J.M. 2004. Review: sorghum phytochemicals and their potential impact on human health. Phytochemistry 65(9): 1199-1221.

Rooney, L.W. and Awika, J.M. 2005. Specialty sorghums for health foods. Pages 283-312, in Specialty Grains for Food and Feed. Abdel-Aal, E. and Wood, P., eds. Eagan Press, St. Paul, MN.

Rossen, J.L. and Miller, R.C. 1973. Food extrusion. Food Technology 27: 46-53.

Singh, N., Smith, A.C and Frame, N.D. 1998. Effect of process variables and monoglycerides on extrusion of maize grits using two sizes of extruders. J. Food Eng. 35: 91-109.

Sloan, A.E. 2005. Demographic directions: mixing up the market. Food Technology 58: 34-45.

Snack Foods Association. 2004. 2004 State of the industry report. Snack Food & Wholesale Bakery 93 (5): SI1 – SI64.

Svihus, B., Uhlen, A.K. and Harstand, O.M. 2005. Effects of starch granule structure, associated components and processing on nutritive value of cereal starch: a review. Animal Feed Science and Technology 122: 303-320.

Turner, D. L. 2004. The use of specialty sorghums for expanded snack food processing. M.S. thesis. Texas A&M University.

USDA. 2005. Dietary Guidelines for Americans. 6th Edition. U.S. Department of Health and Human Services and U.S. Department of Agriculture. Washington, DC.

Von Fulger, C. 1988. Process for producing high fiber expanded cereals. U.S. patent no. 4,759,942.

Van Rensburg, S.J. 1981. Epidemiological and dietary evidence for a specific nutritional predisposition to esophageal cancer. Journal of the National Cancer Institute 67: 243-251.

Wang, W.-M., Klopfenstein, C.F and Ponte, Jr., J.G. 1993. Effects of twin-screw extrusion on the physical properties of dietary fiber and other components of whole wheat and wheat bran and on the baking quality of the wheat bran. Cereal Chem. 70(6): 707-711.

Wen, L.-F., Panayotis, R., Wasserman, B.P. 1990. Starch fragmentation ant protein insolubilization during twin-screw extrusion of corn meal. Cereal Chem. 67(3): 268-275.

Yeh, A. Hsiu, W. and Shen, J. 1992. Moisture diffusion and gelatinization in extruded rice noodles. Pages 189-199 in: Food Extrusion Science and Technology. Marcel Dekker, New York.

APPENDIX A

SENSORY EVALUATION QUESTIONNAIRE

Sensory evaluation of extruded (puffed) sorghums
(Contains sorghum or corn, vegetable oil, and seasoning)

You will be sequentially given 6 extrudate (puff) samples. Write the sample number in the blank above each set of questions. Answer the questions in the order presented. Please rinse your mouth between samples.

Please provide the following information:

Gender: M F

Age: 18-34 35-54 55-69 70 or older

Do you normally consume extruded snacks (cheese puffs, etc.)?

Yes No

Sample #______

Rate the appearance of this sample

1(dislike extremely) 2 3 4 5 6 7 8 9(like extremely)

Rate the flavor of this sample

1(dislike extremely) 2 3 4 5 6 7 8 9(like extremely)

Rate the crunchiness (first bite sensation) of this sample

1(dislike extremely) 2 3 4 5 6 7 8 9(like extremely)

Rate the texture (chewing sensation) of this sample

1(dislike extremely) 2 3 4 5 6 7 8 9(like extremely)

Rate the overall like/dislike of this sample

1(dislike extremely) 2 3 4 5 6 7 8 9(like extremely)

Comments:____

PLEASE RINSE YOUR MOUTH

VITA

Alejandro José Pérez González was born in Monterrey, Mexico. He received his Bachelor of Science degree in food industry engineering from Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM) in December 1998. From 1999 to 2003 he was head of research and development in a leading oilseed company of Mexico. He received his Master of Science degree in food science and technology from Texas A&M University in December 2005.

Permanent address: León Tolstoi #761 Colonia Contry La Silla, Guadalupe, N.L., Mexico, 67173.

Email address: ajperezg@yahoo.com.