Evaluation for hard endosperm, bird-proof sorghum [(*Sorghum bicolor* L. (Moench)] and its effect on food quality

by

Amukelani Lacrecia Shiringani

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Supervisor: Prof. M. T. Labuschagne

Co-supervisor: Dr. W.G. Wenzel

Declaration

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Amukelani Lacrecia Shiringani 25 November 2005

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A	Beginning of gelatinization
AHI	Abrasive hardness index
ARC	Agricultural Research Council
B	Maximum viscosity
BU	Brabender Units
B-D	Breakdown
CSIR	Council of Science and Industrial Research
CV	Coefficient of variation
D	Start of cooling period
E	End of cooling period
E-D	Setback
ET	Endosperm texture
F	End of final holding period
FAO	Food and Agricultural Organisation
GXE	Genotype by environment interaction
GY	Grain yield
Kg/ha	Kilogram per hectare
L	Lightness
LOC	Location
LSD	Least Significance Difference
Potch	Potchefstroom
PW	Full panicle weight
r	Correlation coefficient
rpm	Rotation per minute
SA	South Africa
SW	Seed weight per panicle
TADD	Tangetial abrasive dehulling devices
TSM	Thousand seed mass
%KR	Percentage kernel removed
2n	diploid

CHAPTER 1

General introduction

Sorghum [*Sorghum bicolor* L. (Moench)], is fifth in importance among the world's cereals after rice, wheat, barley and maize (Dogget, 1988). It appears in many forms but all are cane-like grasses some 50 cm to 6 m tall. The types used most commonly have a large, erect stem terminating in a semicompact or compact head or panicle.

Most races are perennials but are treated as annuals in production. Many different taxonomic types and varieties exist within the species. Cultivars that tiller profusely after harvest can be used as ratoon crop. Sorghum has a fibrous root system that may penetrate 24-38 cm into the soil unless compaction is present in the soil. In that case, there may be many roots in the upper part of the soil, which may reach out to a meter or more away from the stem (Kimber, 2000).

The leaves look very much like those of maize and 14 to18 grow on alternate sides of the stem. During a drought, the leaves will curl inward, thus conserving moisture by decreasing transpiration. Tillers may appear at most of the junctions of the leaves and stems, but normally they do not. Normally plants have up to two tillers, which mature one to five days after the main panicle. Panicle form varies by race; some are open, with much space between seeds but others are densely packed (Kimber, 2000).

Sorghum is a major crop in warm, low-rainfall areas of the world. It is a crop with extreme genetic diversity and predominantly self- pollinating, with various levels of out crossing. The normal number of chromosomes in a sorghum plant is diploid. Thus, in the nuclei of sorghum cells, there are 2n =20 chromosomes (House, 1985).

Sorghum does best where the temperatures are uniformly high during the growing season. Growth is retarded at temperatures below 16°C. Extremely high temperatures which injure maize pollen and result in poorly filled ears are not equally injurious to sorghum. Grain sorghum is mainly cultivated in areas where the rainfall is insufficient for maize production. Sorghums are well adapted to areas where the annual precipitation is only 43-64 cm. During periods of extreme drought the plant becomes somewhat dormant but growth resumes when moisture becomes available. It can retain water more effectively than maize, perhaps because of the waxy cuticle. The water requirements of dry matter produced by sorghum is considerably less than that of maize and most other grain crops.

Although many people think of sorghum as the premier drought and heat tolerant cereal, it is a staple food crop and the basic source of nourishment for the human population in many African countries. Grain sorghum may be a more economical feed than maize because the lower price for sorghum compensates for its slightly lower feeding value. Sorghums have a number of important industrial uses including beer, adhesives, dye, resins, ethanol and fuel (House, 1985; National Research Council, 1996).

Sorghum cultivation exceeds 45 million hectares throughout the world and a lot of sorghum varieties are susceptible to extensive bird damage. Bird damage on the developing grain can result in near total crop loss. The percentage of damage in the yield is higher compared to that caused by insects (Tipton et al., 1970). For years, much effort has been spent on attacking and destroying bird species. Millions were destroyed every year between 1953 and 1960 in South Africa using firebombs, flame-throwers, and other explosives, poisoning water holes, and spraying with avicides. These methods cannot be used today, since federals and law, depending on the country, protect birds. Attacking, shooting, destroying, trapping and handling of birds are illegal and prohibited. There are various scaring tactics used as frightening devices that can be quite effective in protecting crops, especially for crops that are vulnerable for short periods. These frightening devices should be employed early in the morning and late in the afternoon (MSUcares, 2001).

Some grain sorghum varieties produced in many areas of Africa and many developing countries, contain condensed tannins which are considered to account for their bird-repellent properties. These polyphenolic tannins are also present in the mature grain, and lower their palatability and nutritional quality to the consumers (Price et al., 1979; Butler, 1981).

Endosperm texture refers to the hardness and softness of the grain. Endosperm hardness of sorghum grain is an important criterion for ease of dehulling. The hardness of sorghum correlates with milling yield, particle size index, test weight and kernel density (Reichert et al., 1988) and percent vitreousness (van Loggerenberg, 2001). The amount of moisture and moisture absorption by the grain influence hardness. When moisture enters the endosperm, the protein-starch bonds that contribute to hardness, are broken or weakened (Hoseney, 1994).

Milling characteristics of cereals refer primarily to the extraction rate (the portion of recoverable flour of acceptable quality) and to the ease of grinding (Reichert et al., 1984). The process of milling aims at separating the various botanically definable parts such as the pericarp, testa, aleurone, embryo, and endosperm ending with pulverization of the endosperm (Reichert and Youngs, 1976). The physical structure of the kernel such as size, shape, and endosperm hardness plays a major role in the efficiency of milling in terms of flour yield, colour, chemical composition (Anderson et al., 1969), and acceptability, that is, they are major factors that affect milling quality of sorghum (Reichert et al., 1984). Generally, hard kernels have the best milling properties (Maxson et al., 1971).

Cooking quality is an important aspect of food quality. However nutritious a food material may be, the consumer will not accept it unless it satisfies specific food quality characteristics (Pushpamma and Vimala, 1984). Consumers prefer different characteristics on food quality depending on the type of food product. Sorghum food products differ with geographical area, for example, south of the Sahara they produce *tô,* Botswana produces *bogobe,* South Indians produce *sankati* and South Africa produces *maltabella.*

The main objectives of this study were to compare brown-seeded (group III) and white-seeded (group I) varieties in terms of yielding potential, bird tolerance, and food quality characteristics.

The specific objectives of this study were to:

- Relationship between yield and yield components
- Identify bird-resistance varieties
- Determine the milling quality and endosperm hardness of these genotypes
- Evaluate viscosity during cooking

CHAPTER 2

Literature review

2.1 Origin

It is difficult to determine where and when domestication of sorghum occurred (De Wet et al., 1970). Kimber (2000) indicated that the origin(s) of the domestication of sorghum, an African grass, and its ennoblement or diversification into five major races and thousands of distinct genotypes is a story that began in the distant human past and is only partially known. It seems as if the precise origin of sorghum is lost in time. However, the work of botanists, plant breeders, archaeologist, and geographers has uncovered the probable evolutionary pathways in the domestication process and the probable spatial dynamics of that evolution under the cultural control. A great deal has been learned about the origins of this cereal and the peoples responsible for the domestication of sorghum races in the last few years.

Murdock (1959) has suggested that the Mande people around the head waters of the Niger River may have domesticated sorghum. Dogget (1965a) indicated that archaeological evidence suggests that the practice of cereal domestication was introduced from Ethiopia to Egypt about 3000 B.C. According to Vavilov (1951), sorghum has originated in Ethiopia and the contribution of Ethiopian origin is well recognized in world sorghum improvement programs. De Wet et al. (1970), suggest that sorghum had a diverse origin and probably arose from *Sorghum verticilliflorum.*

Introgression studies indicated that cultivated sorghums probably developed through disruptive selection (Dogget, 1965b). Crossing occurs between wild and cultivated types; however, these types form distinct populations. It is speculated that as man began selection, there was substantial gene flow between improved and non-improved types. Most intermediate forms do not exist long in nature; those pollinated by cultivated crops would tend to contribute genes in the direction of the cultivated types; and those pollinated by wild types would tend to contribute genes to the wild populations. Polymorphic populations would tend to change over the years. New forms would arise, leading to the types of sorghum now in cultivation. Ethnic isolation would help this process (House, 1985).

2.2 Classification

Sorghum is a cereal of remarkable genetic variability. More than 22000 accessions are present in the World Sorghum Collection in India. This collection is used by plant breeders to improve the crop. Sorghum is difficult to classify, due to its wide diversity.

Table 2.1. Classification of sorghum (Kimber, 2000)

Family	*Poaceae*
Tribe	*Andropogoneae*
Subtribe	*Sorghinae*
Genus	*Sorghum* moench
Subgenera	*Sorghum*
	Chaetosorghum
	Heterosorghum
	Parasorghum
	Stiposorghum
Species from subgenera sorghum	*Sorghumpropinquim*
	Sorghum halepense
	Sorghum bicolor
Subspecies from sp. S.Bicolor	*Sorghum bicolor bicolor*
	Sorghum bicolor drummondii
	Sorghum bicolor verticilliflorum
Races from subsp. S.bicolor bicolor	Bicolor
	Guinea
	Durra
	Kafir
	Caudatum

2.3 Diversity and distribution

The largest diversity of cultivated and wild sorghum is in Africa (Dogget, 1970; de Wet and Harlan, 1971; de Wet and Price, 1976). The great diversity of *S. bicolor* was created through disruptive selection and by isolation and recombination in the extremely varied habitats of Northeast Africa and the movement of people carrying these species throughout the continent (Miller, 1982). There seems to be no agreement that sorghum plants are African in origin but the domestication event(s) may have taken place elsewhere and more than once. When and how sorghum spread from Africa is a matter of conjecture (House, 1985). Snowden (1936) suggested that sorghum had separate centers of origin. The wild race, aethiopicum, gave rise to races durra and bicolor, arundinaceum to guinea, and verticilliflorum to kafir. De Wet and Huckabay (1967) proposed that durras originated from kafirs. Dogget (1965a, b) suggested that the diversity seen in the wild forms might reflect human manipulation and intervention associated with the selection of domesticated types.

2.4 Bird damage in sorghum

Birds are the most numerous and devastating grain sorghum feeders in Africa. Grain sorghum growers are facing losses of fields due to bird damage. Such losses are seldom so severe that the actual growing of the crop is threatened, although in occasional seasons bird damage may take most of the profit. Birds feeding on grain sorghum can cause significant damage since they flock in large populations to the field. Dogget (1988) reported that birds destroy 20-50 g of grain each day, by pecking out the embryo from the soft grain. Therefore, if 50 birds damage 1 kg of grain daily, then 1 million birds can destroy 20 ton of grain each day. Each year in Africa, hundreds of millions of these birds can feed on grain crops at certain times of the year.

In many parts of the world, bird damage to sorghum crops is so severe that control measures must be taken or else most of the crop will be lost (Bullard and Elias, 1980). For example, in Arizona, Bullard and Elias (1980) reported losses in yield ranging from

48-72% as a result of damage to nonresistant sorghum hybrids. In Michigan, losses in experimental sorghum plots were estimated to range from 18-70% as a result of bird damage (Anonymous, 1967), while in Georgia, Bullard and Elias (1980) observed 50% loss in sorghum fields. The damage inflicted is so severe that the development of bird-resistant inbreds and hybrids have become an integral part of many sorghum research programs (McMillian et al., 1972).

According to Tipton et al. (1970), major damage to the grain by birds can occur during the milk stage of development. A limited amount of feeding can continue into the early dough stage of development. Bird feeding on mature seed of grain sorghum can occur to a limited extent and damage will be less. In mature grain sorghum heads, loss of grain caused by birds can result from grain that became dislodged and fall to the ground during the time the bird was attempting to feed.

Resistance has been attributed to the physical character of the panicle. Open-headed varieties seem to reduce grain damage as a result of birds. It was generally considered that birds were better able to perch on the heads of tight-headed varieties than they were on the more open-headed varieties (Tipton et al., 1970).

Brown-seeded varieties have been reported to contain higher tannin levels than red- or yellow- seeded varieties (Bullard and Elias, 1980), and seed color of sorghum shows a highly significant positive correlation with tannin content (McMillian et al., 1972). However, Harris and Burns (1970, 1973) and Subramanian et al. (1983) reported that pericarp color may not be a reliable indicator of tannin concentration. Because of climatic conditions, farming practices, or marketing conditions, many farmers can grow only sorghums. Often, bird depredation restricts the farmer’s choice to brown, tannin-containing, bird resistant (BR-) varieties.

Tannins have the capacity to bind protein. Active tannin oligomers bind with mucoproteins in the mouth of birds causing an astringent tactile response that is repellent (Bullard and York, 1996). The amount of tannin that can be extracted from the seed and chemically assayed as well as the bird repellency of the extracts (Bullard et al., 1981), changes considerably during the process of seed maturation. The tannin content, either on a per seed or on a dry weight basis reaches a maximum early in the maturation process. In mature seed, tannins are usually reported to decline to levels that are different for different cultivars (Chavan et al., 1979).

2.5 Kernel structure

The caryopsis of sorghum consists of three distinct anatomical components: The pericarp (outer layer), endosperm (storage tissue) and germ (embryo). The relative proportion of these components varies depending on cultivars and environmental conditions (Rooney and Murty, 1981).

The endosperm tissue is triploid, resulting from the fusion of a male gamete with two female polar cells. The sorghum endosperm consists of the aleurone layer, peripheral, corneous (also referred to as hard, flinty, vitreous and horny) and floury (also referred as soft) portions (Earp and Rooney, 1982). The aleurone layer is a single layer of block-like rectangular cells located directly beneath the pericarp or below the testa if it is present. The aleurone cells contain large amounts of minerals, water-soluble vitamins, autolytic enzymes and oil. The aleurone cells also contain spherical bodies high in protein and phytin. The aleurone cell layer plays an important role in autolysis and mobilization of kernel constituents during germination (Waniska and Rooney, 2002).

The peripheral endosperm is a rather ill-defined area directly beneath the aleurone layer. The peripheral area consists of small, blocky cells containing small starch granules and may be anywhere from two to six endosperm cells thick. The starch granules are embedded in a dense proteinaceous matrix composed mainly of glutenins or alkali soluble proteins and prolamins (Waniska and Rooney, 2002). The prolamins, alcohol soluble proteins, are located predominantly in the form of protein bodies surrounded and sometimes embedded in the protein matrix. The endosperm contains free protein bodies, those embedded in the protein matrix and those glued together by the glutenin proteins.

The corneous endosperm is located beneath the peripheral endosperm and has a continuous interface between the starch and protein (Rooney and Miller, 1981). The starch granules are very angular in shape with depression where protein bodies were trapped between expanding starch granules. The starch-protein bond is strong and starch granules often break rather than pull from the protein matrix. Like the peripheral endosperm, the corneous is translucent or vitreous, and affects processing and nutrient digestibility (Waniska and Rooney, 2002).

The floury endosperm area has loosely packed endosperm cells. Small voids occur between the spherical starch granules with little or no matrix protein seen. These voids permit the passage of light through the floury endosperm area, causing it to look opaque or chalky in appearance (Hoseney and Faubion, 1968). Protein bodies are present in the floury endosperm, but in much smaller amounts than seen in the corneous or peripheral endosperm areas. The matrix protein that does exist is spread in thin discontinuous sheets over the surface of the starch granules. The protein content of the floury endosperm within the kernel is lower that the corneous endosperm, thus the availability of starch is improved (Seckinger and Wolf, 1973).

Endosperm texture is often referred to as the proportions of vitreous to floury endosperm in the kernel (Kirleis et al., 1984).

2.6 Milling quality and endosperm hardness

Milling quality of sorghum is important and is being considered in breeding strategies (Reichert et al., 1984). Milling yield or extraction rate for cereals depends not only upon the grain sample, but also upon the milling process used (Shepherd, 1979; Wenzel et al., 2001a, b).

Pearling considerably improves the visual appearance and consumer acceptability of the flour by removing the coloured, bitter, rough bran and glumes from the sorghum. The pearled grain could be ground to flour as desired. Also, pearled grain could be used for making sorghum flakes and several snack foods. This pearling technique is not suitable for sorghum varieties with soft endosperm as they undergo excessive breakage during the pearling process.

According to Simmonds (1974) the degree of hardness often determines the use of the grain. Reichert et al. (1984) found that differences in endosperm texture can account for only some of the variability in hardness, suggesting that a visual assessment of endosperm texture in a screening program may not be adequate for predicting milling qualities.

Abdelrahman and Hoseney (1984) reported that grain hardness affects both the milling behavior and the end-use of the grain. According to Eggum et al. (1981) the softness or hardness of the endosperm is an important component of milling. Millers are interested in hard caryopses because it affects the sieving behavior, energy consumption, fineness of the finished product, and most importantly, the milling extraction. Vegrains (2001) reported that the hardest grains have outstanding milling properties and can produce highest yields from milling, while soft grains produce low yields. A sorghum variety with soft endosperm is difficult to abrase/decorticate as such seeds tend to break, resulting in losses of fine endosperm particles.

Grain colour is controlled genetically and is modified by environmental conditions during and after maturation (Rooney and Miller, 1981). Grain colour is determined by pigmentation of the pericarp, testa, and endosperm. Colour in these tissues is controlled by different sets of genes. The R-Y- genes determine whether the pericarp is red (R-Y-), colourless or white (R-yy) or lemon yellow (rrYY). The testa of kernels with B1-B2-S genes is reddish brown or purple and contains condensed tannins (Waniska and Rooney, 2002).

Some sorghum grains are characterized by the presence of a coloured layer (brown or violet) called the testa, situated immediately under the pericarp (Earp et al., 1983). This coloration is associated with a heavy concentration of poliphenols (also called tannins), which inhibit the capacity of the human organism to digest the protein in the grain (Glennie, 1983). It is for this reason that in the traditional hulling process the operation is maintained until the testa is completely removed (Reichert et al., 1988).

Caryopsis with a pigmented testa (B1-B2-) and a recessive spreader gene (ss, group II) or dominant spreader gene (S, group III) contains condensed tannins and are called brown or tannin sorghum (Harn and Rooney, 1986). Group III sorghums have more tannins than group II sorghums, whereas group I sorghums do not contain tannins. Kernel appearance should not be used to judge the class of sorghum since white appearing sorghums may contain a pigmented testa and be classed as tannin sorghum. The Clorox bleach test is necessary to identify sorghums with pigmented testa.

Wet, humid weather during grain maturation causes discoloration and grain damage due to molding and weathering (Waniska and Rooney, 2002). The milling quality of such grain can be adversely affected, depending on the extent of damage to the endosperm. Kernel properties associated with resistance to weathering include kernel hardness, density, pericarp colour and thickness, and a thick wax covering on the grain surface.

Sorghum is an important human food in some developing countries. It is either traditionally processed or mechanically milled before consumption. The presence of tannins have advantages for the grain since it protects the grain from insects (Woodhead et al., 1980), birds (Bullard and Elias, 1980), preharvest germination (Harris and Burns, 1970) and grain mold (Rodrique-Herrera et al., 2000) whereas it has a disadvantage in the flour because it affects the cooking and nutritional quality, the taste, and texture of the food. The main goal of dehulling is to remove the external layers, which contain mainly fiber and tannins. Therefore, dehulling should effectively remove the complete pericarp and testa, at the same time minimizing loss of the endosperm and germ. The degree of dehulling needed varies from one type of grain to another (FAO, 1990).

Grain producing darker coloured whole flours generally gave lower extraction rates as determined with tangential abrasive dehulling device (TADD). This suggests that, at least for light-coloured sorghum varieties (white, yellow), measurement of whole flour colour could give an indication of the extraction rate one would achieve with abrasive-type milling equipment. It could be used as a preliminary screening method (Reichert et al., 1984).

Munck et al. (1981) reported that the milling technology for sorghum flour is still inadequate for the production of flour with an acceptable light colour, and suggested that sorghum breeding programs should be directed in a way to ensure a suitable quality of milling.

2.7 Food quality

Grain produced on a farmer’s field passes through several transformations before it is consumed in the form of food. To ensure that these transformations are accomplished efficiently and to minimum nutrient loss, better interactions between different disciplines are needed, and an understanding of various aspects of grain quality becomes vital (Jambunathan et al., 1982).

2.7.1 Physical properties of the grain influencing food quality

According to Pushpamma and Vogel (1981), the grain appearance has a major influence on its quality and in acceptance of food since visual characteristics significantly control selection. However, once the food is prepared and tasted, visual characteristics become secondary to cryptic and palatability characteristics. Visual characteristics that can influence quality of the grain and consumer acceptability of the product are colour, size, pericarp thickness, texture of the endosperm, presence and absence of the pigmented testa (Kirleis and Crosby, 1981).

2.7.2 Chemical properties of the grain influencing food quality

1. Carbohydrates

Carbohydrates are a major component in grain and are composed of starch, soluble sugars and fiber. Starch is the most abundant component, while soluble sugars and fiber are low (Waniska and Rooney, 2002).

a. Starch

From 32 to 79% of sorghum grain weight is starch. Starches exist in a highly organized manner in which amylose and amylopectin molecules are held together by the hydrogen bonds and are arranged radically in spherical granules. Native granules are considered pseudocrystalls, containing both crystalline and amorphous areas (Rooney and Pflugfelder, 1986). The native granules are cold-water insoluble, swell reversible, and are relatively inaccessible to hydrolysis by amylases.

Starch is the main source of energy utilized during germination. It is composed of linear chains of glucose joined by amylopectin. Amylose consists of linear chains averaging 1500 units. Hydrated amylose forms a helix that can interact with iodide to form a blue or purple colour. Amylopectin is a much larger, branched polymer, composed of about 3000 chains averaging 15 to 20 units (Subramanian et al., 1982). Amylopectin interacts with iodide to form a brown colour. In its properties, sorghum starch resembles maize starch and the two can be used interchangeably in many industrial and feed applications. When boiled with water, the starch forms on opaque paste of medium viscosity. On cooling, this paste sets to a rigid, non-reversible gel. The gelatinization temperature ranges from 68ºC to 80ºC (Sweat et al., 1984; National Research Council, 1996).

b. Soluble sugars

According to Murty et al. (1985), soluble sugar content of the caryopsis changes during development but the maximum can be 5.2%. At maturity, the average soluble sugar content ranges from 0.8 to 4.2% with sucrose being 75% of the sugars (Subramanian et al., 1980). Mature caryopsis contains 2.2 to 3.8% soluble sugars, 0.9 to 2.5% free reducing sugars, and 1.3 to 1.4% non-reducing sugars (Bhatia et al., 1972). Glucose ranges from 0.6 to 1.8% and fructose from 0.3 to 0.7%. High lysine and sugary cultivars contain more soluble sugars than do normal sorghums.

During germination, sugars accumulate in the endosperm after the second day with maximum concentration occurring after eight days (Newton et al., 1980). The major soluble carbohydrate in the caryopsis changes from sucrose to glucose and fructose after two days. The monosaccharides are located in the endosperm and the scutellum after two days. However, sucrose is localized in the scutellum and is the highest on the fourth day of germination. Rooney and Pflugfelder (1986) also found that the soluble sugar content, free glucose and maltose increase during germination.

c. Fiber

Cereal grains are a rich source of fiber. Dietary fiber is plant material that resists digestion by enzymes in the monogastric stomach and upper gastrointestinal tract. The major components of fiber are cellulose, hemicellulose, lignin, and pectin, which are located primarily in the pericarp and endosperm wall (Waniska and Rooney, 2002).

Dietary fibers have unique physiochemical and functional properties, and it can be divided into two broad categories: water-soluble and water-insoluble fiber. Sorghum contains 6.5 to 7.9% insoluble fiber and 1.1 to 1.23% per kernel soluble fiber (Bach-Knudsen et al., 1985). Most of the fiber in sorghum is insoluble, approximately 86.2%, and is located in the pericarp. Fibers in the pericarp provide structural and protective functions. Therefore, fiber content of sorghum products depends on the extent of pericarp removal during milling. Sorghum dietary fiber contains more associated proteins than other cereals. Insoluble dietary fiber increases during food processing due to increased levels of bounds, mainly kafirins, and enzyme resistant starch. Supplementation of sorghum bran in human subjects increases stool weight, decreases intestinal transit time, and increases the frequency of evacuation (Fedail et al., 1984).

2. Protein

Protein content and composition vary due to environmental conditions (water availability, soil fertility, temperature and environmental conditions during grain development) and genotype. Sorghum proteins are located in the endosperm (80%), germ (16%), and pericarp (3%) (Taylor and Schussler, 1986). Kaffirins, or prolamins, and glutelins comprise the major protein fractions in sorghum. These fractions are located primarily within the protein bodies and protein matrix of the endosperm. Nitrogen fertilization significantly increases kafirin accumulation and protein content (Warsi and Wright, 1973). Sorghum protein is deficient in lysine, an essential amino acid. Protein quality is critically important in developing countries where the human diet consists mainly of cereals.

The germ is rich in albumins, and globulins, while the endosperm contains kafirins and glutenins. The albumins, globulins, and glutenins fractions are rich in lysine and other essential amino acids. Cultivars exhibiting improved protein quality usually contain more of these with a corresponding lower proportion of kafirins. Cultivars were selected and bred to contain a larger germ-to-endosperm ratio or to yield more albumins, globulins, and glutenins (Mohan and Axtell, 1975).

Sorghum with easier-to-digest proteins has been identified (Weaver et al., 1998). Improved protein digestibility is caused by more invaginations (the act or process of enclosing something as if in a sheath) in the protein bodies, less kafirin in the endosperm and less protein cross-linking during cooking. Increased digestibility of kafirin was identified in the chemically induced, higher lysine sorghum. The higher lysine content and digestibility are not genetically linked and both appear to be recessive. Hence the higher lysine content and increased digestibility must be combined to improve protein nutritional quality.

According to the Council of Scientific and Industrial Research (CSIR, 2000), the protein quality of sorghum can be improved by simple technologies of malting and fermentation that can be applied at household level. This has overcome the problem of the poor quality of sorghum protein in terms of digestibility and essential amino acids content compared to other grain foods. Food products like porridge and bread have been evaluated by consumers of sorghum, and found to be acceptable (CSIR, 2000). Instant sorghum porridge of improved protein quality has also been produced by compositing with cowpeas, a popular legume food in many African countries.

Research has been undertaken to determine the fundamental reasons for the reduced protein digestibility in sorghum upon cooking. These seem to be multifactorial, involving changes in the structure of the sorghum prolamin proteins as well as binding of the proteins with other chemical components in the sorghum grain.

3. Lipids

Lipids are relatively minor constituents in sorghum. Most of the lipids are located in the scutellar area of the germ. Thus, lipid content is significantly reduced when the germ is removed during decortication or degermination. Typical fatty acid composition of sorghum oil is similar to that of maize oil and is dominated by linoleic and oleic acids (Wall and Blessin, 1970). The lipids can be subdivided into polar, nonpolar, and nonsaponifiable lipids. The composition of nonpolar lipids was clearly dominated by triglycerides (85%), followed by sterols (4.1%), and diglycerides (4%). Triacylglycerides serve as a reserve material for germination. The less abundant polar lipids have important biochemical functions. Of the nonsaponifiable compounds, 3 to 5% include carotenoids, phytosterols, and tocopherols (Rooney, 1978).

4. Anti-nutritional factors

a. Tannins

Butler (1978) defined tannins as a group of plant-derived materials extracted by alcohols, usually from bark or galls (growth due to a wound or infections). These materials were called tannins because of their ability to tan leather. Sorghums containing tannin are called tannin or brown sorghum even though the pericarp colour may be white, yellow or red. Grain appearance is not necessarily related to tannin presence or content. Tannins protect the grain against insects, birds, fungi, and weathering (Waniska et al., 1989). Rates of preharvest germination or early sprouting are lower in brown sorghums. These beneficial effects ensure that brown sorghums will continue to be produced in certain pest ridden areas of the world (Butler, 1990). These agronomic advantages are accompanied by nutritional disadvantages and reduced food quality.

The anti-nutritional effects of tannins include decreased growth rate, protein digestibility, and feed efficiency in animals. Tannins in sorghum reduce digestibility and efficiency of utilization of absorbed nutrients from 3 to 15%. Extracted tannins bind protein and inhibit many enzymes in *in vitro* assays (Hagerman and Butler, 1994).

b. Phytic acid

According to Benito and Miller (1998), phytic acid and phytates are stored primarily in the aleurone layer in phytin bodies or aleurone grains, and to a lesser extent in the germ of sorghum. Phytic acid complexes with essential dietary minerals e.g Ca, Zn, Fe, and Mg to form phytates and cause the minerals to be unavailable for absorption (Lasztity and Lasztity, 1990). The primary role of phytates may be to store phosphorus and inositol, which are gradually utilized during germination. Activity of endogenous phytases during germination or malting reduces the amount of phytase. Removal of the pericarp and aleurone layer by abrasive decortication reduces the phytate content (Doherty et al., 1981; 1982).

2.8 Consumer acceptable characteristics

Food quality traits can be classified into two categories:

1. Culinary characteristics that include easiness of dehulling, volume after soaking, texture of the flour, swelling capacity, rolling capacity or ability of the dough to spread and gel formation.
2. Palatability characteristics that include colour, flavour, texture of the product, taste, mouth feel and keeping quality (Pushpamma and Vogel, 1981).

Success of any food grain or its product depends on acceptance by consumers (Cagampang et al., 1982). Consumer reactions are difficult to measure. Acceptance and preference of foods is conditioned by many complex factors. Attributes of the food and of the acceptance of food varies with the standard of living and cultural background. The dark colour, high fiber content, pronounced flavour, grittiness of the flour, and difficulty to cook into soft products are some of the disadvantages in using sorghum for producing high-status foods (Pushpamma and Vogel, 1981).

2.9 Porridge in Africa

Cereal porridge is the staple food in much of Sub-Saharan Africa (Taylor and Dewar, 2000). Laboratory screening procedures and small-scale porridge tests are used to develop sorghum cultivars with improved yields, agronomic properties, and acceptable porridge quality in some areas. Porridge in Africa can be classed as thick or thin, depending on the concentration of the flour used during preparation.

a. Thick porridge

Thick porridge is solid and can be eaten with the fingers. Good thick porridge has a texture that permits it to be consumed without sticking to fingers, teeth or mouth. Some varieties of sorghum produce sticky, thick porridge. The keeping quality of porridge is of major importance because the porridge is stored overnight, reheated, and consumed. Porridge with poor keeping quality becomes mushy, sticky and loses water.

Sorghums with intermediate to soft endosperm texture produce porridge with a sticky, less firm texture that deteriorates rapidly during storage (Cagampang and Kirleis, 1984). The inherent genetic properties and the growth, harvest, storage, and processing conditions affect porridge properties.

Tô is a staple food in most parts of Africa, south of the Sahara. *Tô* is a thick porridge, prepared from sorghum depending on taste, cost, custom, geographical areas, and/or availability of grains. *Tô* with sauce is the major staple food consumed in Burkina Faso.

The *tô* of Burkina Faso is generally made from sorghum flour prepared by hand decortication of the grain to remove the bran. The *tô* quality of sorghum in Burkina Faso is affected by the milling properties of the grain, by cooking properties of the flour, and by the acceptability of the fresh and stored *tô*. The general appearance of the grain is important. Sorghums that are easily decorticated by hand pounding in a mortar and pestle are desirable. Thus sorghum with a thick pericarp and a corneous endosperm are preferred (Da et al., 1981).

The consumer wants *tô* with firm paste that holds together and does not crumble under finger pressure. It must not stick to the fingers, teeth or roof of the mouth when eaten. Firmness and non-stickiness should remain constant when *tô* is stored overnight. Some varieties of sorghum produce fresh *tô* with acceptable quality, but after storage it turns soft and sticky and is not acceptable to the consumers. Yellow or white *tô* colour is preferred, but pink, red, or gray *tô* with good texture is also accepted. Bland flavour is acceptable (Bello et al., 1992).

b. Thin porridge

Thin porridge is consumed by drinking or with utensils. The quality of sorghum for thin porridge is not as critical as for thick porridges. Colour is a major consideration in many areas. The intermediate and soft sorghums are used for preparation of thin porridges and fermented or unfermented breads (Chandrashekar and Desikachar, 1986).

Mukapu (in Xitsonga) is an example of thin, firm fermented porridge produced in South Africa and Botswana. In South Africa, it is generally produced from coarse sorghum meal, specifically industrially manufactured for the purpose. Red-condensed tannin-free sorghum is used to produce meal. White sorghum is more preferred for *mukapu* in Botswana (*ting* in Setswana). In South Africa, spontaneous fermentation is carried out at room temperature.

To start the fermentation process, sorghum flour (*mapa* in Xitsonga) is added to water inside the backet or traditional pots (*Xikhuwana*). The mixture is left overnight for fermentation. To catalyze the reaction, warm water is used, or storage can be done in the sun during the day or next to the fire overnight in villages. The meal sours with some gas production. The organisms responsible have not been identified, but are presumably mesophilic, heterofermentative lactic acid bacteria. The fermented meal or the sour mixture is called *dini* and is used to inoculate more sorghum meal to produce a culture known as *ntsuvi*. In many households, where *mukapu* is consumed every day, every time after finishing cooking, *mapa* is always added to the remaining *ntsuvi* in *xikhuwana* which shortens the process of *dini* making or which speed up the fermenting process. For cooking of *mukapu*, water is boiled in a pot and *dini* is added until desired and cooked. It is served warm.

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CHAPTER 3

The relationship between yield and yield components of 30 sorghum genotypes at two different locations

3.1 Introduction

Sorghum is a short day plant that flowers only, or most rapidly, if illuminated during less than a certain number of hours per day (Thomas and Vince-Prue, 1997). This photoperiod behavior is an adaptation to region-specific climatic patterns shown by many tropical species. Vaksmann et al. (1996) has reported that sensitivity to photoperiod remains necessary, even for improved varieties, in the present grain production systems in the African savannas and the Sahel, to optimize natural resource use and minimize the risk of adverse climatic effects. The relationship between day length and the duration of the vegetative phase, which ends with floral initiation are complex, and also depends on temperature (Clerget et al., 2004). Baker et al. (1980), working on cereals, found a strong, positive, linear relationship between the rate of day length change at emergence and the mean rate of leaf appearance during the life cycle.

Grain sorghum yield has dropped in recent years because of environmental problems, which have severely limited profitability. Grain sorghum can serve as more drought tolerant crop than either corn or soybeans. Thus, sorghum productivity potential is relatively stable, compared to alternative crops. Grain sorghum also produces good yields and agronomic benefits to subsequent crops in a crop rotation system, particularly with soybeans or cotton grown on heavy clay or droughty soils.

Yield variability is due to many factors including disease, soil water levels, precipitation, and temperature. Planting date, which is influenced by weather, whether material is hybrid and maturity class, affects yield. Yield also is influenced by choice or performance of inputs such as crop hybrids, maturity class, and seeding rate or desired plant population. Maturity class choices can influence the risk of damage from frost and soil water (Williams et al., 1999). Norwood (1982) reported that if subsoil water level and precipitation are adequate, the yield of high populations, narrow-row sorghum will equal and often exceed that of low population, wide row sorghum.

The effects of hybrids on grain yield can differ across environments. Wade and Douglas (1990) reported that under high yielding conditions later maturing hybrids produced higher yields. They also noted that hybrid superiority in any environment is dependant upon the timing and duration of any stresses encountered. The early maturing hybrids produce lower yields than the medium or late maturing hybrids. Yield for the early maturing hybrids and yields for low seeding rates were generally less variable as measured by the coefficient of variation. Early planting dates can influence yield positively (Williams et al., 1999).

Low winter temperatures and variable rainfall results in high variability in crop yields (Diaz-Ambronia and Minguez, 2001). Unsuitable management of resources generates small yield and biomass, which in turn produces little stubble and reduces organic soil matter (Lopez Bellido et al., 1996). Monoculture treatment can produce reduced grain yield, consistent with biomass accumulation (Diaz-Ambrona and Minguez, 2001).

Row spacing in grain sorghum has an influence on canopy architecture and development, light interception, plant development, yield components and grain yield (Staggenborg et al., 1999; Chin Choy and Kanemasu, 1974). Steiner (1986) reported higher yields from narrow rows than from wide rows under favorable growing conditions. The increased yield in narrow rows is a result of improved light and water use efficiency. Narrow rows partitioned a greater amount of the total water used to the plants, increased growth rates and minimized soil water evaporation than the wider rows. Narrow rows deplete stored soil water at a faster rate than wider rows. Therefore if dry periods extend for several weeks, narrow rows experience water stress earlier and for a longer time than wider rows (McGowan et al., 1991). If this stress period is significant or occurs during a critical stage of development, the plant may not be able to take advantage of any increased growth gained by early canopy development and light interception compared with plants grown in dry areas. Staggenborg (1993) reported stable grain sorghum yields over a wide range of plant populations within a given environment. When sorghum row spacings are reduced, optimal yields can be achieved without increasing plant populations (Blum, 1970).

Increasing plant population results in a decline of tiller numbers (Gerik and Neely, 1987). McGowan et al. (1991) and Stickler and Wearden (1965) observed increases in tiller per plant as the row spacings were reduced, suggesting that shifts in light interception and early crop growth rates may be influencing tiller production. Matowo et al. (1997) reported that grain yield can be influenced by tillage and nutrient uptake. When significant difference in grain yield occurred, yields were generally lower with no-till than with conventional tillage. Grain yield can be significantly increased by N fertilization regardless of the source/placement or tillage methods.

Sorghum can adjust yield components to compensate for stress and uses pre-anthesis assimilate for grain fill (Leonard and Martin, 1963). When periods of peak water use coincide with periods of high summer rainfall, high grain yields can be obtained. Production practices that maximize grain sorghum production during favourable years should also provide for stable production during dry years (Jones and Johnson, 1991).

Caryopsis per panicle can be influenced by location with year interaction, row spacing, and in hybrids. Staggenborg et al. (1999) found that caryopses per panicle production was similar at each row spacing for the two hybrids studied. Caryopses per panicle production can be affected by the plant population. Increasing the plant population to more than 90000 / acre can decrease production by more than 250 caryopses / panicle whereas increasing plant densities by 30 000-60 000 /acre can have no effect on caryopses / panicle. As panicle number increases, the number of caryopses that each panicle can support should decrease within a given environment. The main objective of the study was to 1) measure the yield potential of 30 sorghum genotypes at different locations, 2) determine the relationship between yield and yield components of group I and group III genotypes

3.2 Materials and methods

Thirty sorghum varieties were used, including two standards M53 and M107. These varieties were developed at the Agricultural Research Council-Grain Crops Institute Potchefstroom of South Africa. The varieties were selected due to colour, 15 white-seeded and 15 brown-seeded sorghum varieties. The first 15 entries were brown seeded and the second 15 were white seeded varieties.

The experiment was conducted at two locations in the Northwest province of South Africa namely, Potchefstroom and Taung. The type of soil was sandy loam Hutton in Taung and sandy loam in Potchefstroom. Table 3.1 represents the biophysical data in each location.

No pre-fertilization was done but nitrogen fertilizer (urea) was applied 23 days after planting. During the time of no or low rainfall, irrigation was used. The soil was prepared with a plough, followed by discing and flattened by a wondertailer. The experiment was conducted during the 2004/2005 growing season. The planting dates were, 9 November at Taung and 17 November at Potchefstroom.

The seeds were planted at a density of 100 000 plants per hectare. Row length was 5m and inter-row spacing was 1.5m while each plot had two rows. The experiment was laid out in a randomized complete block design with three replications. The source of treatment was white-seeded and brown-seeded sorghum varieties. Weeds were controlled using Larso pre-emergence and by hoe. This was done depending on weed emergence. Physiological maturity was determined by the dark spot on the opposite side of the kernel from the embryo.

3.2.1 Data collection

Sorghum grain yield was determined on 13 June 2005 at Taung and on the 20 June 2005 at Potchefstroom. The plot size was 15m² at both locations. Twenty panicles from each row were selected at random to determine the grain yield which was later converted into kg/ha. Harvesting was done by cutting the peduncle half way between the flag leaf and the 1st panicle obtained from each plot, and weighed. Panicle weight was obtained through the average of 10 panicle weight mass. Seed weight per panicle was determined by threshing 10 panicles, then the grain yield mass was divided by 10. Thousand seed mass was determined by counting a 1000 seeds using a seed counter and then weighing the seeds.

3.3 Results and discussions

Table 3.3 represents the performance of genotypes in terms of grain yield, panicle weight, seed weight per panicle and thousand seed mass in each location, whereas Table 3.5 represents yield and yield components across locations.

Grain yield

Genotypes differed significantly in grain yield for both the environments (Table 3.2) recording a range from 567 to 3098 kg/ha in Taung and 510 to 2909 kg/ha in Potchefstroom. There was a significant genotype x locality interaction for grain yield (Table 3.4) where genotypes ranged from 1001-2682.17 kg/ha. K919-44 and M107 were the highest yielding genotypes in Taung and across locations, whereas in Potchefstroom, K919-35 and K919-11 were the highest yielding genotypes. The lowest yielding varieties in Taung were K919-114 and K919-26, K919-9 and K919-128 in Potchefstroom, while K919-9 and K919-109 were the lowest yielding varieties across locations. The performance of these genotypes showed differences in rankings for different locations. The high yielding genotypes in one location were not the high yielding in another location and vice versa. Low yielding genotypes increase production input for smallholder farmers forcing them to buy seed each season.

Group III genotypes ranged from 1218.33 to 2370.50 kg/ha across locations, from 1095 to 2682 kg/ha in Potchefstroom, and from 567 to 2471 kg/ha in Taung, resulting in Potchefstroom having 11.88% higher yield compared to Taung. Group I ranged from 510-2909 kg/ha in Potchefstroom and from 661-3098 kg/ha in Taung, resulting in Potchefstroom having 16.42% higher in grain yield compared to Taung. Group III ranged from 1218.33 to 2370.50 kg/ha while group I ranged from 1001.00 to 2682.17 kg/ha across locations. Group I genotypes showed 7.93% higher in grain yield compared to group III in combined locations.

Comparing yield differences between the two standards, M107, the white seeded standard, resulted in 34.37% decrease in grain yield at Taung compared to Potchefstroom, whereas M53, the brown seeded standard resulted in 22.25% increase in grain yield at Potchefstroom compared to Taung. White-seeded varieties were 9.90% and 6.05% higher in yield compared to the brown seeded varieties at Taung and Potchefstroom, respectively. When comparing the performance of all genotypes across locations, the Potchefstroom trial had 14.25% higher grain yield compared to the Taung trial. This yield difference could be due to better adaptability and growing conditions at Potchefstroom.

Yield components

Genotypes were highly significantly different in all yield components measured (seed weight per panicle, panicle weight and thousand seed mass) per location and across locations. No significant difference was observed among the replicates, except for panicle weight (Table 3.2). There was significant entries x locality interaction for all yield components (Table 3.4).

1. Seed weight per panicle

The average seed weight per panicle ranged from 9.0-50.67 g in Potchefstroom, from 10.0-54.67 g in Taung and from 17.67 to 47.33 g across location. Genotypes K919-35 and K919-11 produced highest seed weight per panicle in Potchefstroom, whereas K919-44 and M107 were the highest in Taung and for combined locations. The lower yielding genotypes were K919-9 and K919-128 at Potchefstroom, K919-35 and K919-26 in Taung, and K919-9 and K919-94 across locations. Varieties in Potchefstroom produced 14% higher seed weight per panicle compared to Taung. The standards M53 and M107 were not significantly different from each other at Potchefstroom, while M53 was 49.38% lower in seed weight per panicle compared to M107 in Taung. The standard M53 produced average mass in both locations, showing stability whereas there was a tremendous shift in performance of standard M107.

The group III varieties were 7.95% lower in Potchefstroom compared to group I, ranging from 17.67-45.00 g and from 10.00-37.67 g in Taung, while group I ranged from 9.00-50.67 g in Potchefstroom and from 13.00-54.67 g in Taung resulting in 5.66% higher values compared to group III in Taung. Group I genotypes in Potchefstroom were 12.25% higher compared to group I in Taung while group III genotypes were 16.25% higher in Potchefstroom compared to Taung. Group III genotypes ranged from 21.50 to 37.67 g while group I genotypes ranged from 17.67 to 47.33 g across locations. Results for the combined locations shows that group I cultivars are better yielding with respect to seed weight per panicle by 7.23% compared to group III.

2. Panicle weight

Panicle weight ranged from 18-89 g in Potchefstroom, from 16.0-74.3 g in Taung and from 30.67 to 70.83 g across locations. Similar to seed weight per panicle, genotypes K919-11 and K919-35 were higher yielding at Potchefstroom. In Taung the standard M107 was superior, followed by K919-44, while K919-44 and K919-11 were the highest yielding genotypes across location. The lower yielding genotypes in Potchefstroom were K919-128, K919-93 and K919-104, K919-91 and K919-26 in Taung, while across location K919-128 and K919-9 were lower yielding genotypes. Both standard M107 and M53 had different ranks at the two locations. The observed panicle weight at both locations fall in the range that has been reported by Mogashoa (2000) of 60.7-125.6 g, Chaudhuri and Kanemasu (1985) of 20-46 g and Chintu et al. (1996), where the highest panicle weight was 59 g.

Panicle weight for group III ranged from 27.00-72.00 g in Potchefstroom, from 16.00-65.00 g in Taung, and from 34.17-64.33 g across location. Group I ranged from 18-89 g in Potchefstroom, 18-74.33 g in Taung and from 30.67-70.83 g across locations. Group I in Potchefstroom were 20.53% higher compared to group I in Taung, while group III were 30.71% higher in Potchefstroom compared to group III in Taung. When comparing the two groups in the same locations, group III was 8.50% higher compared to group I genotypes in Taung, whereas there was no significant difference between the two groups in Potchefstroom and the combined locations.

3. Thousand seed mass

Genotype K919-73 showed superiority in Taung, Potchefstroom and combined locations though in Taung it ranked second. TSM varied from 20.67-36.33 g in Taung, from 14.67-35.0 g in Potchefstroom and from 20.00-35.33 g across locations. Makgato (2004) reported a range of 20.9-31.4 g from the four sorghum varieties studied. Average thousand seed mass was higher by 18.5% in Taung compared to Potchefstroom. This percentage increase is lower compared to what has been reported by Mogashoa (2000) of 24 and 47% when comparing across locations and seasons. K919-73 and K919-126 showed superior TSM in Potchefstroom and across locations, while in Taung M107 and K919-73 were the highest. The lowest TSM varieties were K919-109, K919-114, and K919-9 in Taung, K919-56 and K919-116 in Potchefstroom, and K919-116 and K919-9 across locations.

Genotypes within group I ranged from 18.33-33.33 g in Potchefstroom, from 20.67-36.33 g in Taung and from 20.00-32.50 g across locations, while genotypes within group III ranged from 14.67-35.00 g in Potchefstroom, from 24.67-35.07 g in Taung, and from 20.17-35.33 g across locations. Group I in Taung produced 21.62% heavier than group I in Potchefstroom, whereas group III were 15.45% heavier in Taung than group III in Potchefstroom. The percentage decrease and increase in the two groups were non significantly different in Taung, Potchefstroom and combined locations (less than 3%).

Correlation of yield and yield components

Grain yield and yield components correlated positively in Taung, Potchefstroom and across the two locations (Table 3.6). Thousand seed mass showed poor reflection of seed weight in Taung (r=0.2158), Potchefstroom (r=0.4242) and across location (r=0.1864). Seed weight per panicle showed a strong relationship with grain yield in Potchefstroom (r=0.9047), Taung (r=0.9945) and across locations (r=0.9146). PW correlated strongly with grain yield and seed weight per panicle, except for TSM. Wenzel (1999) also observed high correlation between yield and yield components studied.

Discussion

When considering genotypes in different locations, genotypes showed tremendous variation. Some varied in performance from being among the superior genotypes for one yield component to being the least in the same or different components in the same or different location. House (1985) reported that sorghum yield components are quantitatively inherited. Almost all characters which are quantitatively inherited are influenced by the environment to a great extent. Differences in temperature, moisture, photoperiod and radiation between floral initiation and anthesis create variation and unstableness among yield components of the genotypes. Thus it is important to plant genotypes so that the period between floral initiation and anthesis should coincide with favourable climatic conditions for maximum yield production.

3.4 Conclusions

The yield potential and adaptability of cultivars in specific environments are the most important criteria for measuring cultivar performance. In a given location, different genotypes can perform differently in terms of yield and yield components. The group I genotypes (white-seeded) produced more than group III (the brown-seeded) in all yield parameters measured, except for panicle weight. Environmental conditions differed between localities resulting in genotype x environment interactions reducing gains for selection. When comparing the performance of these genotypes in Taung and

Potchefstroom, Potchefstroom genotypes (whether group I or group III) produced higher yields in all yield parameters measured compared to Taung.

Though in the present study, only two sites were studied, and stability was not measured, rankings showed that none of the genotypes appeared to be stable. More trials are required to determine stability of these genotypes in various environments and seasons because it is important to have food crops that give security in terms of production irrespective of environmental conditions.

Table 3.1 Biophysical data for Potchefstroom and Taung

Biophysical data	Potchefstroom	Taung
Average minimum temp (ºC)	15.10	14.51
Average maximum temp (ºC)	22.8	23.25
Average rainfall (ml)	18.95	18.70
Latitude	-27.9500	-26.7361
Longitude	24.83	27.0757
Altitude	1178	1347

Table 3.2 Mean squares for measured characteristics in grain sorghum for Taung and Potchefstroom

	Taung				Potchefstroom			
Source	GY	SW	PW	TSM	GY	SW	PW	TSM
Blocks	60152ns	21.33ns	151**	9.47ns	29275ns	7.478ns	7.478ns	10.411ns
Entries	1198516***	360***	748.06***	34.68**	1106519***	311***	925.80***	62.131***

GY=grain yield, SW=Seed weight per panicle, PW=Panicle weight , TSM=Thousand seed mass ns=Non significant Entries=genotype * $p \leq 0.05$ ** $p \leq 0.01$ *** $p \leq 0.001$.

Table 3.3 Yield and yield components of 30 sorghum genotypes at Taung and Potchefstroom.

	Potchefstroom				Taung			
Genotype	GY(kg/ha)	SW(g)	PW (g)	TSM(g)	GY(kg/ha)	SW(g)	PW (g)	TSM(g)
K919-116	1266	22.33	46.00	14.67	1814	32.00	54.00	25.67
K919-106	1492	24.67	63.67	26.33	2471	33.67	65.00	28.67
K919-94	1101	17.67	36.67	25.33	1436	25.33	37.oo	29.33
K919-93	1095	19.33	27.00	25.00	1662	29.33	50.67	26.00
K919-80	1643	29.00	41.33	22.67	1643	29.00	50.00	27.33
K919-76	2153	38.00	65.00	25.00	1284	23.67	42.67	31.00
K919-73	2682	45.00	70.00	35.00	1398	24.67	41.00	35.07
K919-63	1983	36.33	63.67	30.33	1114	19.67	32.00	28.67
K919-57	1341	28.67	38.00	18.00	1341	23.67	33.00	32.00
K919-56	1265	22.67	38.00	17.33	1813	32.00	41.33	28.33
K919-43	1247	21.33	54.67	22.67	2134	37.67	61.67	27.00
K919-42	2663	38.67	68.00	23.00	2078	36.67	53.00	29.67
K919-33	2097	44.33	72.00	26.67	793	14.00	31.00	28.67
K919-26	2021	37.33	52.33	22.00	567	10.00	16.00	32.33
M53	1870	33.00	54.00	23.67	1530	27.00	55.67	24.67
K919-128	510	9.00	18.00	24.67	1927	34.00	43.33	29.00
K919-126	2550	40.67	77.67	33.33	2116	35.33	48.67	31.67
K919-114	2078	38.67	57.33	26.67	661	14.67	26.33	24.00
K919-109	1360	29.67	40.67	19.00	1058	18.67	25.67	24.00
K919-105	2191	33.00	64.00	24.33	2153	38.00	65.67	25.33
K919-104	2399	42.33	27.00	28.67	1077	19.00	36.00	26.33
K919-100	1436	25.33	46.00	22.67	1417	25.00	34.00	32.67
K919-91	1851	32.67	47.00	18.33	1624	28.67	18.00	28.67
K919-60	1681	29.69	50.33	23.00	1907	16.00	21.67	27.67
K919-44	2267	40.00	69.00	23.33	3098	54.67	72.67	30.00
K919-35	2909	50.67	81.00	25.00	737	13.00	26.00	27.67
K919-9	869	15.3	31.33	19.33	1133	20.00	30.33	20.67
K919-11	2776	49.00	89.00	29.00	1983	35.00	52.67	30.33
K919-25	1530	27.00	43.67	20.33	1473	26.00	36.67	26.67
M107	1983	35.00	58.00	27.00	3022	53.33	74.33	36.33
CV (%)	8.87	15.77	7.57	11.57	10.19	10.98	11.45	8.12
LSD(0.05)	218.8426	5.3220	4.2725	2.9477	220.1210	3.2515	5.1537	2.4538

GY=Grain yield SW=Seed weight per panicle PW=Panicle weight TSM=Thousand seed mass CV=Coefficient of variation LSD=Least significant difference

Table 3.4 Mean squares for measured sorghum characteristics across locations

Source	GY	SW	PW	TSM
Entries	101079.866***	264.434***	1010.799***	67.231***
Loc	525960.556***	665.089***	5259.606***	893.339***
Entries x Loc	66306.533***	356.974***	663.065***	29.580***

Entries=Genotypes, GY=Grain yield, SW=Seed weight per panicle, PW=Full panicle weight

TSM =Thousand seed mass, Loc= Location ***P≤0.001

Table 3.5 Grain yield and yield components across locations.

Genotype	Grain yield	Seed weight per panicle	Panicle weight	TSM
K919-116	1539.67	27.17	50.00	20.17
K919-106	1981.67	35.00	64.33	27.50
K919-94	1218.33	21.50	36.83	27.33
K919-93	1378.67	24.33	38.83	25.50
K919-80	1643.00	29.00	45.67	25.00
K919-76	1718.67	28.83	53.83	28.00
K919-73	2040.00	34.83	55.50	35.33
K919-63	1548.83	28.83	52.83	29.50
K919-57	1341.00	26.17	35.50	25.00
K919-56	1539.33	27.33	39.67	22.83
K919-43	1690.50	29.50	58.17	24.83
K919-42	2370.50	37.67	60.50	26.33
K910-33	1445.17	27.17	51.50	27.67
K919-26	1294.00	23.67	34.17	27.17
M53	1700.17	30.00	54.83	24.17
K919-128	1218.50	25.17	30.67	26.83
K919-126	2332.83	34.33	63.17	32.50
K919-114	1369.50	26.67	41.83	25.33
K919-109	1209.00	24.17	33.17	21.50
K919-105	2172.33	35.50	64.83	24.83
K919-104	1737.83	30.67	31.50	27.50
K919-100	1426.17	25.17	40.00	27.67
K919-91	1737.67	30.67	32.50	23.50
K919-60	1294.17	24.50	36.00	25.33
K919-44	2682.17	47.33	70.83	26.67
K919-35	1823.00	31.83	53.50	26.33
K919-9	1001.00	17.67	30.83	20.00
K919-11	2379.83	42.00	70.83	29.67
K919-25	1501.67	26.50	40.17	23.50
M107	2502.50	44.17	66.17	31.67
CV (%)	9.49	17.73	9.33	9.74
LSD(0.05)	119.6691	3.9566	3.3280	1.9067

TSM=Thousand seed mass CV=Coefficient of variation LSD=Least significant difference

Table 3.6 Correlation coefficient of yield and yield components

	Potchefstroom			Taung			Across locations		
	GY	SW	PW	GY	SW	PW	GY	SW	PW
SW	0.9047***			0.9945***			0.9146***		
PW	0.7893**	0.7144**		0.8516**	0.8605**		0.8208**	0.7467**	
TSM	0.4871**	0.4242**	0.4465**	0.2266*	0.2158*	0.1185ns	0.2446**	0.1864*	0.1283*

GY=grain yield, SW=Seed weight per panicle, PW=Panicle weight , TSM=Thousand seed mass * $p \leq 0.05$, ** $p \leq 0.01$, ***$p \leq 0.001$

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CHAPTER 4

Screening for bird-resistant sorghum genotypes among 30 different sorghum varieties

4.1 Introduction

Birds are the most important pests of sorghum in Africa and other parts of the world. They are capable of inflicting heavy losses and causing economic damage. In Africa the most notorious species is Quelea-quelea. It is found in the Sahel region, from Senegal in west Africa through to Sudan, Uganda, Kenya, and Southern Tanzania, Malawi, Zambia, and South Africa (Dogget, 1988).

Birds are mainly controlled by scaring them away from the sorghum fields and destroying their nesting sites (Rodewald, 2001). Sorghum growers in many limited rainfall areas have used various plant characters to reduce bird damage. The awns, large glumes and inverted heads can contribute in reducing grain losses when there is plenty of other food around. During the time when the climate is sufficiently dry at grain filling and harvest, very compact heads with goose-necked peduncles can considerably reduce the amount of grain eaten by birds.

Bird-resistant sorghum contains tannins, which give the unripened grain a bitter taste. The tannin content decreases as the grain matures (Butler, 1982), and by the time the grain moisture content reaches 16 to 18%, tannin content is low enough and the grain can be vulnerable. Bird-resistant grain sorghums are more resistant to weathering than other grain types. The seeds have high dormancy, which keeps the seeds from sprouting under wet conditions after grain is mature (McMillian et al., 1972). Some seeds may shatter during harvest and may survive the winter and germinate in the spring, creating a weed problem in the following crop (Rodrique-Herrera et al., 2000).

Bird species differ greatly in feeding preferences. There are sorghum grains that are more preferred and desired than others. The more vulnerable type of grains is the sweetest, easiest to take, and pure white are mainly the sweet grains. The brown, bitter ones are less preferred (Dogget, 1988).

Birds show an astonishing degree of selectivity between sorghum lines of differing polyphenol content (Bullard et al., 1980). Low tannin lines (group I) are reported to be destroyed completely and rapidly, usually within three weeks after flowering. Group II sorghum can show a significant degree of bird resistance, but can be destroyed at essentially the same rate as the low tannin sorghum. Group III sorghum can show little damage until late in the season, after which they too are severely damaged (Butler, 1981). Birds can eat every seed or grain that is available when hungry. For many years, farmers have applied some cultural control of birds (MSUcares, 2001). Bird damage can be avoided when crops are grown under irrigation and when the times of movement of birds are observed.

Selecting a suitable planting date and maturity length, can minimize the damage. It is also important to plant fields at a time when they can mature with other nearby fields, since it provides other feeding sites to the birds (Dogget, 1988). It may be possible to time the period during which the grain is green and soft to coincide with the time of the year when the birds' numbers are low. Once the grains have hardened, they are less vulnerable to small species of birds (Dogget, 1988; Bullard et al., 1981; Harn and Rooney, 1985).

The main objectives of this study were to (1) identify bird-resistant sorghum genotypes among white-seeded and brown seeded varieties, and (2) to compare the percentage of damage among these genotypes.

4.2 Materials and methods

The materials and trial layout were the same as described in Chapter 3.

Each plot consisted of two rows. Ears of one of the two rows were covered with nets immediately after the panicle emergence and the other row was left uncovered. Bird damage was scored as percentage yield loss given by 1-(grain yield of uncovered rows/grain yield of covered rows). The compactness of panicles was evaluated on a scale of 1= open panicle and 5= compact panicle. Agrobase, 2000 was used to analyse the data

4.3 Results and discussions

The percentage bird damage and ear compactness is presented in Table 4.2. The bird damage at Taung was 100% and this data could therefore not be used further for analysis. The varieties were classified into two seed coat colours, white and brown-seeded. Fifteen genotypes were brown and the other 15 were white. The white-seeded genotypes are also known as group I sorghum, which are homozygous recessive at least for one of the AA or BB locus. The brown-seeded genotypes are known as group III sorghum, consisting of dominant alleles at all three loci AABBSS and are reported to be bird resistant. According to House (1985) the presence of A-B alleles causes a brown testa and S- is a testa spreader allele which causes brown colour in the epicarp. The testa spreader gene (S-) can only expresss itself in the presence of dominant A-B genes and vice versa.

Type of panicle and percentage bird damage

Genotypes were highly, significantly different from each other at Taung and Potchefstroom with respect to ear compactness (Table 4.1). In both locations, ratings for panicle compactness ranged from 2.5 to 5.00. K919-42 had a highly compact head type in both locations while K919-63 and K919-25 had a intermediate head type. There was a highly significant difference among genotypes in each group (Table 4.1). In group I genotype M107 had a completely closed panicle in Taung while in Potchefstroom it was K919-114 and both were rated 5. K919-25 had the non-compact panicle compared to group I genotypes in both locations. In group III, K919-42 had a completely closed panicle, while K919-63 had an open panicle in both locations. The panicles of group III genotypes were 10.85% and 7.17% more closed compared to group I in Taung and Potchefstroom respectively.

There was a highly significant difference among genotypes with respect to percentage bird damage in Potchefstroom (Table 4.1). The damage also differed among genotypes of the same group. Group III genotypes had 10.77% lower damage compared to group I genotypes. Percentage bird damage was positively correlated with ear compactness (r=0.8623). All the varieties planted indicated intermediate to compact type of heads. Non-compact panicle is one of the physical characters that reduces the percentage of bird damage. In tight or compact-headed varieties birds can stand comfortably when feeding on the grain. Therefore open-headed varieties are less vulnerable to birds. These results are similar to the ones reported by Tipton et al. (1970), where they found that non-compact heads were damaged less by birds compared to the compact headed hybrids.

The percentage bird damaged in Potchefstroom ranged from 70.7 to 100%. Many group I genotypes resulted in 100% bird damaged except for K919-44 (70.7%), K919-91 (80.7%), K919-109 (87%), and K919-35 (92.7%). Bird damage was severe in group I compared to group III genotypes. The percentage bird damage of group III genotypes ranged from 76.7% in K919-76 to 100 in K919-33. The damage in this study was higher compared to what has been reported by Tipton et al. (1970), and Hoshino and Duncan (1981). In an experiment conducted by Hoshino and Duncan (1981), bird-resistant hybrids resulted in no damage except for one hybrid with 0.7% bird damage. Their results suggested that tannin in grain was effective in preventing bird damage. At various stages of grain development, Tipton et al. (1970) reported a range of 1 to 79 % bird damage in brown, light brown, red, and reddish brown hybrids. However, their experiment was terminated four months after planting whereas the current experiment was terminated seven months after planting. Therefore, delaying harvest in sorghum fields can result in 100% bird damage, irrespective of whether the cultivars contain tannin.

Though the damage was not scored per stage of development, progressive bird damage in group III was observed to differ with grain moisture content. Bullard et al. (1981) reported that tannin concentration changes as the grain develop. Tannin synthesis occurs as chlorophyll develops in the pericarp. When the grain ripens, the tannin content becomes low, thus resulting in increasing susceptibility to birds of the brown-seeded varieties. Bullard and York (1996), reported that genotypes and sunshine can influence the measurements of tannin biosynthesis. Bird damage in grain sorghum has been found to be correlated with tannin content in seed, seed colour, flowering date and plant height. Shading and temperature have been reported to influence the rate of tannin deposition (Bullard and York, 1996). The mean temperature during the grain development ranged from 8.1 to 26.5ºC in Potchefstroom and 7.2 to 25.1ºC in Taung. These temperatures have shown a very slight difference, but it could have reduced tannin concentration among the brown-seeded varieties.

High bird populations and scarcity of other food sources results in high tannin genotypes being subjected to the ravages of birds. Planting grain sorghum during the time where the nearby fields are occupied, reduces the percentage of bird damage since there is a lot of food around. The percentage of bird damage differed between locations and among genotypes. The Taung trial resulted in 100% bird damage whereas the Potchefstroom trial was left with a few seeds. Hoshino and Duncan (1981) reported that the damage between locations could differ. Hybrids with the greatest amount of damage or high in tannin at one location may not be necessarily equal the hybrids with the highest bird damage or high in tannin at another location. Genotype x environment interactions between bird damage and tannin content are of major importance to the agronomist in producing high quality sorghum grain.

Table 4.1 Mean squares for percentage bird damage and ear compactness in Taung and in Potchefstroom

Group	Source	Ear compactness		Percentage
		Taung	Potchefstroom	Bird damage (Potchefstroom)
Across	Blocks	1.171*	1.937***	6.051ns
Groups	Entries	1.997***	2.306***	264.531***
Group I	Blocks	0.116ns	0.404ns	31.850***
	Entries	2.478***	2.291***	244.200***
Group III	Blocks	2.289**	2.222**	6.756ns
	Entries	1.260**	1.308**	135.089***

NS=non significance * $P \leq 0.05$, $^{**}P \leq 0.01$, $^{***}P \leq 0.001$

Table 4.2 Differences in ear compactness and percentage bird damage among 30 grain sorghum genotypes (Taung had 100% bird damage)

Genotypes	Group	Ear compact. (Taung)	Ear compact.(Potch)	Bird damage in Potch (%)
K919-116	III	4.93	4.67	86.0
K919-106	III	4.00	4.43	90.3
K919-94	III	3.50	3.00	86.0
K919-93	III	5.00	4.50	82.3
K919-80	III	4.33	4.17	96.7
K919-76	III	4.00	4.50	76.7
K919-73	III	3.50	3.00	80.3
K919-63	III	2.50	2.50	81.3
K919-57	III	4.67	4.27	78.3
K919-56	III	4.03	4.00	84.7
K919-43	III	4.80	5.00	84.0
K919-42	III	5.00	5.00	90.3
K919-33	III	3.83	4.00	100
K919-26	III	4.80	4.27	78.3
M53	III	4.40	4.67	82.0
K919-128	I	3.17	3.00	100
K919-126	I	3.67	4.17	100
K919-114	I	4.60	5.00	100
K919-109	I	2.50	2.73	87.0
K919-105	I	3.33	3.67	100
K919-104	I	4.73	4.50	100
K919-100	I	4.87	4.50	100
K919-91	I	3.77	3.50	80.7
K919-60	I	4.67	4.83	100
K919-44	I	4.70	4.50	70.7
K919-35	I	4.00	4.33	92.7
K919-9	I	2.50	2.67	100
K919-11	I	4.33	4.67	100
K919-25	I	2.50	2.50	100
M107	I	5.00	4.83	100
CV (%)		15.42	11.23	2.40
LSD		0.6616	0.4808	3.0328

Bird damage=1-(grain yield of uncovered rows/grain yield of covered rows)*100, Ear compactness scale was 1=non-compact and 5=compact panicle NS=non-significance *P≤ 0.05, **P≤ 0.01, ***P≤ 0.001, LSD=Least significance difference CV=Coefficient of variation

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CHAPTER 5

Milling quality of sorghum varieties with different endosperm texture

5.1 Introduction

Grain sorghum [*Sorghum bicolor* L. (Moench)] is one of the primary food sources in the semi-arid tropics of Africa and Asia. Sorghum improvement programs in Africa and Asia are concerned with sorghum as a food crop. A number of food quality criteria have been identified and it appears that the majority of these quality criteria are directly affected by the endosperm texture of the sorghum grain (Rooney and Sullins, 1977; Boiling and Eisener, 1981; Mukuru et al., 1981; Scheuring et al., 1981; Dogget, 1981).

Sorghum is not cooked as a whole grain like rice. It is ground to flour and used in the preparation of porridges and both leavened and unleavened bread (Vogel and Graham, 1979). The bran is a major cause of the coarse texture of sorghum products, so to refine sorghum flour, bran has to be eliminated with minimum loss of nutritional constituents. Desikachar (1981), reported that adding small amounts of moisture, just sufficient to wet the bran, allows it to be loosened and easily pearled from the grain. The most bran resists fine grinding, unlike the endosperm that is relatively drier and more friable.

Miniature experimental mills have been developed to provide a direct measure of extraction. Shepherd et al. (1970), reported that application of experimental roller mills to sorghum varieties gave uneconomically low extraction rates of 36.6 to 55.6%. Anderson et al. (1969) suggested that a different type of milling process is required. Abrasion-type grain mills are gradually finding favour in a number of developing countries for use with sorghum (Hulse et al., 1980).

There are numerous precedents in the use of small-scale or laboratory devices to predict the milling of grains. Some attempts have been made to evaluate sorghum dehulling quality. Rooney and Sullins (1969) and Maxson et al. (1971) used a strong-scott barley pearler fitted with a wire brush to dehull 100-200 g of samples of grain. Rooney et al. (1972) used a satake grain mill similar in principle to a strong-scott barley pearler to dehull 150 g of sorghum sample. The disadvantages of the barley pearler are that it is relatively cumbersome to use, requires a relatively small sample size, and it processes only one sample at a time. Hogan et al. (1964) and Normand et al. (1965) employed tangential abrasion to remove successive layers from sorghum and other cereal grains.

The tangential dehulling principle is used to develop a rapid, highly reproducible, multi-sample dehulling device. The tangential abrasive dehulling device (TADD) has been used to predict dry abrasive-type dehulling characteristics (mechanical dehulling) and it may also have application in the prediction of traditional dehulling properties. The TADD is used to evaluate dehulling quality based on the abrasive hardness index (AHI) and the extraction rate based on flour colour.

Different methodologies may be required for the prediction of traditional and mechanical dehulling properties, since these processes differ markedly. Traditional methods of dehulling sorghum in Africa vary from area to area but are often aided by the addition of water (Reichert and Youngs, 1977). An amount of 20-25% of water by weight is added to the grain in a mortar. The grain is allowed to stand for a few minutes and then pounded with a pestle for 10-20 minutes. During the tempering process, the bran layers swell and become partially detached from the endosperm. Pounding provides the abrasive action necessary to remove bran layers from the endosperm. Relatively hard sorghum varieties with a thick, chalky mesocarp appears well suited to this processing.

The ease of dehulling by the mechanical method is a function of the degree of adhesion between the endosperm and bran layers as well as the hardness of the grain. Soft grains tend to crack easily under the pressure of the abrasive surface resulting in removal of fine material from all parts of the seed rather than from the peripheral layers only. Therefore seeds with vitreous (harder) properties are desirables. The objectives of this study were to

1) Compare group I and group III genotypes in terms of endosperm texture, 2) to compare flour colour and milling yield among those genotypes.

5.2 Materials and Methods

The material for these trials was the same as described in Chapter 3. Seed from the Potchefstroom trial was used for these analyses.

A tangential abrasive dehulling device (TADD) was used for dehulling samples. Eight samples weighing 50 g each were poured into the TADD's eight cups, with sandpaper (P60, 454HL,3M-ite Resin Bond Cloth). The TADD has a resinoid disk with diameter equal to 37 mounted horizontally beneath the eight cups. The disk was set to rotate at 1725rpm. The time of abrasion was 1 to 5 min, with 1 min intervals. After dehulling, the samples were removed using a DVC industrial vacuum cleaner attached to the TADD machine. Samples were weighed to obtain the percentage kernel removed after each minute. The AHI was calculated from the regression line of the abrasion time versus the abrasion percentage at each time interval (1-5 min). The dehulled samples were milled using the cyclotec 1093 with a 2 mm screen for meal production and the mill's collection was weighed. The percentage milling yield was determined by final weight of meal/initial weight of sample (that is 50 g) *100. The Hunterlab Color-flex 45º/0º and Hunterlab Universal Software V4.01 was used to determine the color of the meal. The Hunterlab scale used was L, a, and b. The L measured the lightness and varied from 100 for perfect white and zero for black. The chromacity dimensions (a and b) gave designations of colour as follows: a=redness when positive, grey when zero, and greenness when negative while b= yellowness when positive, grey when zero, blueness when negative.

The relative proportion of the corneous to floury endosperm within a sorghum kernel is often referred to as endosperm texture. Endosperm texture was determined by visual examination of longitudinal half kernels as described by Maxson et al. (1971). The ratings ranged from 1=completely corneous and 10=completely floury.

5.3 Results and discussions

The results for percentage kernel removed, AHI, visual analysis of endosperm texture, milling yield, and flour colour are presented in Table 5.1. The samples were not replicated except for endosperm texture, therefore grand means were used to compare the results.

Percentage kernel removed

The 30 varieties tested showed differences in percentage kernel removed for the 5 minutes, separated into 1-minute intervals. Increasing time resulted in an increase in percentage kernel removed. In the final minute, group I varieties ranged from 31.44 to 60.12% where K919-104 and K919-25 were the highest with 60.12 and 51.13% respectively, while group III ranged from 38.14 to 52.53, where M53 and K919-63 had the highest percentage of 50.47 and 52.53 respectively. These high percentages of kernel removed indicate the softness of the endosperm in these varieties and the degree of ease in which the kernel breaks. The varieties K919-93 and K919-80 produced the lowest yield of 38.14 and 38.74 in group III respectively while M107 and K919-105 produced the lowest yield of 31.44 and 32.05 % kernel removed respectively in group I varieties. In the final 1 min (of the 5 min), percentage kernel removed was higher on average for group III sorghum with 4.3 % compared to the average of group I sorghum. The above results showed that the hardest and softest samples can produce big differences in percentage kernel removed.

The abrasive hardness index

The inverse of the slope for each sample regression line was multiplied by 60 to give the abrasive hardness index (AHI), which is defined as the time in seconds necessary to abrade 1% of the kernel. The AHI showed that there is variability among the genotypes. The group I sorghum ranged from the softest of 6.18 and 6.51% of K919-104 and K919-25 respectively and to the hardest of 10.71 and 10.12% of K919-105 and K919-44 respectively. The group III sorghum ranged from 6.17-9.31% on AHI. K919-56 and K919-93 were the hardest grain with 9.31 and 8.40% compared to other varieties. The varieties K919-63 and K919-116 were the softest with 5.51 and 6.17% given by AHI. Group I sorghum had 19.43% harder grain compared to group III sorghum. Oomah et al. (1981) and Reichert et al. (1981) reported a range of 5.0 to 12.8 of the AHI, which is almost similar to what has been found in this experiment, where as Reichert et al. (1988) reported a range of 2.5-21.3 and 11.6-19.6 in different varieties.

Endosperm texture through visual analysis showed highly significant differences in groups and among genotypes. Group I genotypes ranged from 1.67 to 6.67 whereas Group III genotypes ranged between 4.67 to 9.67. Group III sorghum was 59% floury while Group I was 41% glassy.

Milling yield

The percentage-milling yield of the 30 varieties tested ranged from 39.88-68.56% in both group I and group III varieties. In group I varieties, standard M107 and variety K919-44 produced the best results with 68.56 and 67.16% respectively. K919-104 and K919-25 produced the lowest yield with 39.88 and 48.47% in group 1 respectively. In group III varieties K919-93 and K919-80 produced the best yield of 61.86 and 61.26% respectively, while M53 and K919-63 produced the lowest yield of 49.53 and 47.44% respectively. The group I varieties had 8.4% higher milling yield compared to group III. Reichert et al. (1984) reported a range of 42.0-98% milling yield in group I sorghum from the 31 varieties studied. K919-104 produced the lowest yield in group I, performing abnormally when compared to other varieties in its group. It is important to include this variety in the next trial to confirm these results and also assessment of genotype x environment interaction, which will determine its capability in milling.

Flour colour

Lightness of the 30 varieties was ranked according to the magnitude of the L value, which ranged from 75.98-85.57 in group I and from 75.32-80.48 in the group III. Varieties of group I, K919-128 and K919-9 were very light compared to the other varieties producing 85.57 and 85.43 in the final minute (5 min) of abrasion whereas K919-104 and K919-105 performed poorer compared to the rest of the group having

75.98 and 78.18 respectively. In group III, K919-63 and M53 performed better with 79.21 and 80.48 L values respectively while K919-76 and K919-106 were the poorest among two groups. Group I varieties were 4.78% higher in lightness compared to group III at the final minute, however, some varieties in group III were lighter in colour, falling in the same range as group I. Although group III has been reported to have softer endosperm (Reichert et al., 1988; Chibber et al., 1978), the lightness of their flour showed that these grains also, has capacity to withstand a certain degree of dehulling/abrasion. Further improvements of these varieties can results in good milling characteristics and an increase in consumer's preference. The samples exhibited a combination of yellow and red colours, as indicated by positives values of a and b. Negative a values were observed indicating greenness.

Correlation

Milling quality characteristics were highly correlated to each other (Table 5.2). Milling yield, AHI, lightness and redness were positively correlated to each other. Endosperm texture and percentage kernel removed were negatively correlated to all the parameters except yellowness of the flour and between each other. AHI and endosperm texture were negatively correlated with each other while Reichert et al. (1984) found no correlation between AHI with endosperm texture. AHI showed strong reflection on milling yield (r=0.9009), compared to lightness (r=0.4797) and redness (r=0.4032). Yellowness showed a strong independence to lightness (r=-0.9306) and to redness (r=-0.7731), while redness and lightness showed dependence on each other (r=0.6576). Kirleis and Crosby (1981) reported that a multiple linear regression analysis revealed that the abrasive milling performance of sorghum is related to all hardness parameters investigated.

5.4 Conclusions

On average group I varieties were harder than group III varieties as indicated by the abrasive hardness index and visual assessment of endosperm texture. Group I produced the best milling yield and lighter flour colour as compared to group III, however, some group III genotypes were in the same range as the group I with respect to AHI, endosperm texture, milling yield and flour colour. Therefore the selection of genotypes due to pericarp colour cannot be accurate.

AHI showed a very strong relationship with milling yield and flour colour, confirming the importance of endosperm hardness during processing of the grain and in the end-product. Sorghum porridge consumers prefer lighter flour compared to red and brown, and grains that produce high milling yields, therefore selection of grains with harder endosperm must be in the initial stage in breeding strategies.

Table 5.1 Milling quality characteristics of different sorghum genotypes

Genotypes	Group	%kernel removal	AHI	Endosperm texture	Milling yield	Lightness	A	b
K919-116	III	49.32	6.17	8.67abcd	50.68	76.03	3.00	11.81
K919-106	III	40.54	8.14	8.00bcde	59.46	75.42	2.75	10.21
K919-94	III	48.94	6.66	7.67cde	51.06	77.64	2.73	9.65
K919-93	III	38.14	8.40	7.67cde	61.86	75.88	3.27	10.55
K919-80	III	38.74	7.99	9.00abc	61.26	76.58	2.32	11.22
K919-76	III	40.98	7.58	9.33ab	59.02	75.32	2.74	10.57
K919-73	III	47.92	6.58	9.33ab	52.08	79.19	1.66	11.39
K919-63	III	52.53	5.51	9.67a	47.47	79.21	1.77	11.6
K919-57	III	43.01	7.49	8.67abc	56.99	76.42	2.57	9.55
K919-56	III	39.53	9.31	7.33de	60.47	79.07	1.76	11.71
K919-43	III	39.84	8.08	5.67fg	60.16	78.98	1.91	10.68
K919-42	III	47.39	6.58	8.33abcd	52.61	78.56	2.31	10.50
K919-33	III	41.22	7.82	8.33abcd	58.78	78.68	1.66	11.59
K919-26	III	44.86	7.19	7.33de	55.14	78.97	1.56	12.14
M53	III	50.47	6.85	4.67gh	49.53	80.48	0.41	11.54
K919-128	I	36.03	9.06	3.00ijk	63.97	85.57	-0.7	14.30
K919-126	I	41.45	8.09	4.67gh	58.55	81.82	1.62	9.88
K919-114	I	37.08	9.41	2.00k	62.92	84.05	0.36	12.93
K919-109	I	49.04	7.38	6.67ef	50.96	80.30	1.45	9.75
K919-105	I	32.05	10.71	2.00k	66.95	78.18	2.47	11.36
K919-104	I	60.12	6.18	3.67hij	39.88	75.98	2.96	9.58
K919-100	I	37.33	8.37	2.00k	66.05	81.81	0.43	13.52
K919-91	I	37.33	9.30	4.33ghi	62.77	79.86	1.87	9.25
K919-60	I	35.65	9.77	2.67jk	64.65	82.44	-0.02	12.56
K919-44	I	32.84	10.12	1.67k	67.16	83.68	-0.57	13.87
K919-35	I	33.03	9.98	2.67jk	64.97	81.9	0.88	11.62
K919-9	I	42.59	8.49	1.67k	57.41	85.43	0.14	12.29
K919-11	I	35.86	8.69	2.00k	64.14	82.39	-0.21	14.28
K919-25	I	51.13	6.51	2.33jk	48.47	78.47	1.94	9.11
M107	1	31.44	9.73	3.67cde	68.56	80.31	1.26	11.02

Group I represent low tannin sorghum, group III represent high tannin Sorghum. a=yellowness, b=redness lightness=whiteness of the flour. Endosperm texture information: Genotype=highly significant, Group=highly significant, Least Significance Difference=1.5919, Coefficient of variation=26.37% AHI= Abrasive hardness index.

Table 5.2 Correlation coefficients between sorghum milling quality characteristics

	Milling yield	AHI	% Kernel removed	Endosperm texture	Lightness	Yellowness
AHI	0.9009***					
% KR	-0.9941***	-0.9178***				
ET	-0.3427*	-0.5437**	0.3392*			
Lightness	0.4100*	0.4797**	-0.4010*	-0.6945***		
Yellowness	-0.4325*	-0.4595*	0.4155*	0.6534***	-0.9306***	
Redness	0.4925**	0.4032*	-0.4658*	-0.4229*	0.6576***	-0.7731***

AHI=Abrasive hardness index, Endosperm texture or ET= Visual assessment of endosperm texture, %KR= percentage kernel removed, *$p \leq 0.05$, **$p \leq 0.01$, ***$p \leq 0.001$

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CHAPTER 6

Differences of group I (low tannin) and group III (high tannin) sorghum genotypes based on viscosity parameters

6.1 Introduction

Sorghum grains are used as the staple food in several regions of Africa, China, and the Indian subcontinent, particularly in the semi-arid tropics. Sorghum grain types, processing methods, and food habits vary considerably with the geographical area (Johnson, 1981). Despite low yields, local cultivars are generally preferred by consumers due to their characteristics, and unidentified food quality attributes (Morris, 1981). The most common products from whole grain flour are porridges.

Sorghum grains are reported to contain five different sugars, that is sucrose, stachyose, raffinose, glucose, and fructose in varying proportions (Subramanian et al., 1980). These different sugars influence sorghum quality. Although sorghum grains do not contain gluten, when sorghum flour is mixed with water and kneaded, it produces sticky dough. According to Desikachar and Chadrashekar (1981), good quality dough should be sticky and rollable without any breakage. Water-soluble components play an important role in the quality of dough and the nature of these components needs to be characterised (Subramanian and Jambunathan, 1981).

Kirleis and Crosby (1981) reported that the grain endosperm texture could influence the quality of cooked porridge. Consumers seem to accept cultivars with hard endosperm rather than soft endosperm (Pushpamma and Vogel, 1981). The textural quality of traditional sorghum porridges determines their acceptability to consumers (Cagampang et al., 1982). Sorghum porridge varies in consistency from thick gruels, consumed using spoons, to stiff, crumbly porridge eaten with the hand. Porridge consistency is directly related to solids content, or more strictly to the concentration of gelatinized starch. The concentration of the flour in porridge determines whether it is classed as thin or thick porridge (Rooney and Waniska, 2002).

The role played by chemical and physical factors of the grain on food quality appears to be a complex phenomenon (Rooney and Sullins, 1969). Chemical components such as protein, starch, lipids and ash show an influence on cooking and eating quality of sorghum. Starch is an important constituent in many foods. It plays a role achieving the desired viscosity in products such as porridges. Starch occurs in the leucoplasts of tubers, leaves, seeds and other portions of the plant.

Starch is composed of two polymers called amylopectin and amylose. During the plants' development of the leucoplasts, the amylose and amylopectin are developed within the leucoplasts in starch granules. Amylose and interaction between protein and starch inside the endosperm cells are some of the factors affecting porridge quality (Bello et al., 1990). Amylose content of sorghum may be related to differences in keeping quality of sorghum porridges. The environment can affect amylose content and the procedure used to process the grain, ground whole sorghum, ground pearled sorghum and isolated starch (Ring et al, 1981).

Viscosity is a property used to define degree of porridge thickening during cooking. The viscosity is expressed in Brabender units (BU). Different starches have different viscosities requiring different forces and yields different graphs when evaluated with the Brabender viscograph. There are different factors that influence viscosity and gel strength such as heating, temperature, stirring or shearing action. The objectives of this study were to 1) Compare group I and group III sorghum varieties in terms of thickening of starch during cooking (viscosity) 2) Identify the best genotypes between group I and group III for viscosity.

6.2 Materials and methods

Twenty-eight sorghum genotypes developed by the Agricultural Research Council-Grain Crops Institute, Potchefstroom of South Africa were used. The genotypes included two standards M107 (group I) and M53 (group III). These varieties were planted at Taung in the North West of South Africa. Information of experimental layout is provided in chapter 3.

After harvest, 200 g per sample were milled using a hammer mill. Two gram of flour per sample was weighed. Moisture content was recorded using the Presica HA 300 (Swiss quality, INSTRULAB cc, Midrand SA.). Viscosity was measured using the Brabender ® Viskograph 'E' (Model 802525, Brabender® OHG Duisburg, Germany). The heating/cooling temperatures were: heating from 30ºC to 92ºC at 3^{o}C per minute, holding of 92ºC for 10min and cooling from 92ºC to 30ºC at 3 ^{o}C per min for 10 min. Measuring range of 700cmg, sensitivity of the recorder was used. A 12% solution with 54 g flour and 396 ml distilled water was used.

Viscosity parameters recorded were; the beginning of gelatinization, maximum viscosity, start of cooling period, end of cooling period, end of final holding period, breakdown, and setback. All values were expressed in Brabender units (BU). Data was analyzed using Agrobase, 2000.

6.3 Results and discussion

Table 6.1 represents viscosity values of the two groups and table 6.2 represents the mean squares for measured viscosity characteristics of the two groups and across the two groups.

Beginning of gelatinization

There was no significant differences between genotypes across groups and among genotypes within the same group in the beginning of gelatinization, which confirms the observation of Abd.Allah et al. (1987) of sorghum starches having the same viscosity at the beginning of gelatinization. Average viscosity in group I ranged from 30.67 to 46 Bu and from 27 to 33.33 Bu in group III. K919-60, K919-114 and K191-35 indicated high viscosity values of 46, 32.33 and 32,33 respectively in group I, whereas K919-43, M53 and K919-33 had high viscosity in group III yielding 33.33, 32.33 and 30,07 Bu respectively. On average, group I genotypes were higher in viscosity with 7.59% at the beginning of gelatinization compared to group III genotypes. Even though group III sorghum showed low viscosity, standard M53 was high with 2.08% Bu compared to standard M107. The gelatinization temperature of both groups was different, however these genotypes' starch began gelatinization between 60-80ºC (Fig 5.1). Different starches exhibit different granular densities, which affect the ease with which these granules can absorb water (Hoseney, 1994). Since K919-60, K919-43 and K919-114 showed initial rapid gelatinization, it can be suggested that they have the largest granules which are less compact and therefore absorb water faster. However, this suggestion must be confirmed on further experimentation.

Maximum viscosity

The peak viscosity at any concentration is an important feature of starch (Adebowale et al., 2005), since the swelling of starch and its solubility influences the cooking quality of sorghum. The response of genotypes per group and across groups showed highly significant difference in maximum viscosity. Peak viscosity of group I genotypes ranged from a low of 264, 506 and 6453 BU from genotype K919-114, K919-60 and K919-11 respectively, to a high of 1104, 959 and 893 Bu from genotypes K919-104, K919-109 and K919-105 respectively, while group III genotype ranged from a low of 632, 716 and 754 BU produced by genotype K919-43, K919-26 and K919-94 respectively to high of 1059, 1040 and 1021 produced by K919-42, M53 and K919-93 respectively. Group III genotypes produced an average of 9.51% higher peak viscosity compared to group I. In group III genotypes showed an increase in thickness compared to group I when optimum gelatinization is reached. On average the standard M53 performed better compared to standard M107 with 27.20% peak viscosity. Though the same concentration of starch, water and temperature was used, the two groups showed differences in paste viscosity and ultimate optimum gelatinization as measured by viscosity. The peak viscosity values observed in this study were higher compared to those reported by Adebowale (2005) ranging from 97-126.78 at 95ºC and by Subrahmanyan and Hoseney (1995) ranging from 415-726 at 95ºC, However, the starch samples used were chemically treated. Therefore natural starch increases the possibility to obtain high peak viscosity values.

Start of Cooling Period (SCP).

Both groups, and genotypes across groups were highly significantly different at the start of the cooling period. Group I genotype average values were 5.55% lower than group III at SCP. The genotypes that showed higher thickness in group I were K919-104, K919-109 and K191-25 with 723, 632 and 627 BU mean values respectively while K919-114, K919-60 and K919-100 showed poor thickness producing 174, 391 and 441 mean values respectively. The group III genotypes ranged from a high viscosity of 691, 678 and 665 produced by genotype M53, K919-42 and K919-93 respectively to low viscosity values of 423, 494 and 503 produced by K919-43, K919-80 and K919-26 respectively. When considering the performance of the standards, M53 was 23.34% thicker than M109

End of cooling period

Genotypes within each group and across groups were highly significantly different with respect to end of cooling period. Group I was 2.46% thicker at the end of cooking compared to group III. The average viscosity in group III ranged to a high of 1478, 1503, and 1534 Bu produced by K919-63, K919-42 and M53 respectively from a low of 1186, 1206 and 1215 Bu produced by K919-80, K919-94 and K919-43 respectively. The group I genotype averaged from a low 581, 1169 and 1307 Bu produced by K919-114, K919-60 and K919-100 respectively to a high of 1637, 1644 and 1645 Bu from genotype K919-126, K919-25 and K918-104 respectively. The above results showed that starch gained viscosity during cooling.

End of final holding

According to Beta et al. (2001) final viscosity indicates the ability of the material to form a viscous paste or gel after cooking and cooling. There were highly significant differences observed among genotypes per group and among genotypes across the groups. Group I genotypes had a 0.18% higher average value than group III. Genotypes ranged from 568, 1116 and 1253 Bu in group I produced by genotype K919-114, K919-60 and K919-100 respectively to 1582, 1576 and 1548 Bu produce by K919-104, K919-126 and K919-25 respectively. Group III sorghum ranged from 1141, 1163 and 1222 Bu produced by K919-94, K919-80 and K919-26 respectively to a high of 1441, 1471 and 1495 Bu from genotype K919-63, K919-42 and M53 respectively. When considering the two standards, the brown-seeded standard was 10.93% thicker in terms of viscosity compared to M107, the white-seeded standard. End of final holding affects textural and sensory properties of food and is considered important in food processing operations such as canning

Breakdown

Breakdown indicates the stability of starch during heating at 92ºC. Group III sorghum was less stable when compared to group I with 17.35% in breakdown. Genotypes across the groups and genotypes among group I and Group III showed a highly significantly different. The standard M53, was 21.23% less stable when compared to standard M107. Genotypes K919-42, K919-93, M53 had the highest breakdown values in group III with 382, 356 and 348 Bu respectively while K919-43, K919-26 and K919-94 had the lowest values of 210, 213 and 245 Bu respectively. In group I, genotypes K919-104, K919-109 and K919-105 had high breakdown values of 381, 327 and 318 Bu respectively, while K919-114, K919-60 and K919-11 produced low values of 90, 115 and 170 Bu respectively. The above results indicate that the holding strength of starch differs between genotypes. It seems as though overcooking and overstirring of starch decreases viscosity. High temperature swollen granules may break and loose their contents and hydrogen bond that hold the polymers, resulting in a greater decrease in viscosity. The ability of a starch sample to withstand this heating is an important factor for most food processing operations.

Setback

During setback, group III genotypes were not significantly different, whereas group I genotypes and genotypes across groups were highly significantly different. Group I showed higher thickness of 8.05% during the cooling period. Group I genotypes' thickness during setbacks ranged from a low of 407, 777 and 799 from genotypes K919-114, K919-60 and K919-109 respectively to a high of 949, 1010 and 1017 produced by genotypes K919-91, K919-126 and K919-25 respectively. Group III genotypes ranged from low viscosity of 692, 697 and 762 produced by K919-80, K919-94 and K919-106 to a high viscosity of 870, 871 and 898 produced by variety K919-76, K919-63 and K919-116 respectively. During setback, standard M107 was thicker by 6.09 % compared to M53 . The above difference between the initial and final period varies from genotypes to genotypes.

Correlation

Viscosity parameters correlated significantly with each other (Table 6.3). Beginning of gelatinization showed negative correlation to maximum viscosity (r= -0.2171) and breakdown (r= -0.2568), and no further correlation was observed between beginning of gelatinization with other parameters. Breakdown and maximum viscosity correlated with all parameters. Maximum viscosity, start of cooling period, end of cooling period, final holding period, breakdown and setback correlated positively with each other.

6.4 Conclusions

For all the parameters measured, group I was higher in viscosity except for maximum viscosity, which is the most important parameter during pasting. Group III sorghum showed an average of 17.35% breakdown which showed less stability of the genotypes during heating, however, most consumers do not overcook the porridge .

When considering the two standards, M53 showed high viscosity in all parameters except during setback. It can be concluded that M53 is better compared to M107 when pasting properties are compared, regardless of the percentage increase indicated during breakdown.

Consultation of consumers in Potchefstroom (North West province of SA) emphasizes the difference in preferences of the product. The majority of the consumers prefer serving hot porridge while others prefer cold porridge. The level of thickness differs with individuals and ranges from thick in adult and thin in children. Men prefer the thickest porridge, which prevent them from eating the whole day. Women prefer less thick porridge compared to men, whereas children eat it as a breakfast meal. Consumers, regardless of gender and age require sorghum flour, which uses a lower volume of flour and is believed to be very economic. Based on the above, varieties K919-104, M53, K919-42 and K919-93 can be recommended for consumers desiring to serve both hot and cold porridge, due to maximum thickness showed during both heating and cooling temperatures.

Table 6.1 Differences in viscosity between group I and group III genotypes in sorghum.

Genotype	Group	A	B	D	E	F	B-D	E-D
K919-116	III	30.33	778	507	1405	1317	271	898
K919-106	III	28.67	851	565	1327	1253	285	762
K919-94	III	29.67	754	509	1206	1141	245	697
K919-93	III	29.67	1021	665	1450	1386	356	785
K919-80	III	30.33	759	494	1186	1163	265	692
K919-76	III	27.00	844	522	1392	1371	323	870
K919-73	III	29.00	824	550	1390	1425	273	840
K919-63	III	30.33	882	608	1478	1441	275	871
K919-56	III	30.33	858	592	1406	1404	266	814
K919-43	III	33.33	632	423	1215	1256	210	792
K919-42	III	28.33	1059	678	1503	1471	382	826
K919-33	III	30.67	791	519	1286	1239	271	767
K919-26	III	30.67	716	503	1278	1222	213	775
M53	III	32.33	1040	691	1534	1495	348	842
K919-128	I	31.00	876	582	1516	1453	294	934
K919-126	I	31.00	817	627	1637	1576	190	1010
K919-114	I	32.33	264	174	581	568	90	407
K919-109	I	30.67	959	632	1431	1349	327	799
K919-105	I	31.00	893	576	1471	1409	318	895
K919-104	I	31.00	1104	723	1645	1582	381	922
K919-100	I	31.67	650	441	1307	1253	210	866
K919-91	I	30.67	761	572	1521	1442	188	949
K919-60	I	46.00	506	391	1169	1116	115	777
K919-44	I	30.67	872	578	1492	1411	294	915
K919-35	I	32.33	731	462	1351	1300	269	889
K919-11	I	31.33	645	476	1332	1264	170	856
K919-25	I	31.33	887	627	1644	1548	259	1017
M107	I	31.67	817	530	1429	1348	287	899
CV(%)		17.19	10.60	8.85	8.95	9.44	17.14	11.22
LSD		7.328	116.8620	65.7291	168.6007	171.4914	61.6842	127.9376

A=Beginning of gelatinisation B=Maximum viscosity D=Start of cooling period E=End of cooling period

F=End of final holding B-D=Breakdown E-D=Setback CV=Coefficient of variation LSD=Least significant difference

Table 6.2 Mean squares for measured viscosity parameters in sorghum

Groups	Source	A	B	D	E	F	B-D	E-D
Across groups	Blocks	5.583ns	26278*	26329**	96200**	47623*	3058ns	25449*
	Entries	30.48ns	88795***	36033***	126088***	113889***	15340***	40525***
Group I	Blocks	31.6ns	435776*	34192**	160190**	122902**	4162ns	48726**
	Entries	47.3ns	129180**	54750**	221485**	196420.**	21190**	66025**
Group III	Blocks	7.5ns	448ns	1992ns	2490ns	28241*	916.ns	1980ns
	Entries	7.5ns	46576	18533**	38573**	40102**	7793**	11407ns

A=Beginning of gelatinisation B=Maximum viscosity D=Start of cooling period E=End of cooling period F=End of final holding period ns=Non-significant * $p \leq 0.05$, ** $p \leq 0.01$ ***$p \leq 0.001$

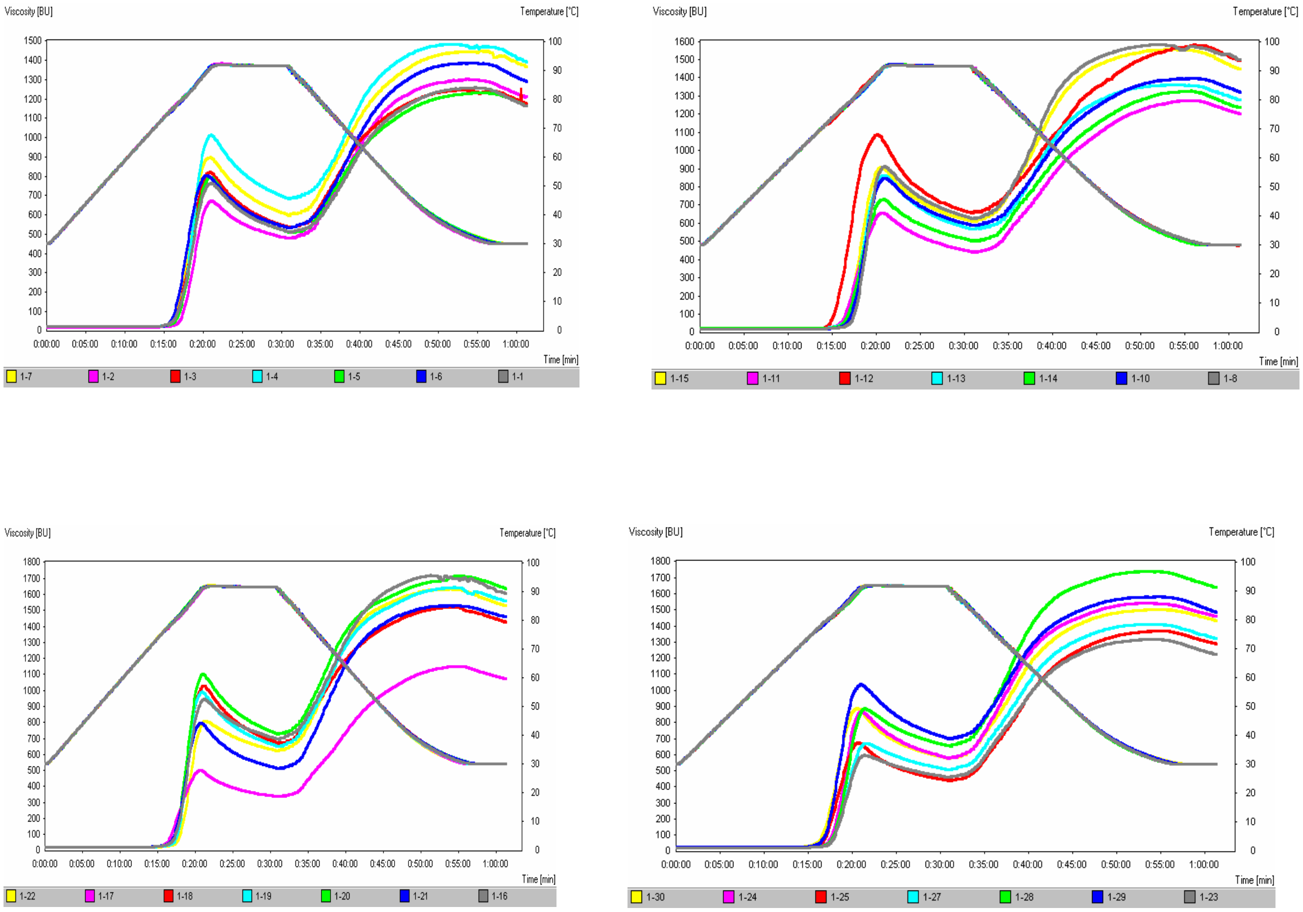
Table 6.3 Correlation coefficients among viscosity parameters in sorghum

	A	B	D	E	F	Breakdown
B	-0.2171*					
D	-0.1674 ns	0.9576*				
E	-0.1161ns	0.8173*	0.8761**			
F	-0.1280ns	0.8018**	0.8470**	0.9726**		
Breakdown	-0.2563*	0.9056**	0.7451**	0.6025**	0.6096**	
Setback	-0.0507ns	0.5431**	0.6046**	0.9137**	0.8929**	0.3673**

A=Beginning of gelatinisation B=Maximum viscosity D=Start of cooling period E=End of cooling period F=End of final holding period ns=Non-significant * $p \leq 0.05$, ** $p \leq 0.01$

Figure 6.1 Representation of viscosity parameters of 28 sorghum genotypes in three replications yielded by the Brabender® Viskograph “E’.

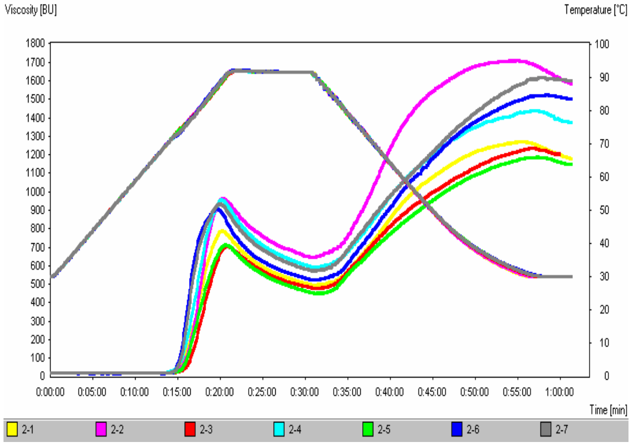
Replication 1

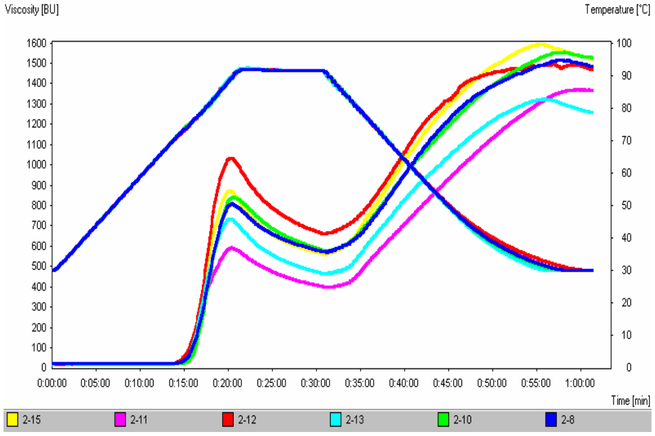


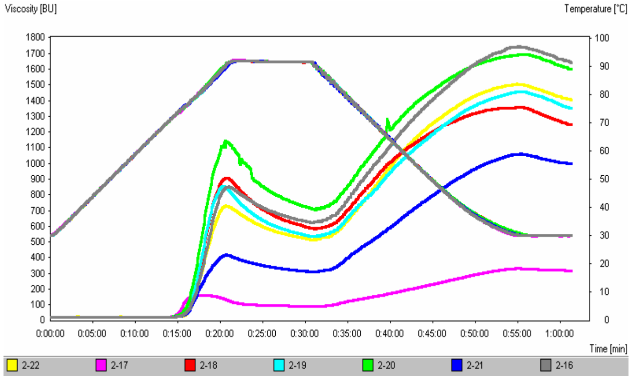
Genotype representation

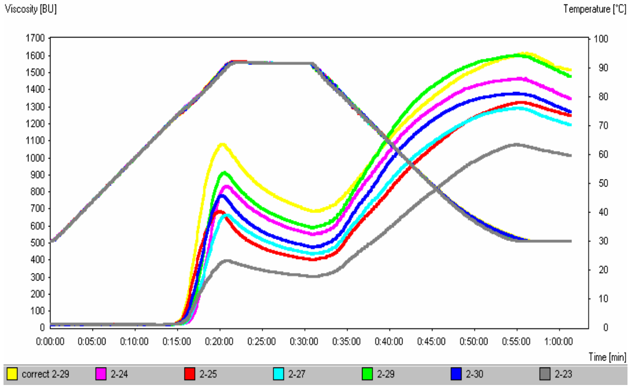
1-1=K919-116, 1-2=K919-106, 1-3=K919-94, 1-4=K919-93, 1-5=K919-80, 1-6=K919-76, 1-7=K919-73, 1-8=K919-63, 1-10=K919-56, 1-11=K919-43, 1-12=K919-42, 1-13=K919-33, 1-14=K919-26, 1-15=K919-128, 1-16=K919-126, 1-17=K919-114, 1-18=K919-109, 1-19=K919-105, 1-20=K919-104, 1-21=K919-100, 1-22=K919-91, 1-23=K919-60, 1-24=K919-44, 1-25=K919-35, 1-27=K919-11, 1-28=K919-25, 1-29=M53, 1-30=M107

Replication 2





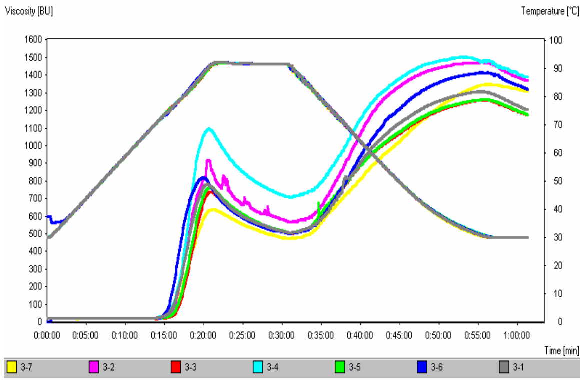


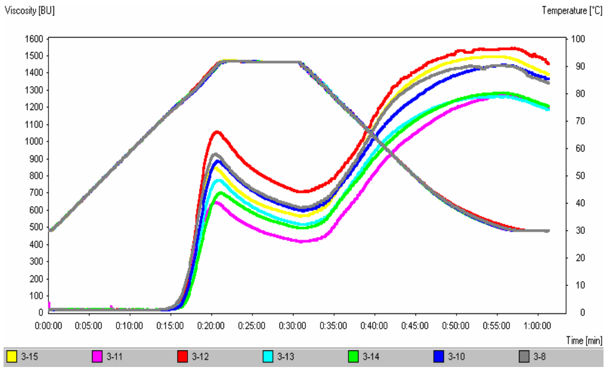


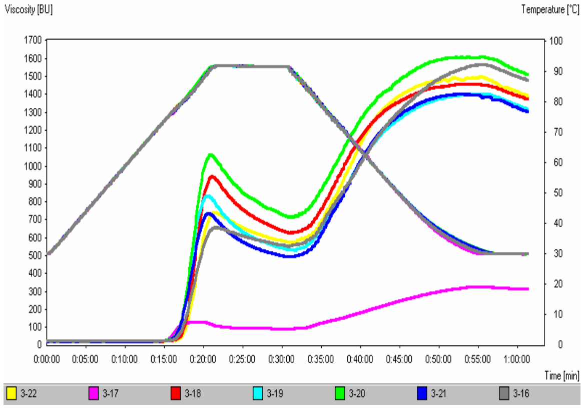
Genotype representation

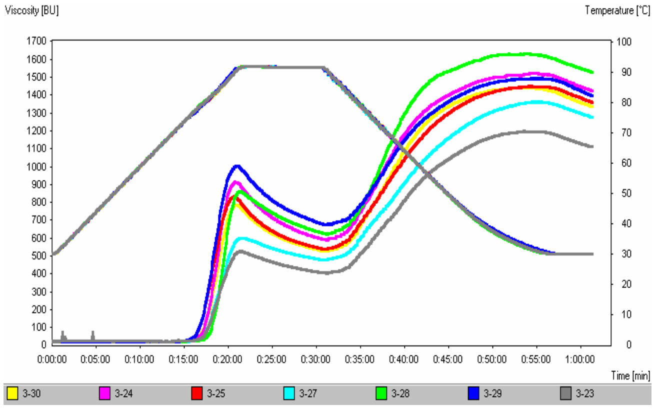
2-1=K919-116, 2-2=K919-106, 2-3=K919-94, 2-4=K919-93, 2-5=K919-80, 2-6=K919-76, 2-7=K919-73, 2-8=K919-63, 2-10=K919-56, 2-11=K919-43, 2-12=K919-42, 2-13=K919-33, 2-15=K919-128, 2-16=K919-126, 2-17=K919-114, 2-18=K919-109, 2-19=K919-105, 2-20=K919-104, 2-21=K919-100, 2-22=K919-91, 2-23=K919-60, 2-24=K919-44, 2-25=K919-35, 2-27=K919-11, 2-28=K919-25, 2-29=M53, 2-30=M107

Replication 3









Genotype representation

3-1=K919-116, 3-2=K919-106, 3-3=K919-94, 3-4=K919-93, 3-5=K919-80, 3-6=K919-76, 3-7=K919-73, 3-8=K919-63, 3-10=K919-56, 3-11=K919-43, 3-12=K919-42, 3-13=K919-33, 3-14=K919-26, 3-15=K919-128, 3-16=K919-126, 3-17=K919-114, 3-18=K919-109, 3-19=K919-105, 3-20=K919-104, 3-21=K919-100, 3-22=K919-91, 3-23=K919-60, 3-24=K919-44, 3-25=K919-35, 3-27=K919-11, 3-28=K919-25, -29=M53, -30=M107

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CHAPTER 7

General conclusions and recommendations

Genotypes were highly significantly different with respect to their yield potential. In a given location a wide yielding range among genotypes was observed. The present study showed a highly significant GXE interaction, which caused changes in rankings for cultivars. This shows that stability analysis of these genotypes should be done in the future. On average, the white-seeded cultivars produced higher yields compared to the brown-seeded cultivars in both locations. High yield is important when planting in different environments, therefore the white seeded-genotypes can be recommended to the farmers.

Brown-seeded genotypes showed less bird damage in Potchefstrom than the white-seeded genotypes, while non-resistance was observed in Taung for all the cultivars. Tannin content can protect genotypes from being eaten by birds, however, delaying harvesting time, and scarcity of other foods around results in birds eating both low tannin and high tannin grains.

On average, the white seeded-genotypes had harder grains in all the methods of analysis used (TADD and visual analysis of endosperm), though some brown-seeded cultivars performed similarly to the white seeded-genotypes. All genotypes with harder endosperm produced better milling yield and flour colour. In terms of viscosity, the white seeded-genotypes also showed higher viscosity in all the parameters measured, and showed better holding capacity when heating at high temperature for a few minutes compared to group III. Though the consumer preferences differs with the geographical area, grain producing higher milling yields, lighter flour colour and higher viscosity seems to be common. Therefore white-seeded genotypes can serve these basic preferences.

CHAPTER 8

Summary

Grain sorghum is an important cereal crop for food security in developing countries. The crop is mainly preferred due to its adaptability to harsh environments including extreme temperatures and water limiting environments. However, for grain sorghum to compete equally with maize, certain improvements must be made. The objectives of the study were to measure the 1) yield potential of genotypes 2) identify bird-resistance genotypes 3) compare Group I and Group III genotypes in terms of food quality characteristics. Thirty genotypes including two standards, developed by the Agricultural Research Council, Potchefstroom, South Africa were used. These genotypes were planted in Potchefstroom and Taung, in the North West province of South Africa. The experiment was laid out in a randomized complete block design with three replications.

Data collected for yield potential included grain yield, seed weight per panicle, full panicle weight, and thousand seed mass. Data was analyzed per location and across locations using Agrobase, 2000. The results showed highly significantly differences among genotypes in the locations and across locations in all yield characteristics measured. The interaction between entry and location was highly significant.

Genotypes were evaluated for bird resistance through the percentage grain yield loss. Percentage bird damage was highly significantly different between groups and among genotypes in Potchefstroom. The damage was severe in group I compared to group III. Taung resulted in 100% bird damage.

Two hundred and fifty gram per sample was assessed in a Tangetial Abrasive Dehulling Device for abrasive hardness index (AHI), followed by milling and flour color assessment. The samples were not replicated except for endosperm texture, and grand means were used to compare the groups. Group I performed better than group III in terms of milling yields, flour color, AHI, percentage kernel removed and endosperm texture. These milling quality characteristics showed significant correlation with each other and most importantly correlated with endosperm hardness. Therefore, many food quality characteristics in sorghum are determined by endosperm texture. A 12% solution (flour and water) was used to analyze viscosity of the porridge using the Brabender ® Viskograph 'E'. The response of genotypes during cooking showed highly significant differences. Groups were highly significantly different for maximum viscosity, start of cooling period, breakdown, and setback and non-significant for beginning of gelatinization, end of cooling period, and end of final holding. Viscosity parameters measured were positively correlated to each other.

Opsomming

Graansorghum is ‘n belangrike graangewas vir voedselsekuriteit in ontwikkelende lande. Die gewas word verkies omdat dit aangepas is in marginale toestande met hoë temperature en vogstremming. Maar vir graansorghum om te kompeteer met mielies moet daar sekere verbeterings gemaak word. Die doelwitte van hierdie studie was om te bepaal 1) Wat die opbrengspotensiaal van die genotipes is 2) Of daar voël weerstandige genotipes is 3) Om Groep I en Groep III genotipes te vergelyk vir hulle voedselkwaliteits eienskappe. Dertig genotipes, insluitend twee standaarde, wat ontwikkel is deur die Landbou Navorsingsraad, Potchefstroom, Suid Afrika, is gebruik. Die genotipes is geplant in Potchefstroom en Taung, in die Noordwes provinsie van Suid Afrika. Die eksperiment is uitgelê as ‘n gerandomiseerde blokontwerp met drie herhalings.

Data wat versamel is om opbrengspotensiaal te meet is graanopbrengs, saadmassa per panikel, vol panikel massa en duisend saad massa. Data is geanaliseer per lokaliteit en oor lokaliteite met Agrobase98 LAN. Die resultate het hoogs betekenisvolle verskille tussen genotipes binne en tussen lokaliteite aangetoon vir alle gemeette eienskappe.Die interaksie tussen inskrywing en lokaliteit was hoogs betekenisvol.

Genotipes is geëvalueer vir voël weerstand deur persentasie graanverlies te bepaal. Persentasie voëlskade was hoogs betekenisvol verskillend tussen groepe en tussen genotipes vir Potchefstroom. Die skade was baie hoog in groep I genotipes in vergelyking met die in groep III. Taung het 100% voëlskade gehad.

Tweehonderd en vyftig gram per monster is geëvalueer in ‘n “Tangetial Abrasive Dehulling Device” om abrasie hardheids indeks te bepaal (AHI), gevolg deur maal em meelkleur assessering. Hierdie analises is nie gerepliseer nie, behalwe die endosperm hardheid, en die gemiddeldes is gebruik om groepe te vergelyk. Group I het beter presteer as groep III in terme van maal opbrengs, meelkleur, AHI, persentasie van die sade verwyder en endosperm tekstuur. Hierdie maaleienskappe was betekenisvol met mekaar gekorreleer en dan baie belangrik was dit met endosperm hardheid gekorreleer. Daarom

kan heelwat kwaliteitseienskappe afgelei word van die endosperm tekstuur. ‘n Twaalf persent oplossing (meel en water) is gebruik om viskositeit te analiseer van pap met ‘n Brabender ® Viskograph ‘E’. Die verskille tussen genotipes tydens die kookproses was hoogs betekenisvol. Groepe was ook hoogs betekenisvol verskillend vir maksimum viskositeit, begin van afkoelingstyd, afbreek, and omkeer maar nie betekenisvol vir begin van gelatinisering, einde van afkoeling, en die finale houtyd nie. Die viskositeits eienskappe was positief met mekaar gekorreleer.