Development of a database of sorghum cultivars in southern Africa, with emphasis on end-use quality, particularly brewing quality

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DECLARATION

I declare that the dissertation here with submitted for the degree MSc Food Science at the University of Pretoria, has not previously been submitted by me for a degree at any other university or institution of higher education.

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DEDICATION

This dissertation is dedicated to God the Father, God the Son and God the Holy Spirit for granting me the opportunity to get to this level, despite all odds. To my parents, siblings, my wife (FOLUWAKE) and to everyone that supported me spiritually, financially and morally, thank you all for the love.

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ABSTRACT

Development of a database of sorghum cultivars in southern Africa, with emphasis on end-use quality, particularly brewing quality

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Degree: MSc Food Science

The level of sorghum production in southern Africa is very low compared to the rest of Africa. Low adoption rate of available improved sorghums due to lack of information about their properties has been identified as a problem. This problem may have contributed to the low level of sorghum production and utilisation. A database on agronomic properties, grain, and processing and end-use quality attributes of sorghum cultivars available in southern Africa was developed in order to improve adoption rate of these improved sorghums. This database information was provided for easy access to both sorghum producers and processors, which will ensure improvement in sorghum production and utilisation. A total of 51available improved sorghum cultivars were included in the database. However, the available information on the end-use quality of the sorghum cultivars is limited, especially with regard to selection of suitable cultivars for specific applications, such as adjunct in lager beer brewing.

Identification of suitable sorghum type(s) as for use as adjunct in lager beer brewing remains an aspect yet to be systematically researched, which will enable selection of suitable sorghum type(s).Five different sorghum types were selected for determination of their grain and lager beer

wort quality properties. The types were white tan-plant, white non-tan plant, red non-tannin, white tannin (type II) and red tannin (type III). Grain hardness ranged from corneous to floury, with non-tannin types having mostly corneous to intermediate endosperm. The tannin sorghum types had mostly floury endosperm, as expected. The sorghum types with floury endosperm had higher protein content than the corneous endosperm types. Grain tannin content was up to 45.3 g catechin equivalent/100 g, which contributed significantly to the level of total phenols in the grain. Wort samples were produced by mashing the milled sorghum with exogenous enzymes. The wort quality attributes was mostly influenced by the grain tannin property, which correlated significantly and negatively as follows: wort extract ($p<0.001$, r = -0.846), fermentable sugars ($p<0.001$, r = -0.810) and FAN ($p<0.1$, r = -0.498). This poor wort quality can be linked to tannin inactivation of the exogenous enzymes during mashing.

Tannin inactivation by steeping in a dilute NaOH solution did not consistently improve wort quality. Contrary to expectations, tannin still remained significantly and negatively correlated with wort quality attributes, but with slightly lower correlation coefficients. Sorghum malting combined with exogenous enzymes mashing yielded great improvement in wort quality. Decortication of tannin sorghums, as well as compositing with white tan-plant types can be considered in the application of tannin sorghum types as adjunct. The red non-tannin sorghums, in terms of wort extract, FAN and fermentable sugars have potential as adjunct in lager beer brewing, due to their similar wort quality attributes to white tan-plant sorghums. Brewing trials with red non-tannin sorghum types is necessary in order to determine their beer brewing and beer quality properties in comparison with white tan-plant sorghums, which are currently used commercially.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

Sorghum (*Sorghum bicolor* (L) Moench), is the fifth most important cereal after rice, wheat, maize and barley (FAO, 2010) and the most popular indigenous African cereal grain. Sorghum is widely cultivated across the African continent, which is characterised by both semi-arid and arid sub-tropical conditions (Taylor, 2003). In Africa, sorghum is the second most important cereal grain produced and serves as major staple food for millions of people in the semi-arid tropics of Asia and Africa (FAO, 2010). In the world at large, sorghum total production in 2009 was about 62 million tons with a yield of about 1.42 tons/ha(FAO, 2011). The total production in 2009 for Africa was estimated to be around 27 million tons and a low yield of about 0.98 tons/ha. This is because sorghum is still mostly produced by small-scale subsistence farmers, who have limited access to production inputs such as improved seeds (hybrids or open-pollinated varieties (OPV)) (FAO, 2010).

Sorghum still remains an under-utilised resource in Africa (Taylor, Schober and Bean, 2006). This is because level of production and utilisation largely remain at the subsistence farming system level. The South African Sorghum Section 7 Committee (2007) recommended the use of improved hybrid and OPV varieties as a means of boosting competitiveness and profitability of sorghum. According to Obilana (1998), 27 improved varieties had been released in eight Southern African Development Community (SADC) countries and 9 (33%) were being cultivated in six countries of the region. Chisi (2003) also reported a similar trend which revealed that adoption rate of available improved varieties and cultivars by intended users in the SADC region is very low. Lack of well organised and adequate information was reported as one of the factors limiting level of adoption of these improved sorghum varieties and cultivars in southern Africa (Chisi, 2003). A database that will provide information on agronomic and environmental requirements, plant type, and grain quality attributes of these sorghum varieties and cultivars is needed. Gopal Reddy, Upadhyyaya and Gowda, (2006) also supported the need for a system of well organised documentation of information with respect to sorghum germplasm collections in breeding programmes.

Large-scale commercial production of sorghum in southern Africa is mostly for brewing and in the 1990s about 200,000 tons of grain was malted to produce 3000 million litres of opaque beer (home and commercial) (Beta and Dzama, 1997). According to the report of South African Sorghum Section 7 Committee (2007), the opaque beer market is declining due to consumer trends towards drinking clear beer (lager beer) resulting from improvements in personal income. Clear beer brewing has been identified as a more viable market capable of boosting sorghum utilisation with respect to improved cultivars (Larson and Erbaugh, 2007). Ezeogu (2007) also noted the need for determination of sorghum cultivar differences as one of the means of improving sorghum malting and brewing quality potential. Therefore evaluation with regard to grain quality attribute characterisation, as well as brewing quality potential to determine the suitability of these improved sorghum varieties and cultivars in southern Africa is necessary.

The main aim of this study is to improve utilisation of sorghum in southern Africa through comprehensive appraisal of the available improved sorghum cultivars, by providing adequate and accessible information regarding grain quality attributes as well as their clear beer brewing quality properties.

2. LITERATURE REVIEW

Sorghum grain crop improvement with regard to production, availability, utilisation and consumption can serve as a major key to addressing food security and nutrition problem in Africa (FAO, 2010). This is because the level of sorghum production compared with other major cereal grains is very low and erratic. As stated, low productivity of sorghum has largely contributed to its under-utilisation in southern Africa compared to the rest of Africa. The intensity of sorghum grain quality attribute characterisation has also been reported to impact on the level of end-use diversification (Serna-Saldivar, 2010). Therefore, this review will focus on improvement strategies already adopted to boost sorghum utilisation in southern Africa.

2.1 SORGHUM BREEDING, PRODUCTION AND UTILISATION IN SADC

Sorghum is an important traditional African cereal crop and a viable food grain for food security (Chisi, 2003; Taylor and Emmambux, 2008). This is due to sorghum's useful agronomic characteristics. The important ones are drought-tolerance and the ability to grow in low rainfall regions. Total sorghum production in southern Africa was about 320,000 tons in 2009 (FAO, 2011). In comparison with the rest of Africa, southern Africa has the lowest sorghum production level (Table 2.1). This level of sorghum production has limited large-scale commercial utilisation, with the exception of opaque beer brewing in Zimbabwe and South Africa (Dendy, 1995). However, sorghum has major utilisation for traditional food and beverage consumption in tropical areas and as feed in temperate areas (House, Osmanzai, Gomez, Monyo and Gupta, 1995). Examples of such products are sorghum meal, sorghum rice, and malt (for production of sorghum beer) (Sorghum Section 7 Committee, 2007).

Table 2.1: Total sorghum production in 2009 for southern Africa compared to the rest of Africa (Data Source: FAO (2011))

Africa Region	Production (tons)	Yield (tons/ha)
Southern Africa	322,541	1.99
Middle Africa	1,342,019	0.94
Northern Africa	5,085,659	0.74
Eastern Africa	5,265,724	1.18
Western Africa	15,149,694	1.02

2.1.1 Sorghum improvement programmes in SADC

The following factors were identified by farmers in the SADC region as major constraints to sorghum production: drought, diseases such as stem borer, bird damage, soil fertility and seed availability (Haussamann, Obilana, Ayiecho, Blum, Schipprack and Geiger, 2000).Through extensive breeding programmes, SADC in collaboration with the International Crops Research Institute for Semi-Arid Tropics (ICRISAT)/ Sorghum and Millet Improvement Programme (SMIP) released a large number of improved sorghum varieties (Heinrich and Mgonja, 2002). These improved varieties have disease- and pest-resistance, and in conjunction with good management practices are naturally sustainable (Chisi, 2003). Other needs targeted were early maturity, grain and fodder productivity as well as end-use quality (Obilana, 1998). According to Heinrich and Mgonja (2002), SMIP activity also resulted in the development of varieties suitable for industrial use. SMIP was also involved in evaluation of adoption rate of these improved varieties by farmers.

In addition to sorghum production improvement strategies in SADC region, adoption of regionalised breeding system was identified as suitable approach to national agricultural research system (NARS) (Mgonja, Chandra, Gwata, Obilana, Monyo, Rohrbach, Chisi, Kudita and Saadan, 2005). These authors justified the need for this new approach based on the genotype and environment interaction effect (GxE), which is influence of environment on the performance of individual genotypes as released differently by the NARS of individual countries. It was noted that southern Africa region is grouped based on the length of growing period (LGP) (period when water and temperature regimes allow crop growth), as well as period of continuous rainfall more than half of the potential evapo-transpiration not including the time when the temperature is below the level required for crop growth. This approach will enable wider adaptation of sorghum based on this new breeding programme in order to boost its production across the SADC region.

2.2 TYPES OF SORGHUM VARIETIES AND CULTIVARS

Sorghum (*Sorghum bicolor* (L) Moench) from the family *Poaceae*, tribe *Andropogoneae*, genus of *Sorghum* and species of *bicolor* is the primary cultivated specie (House, 1995). Sorghum has five basic races. They are durra, kafir, guinea, bicolor and caudatum (House, 1995). There are 10 hybrid races: *guinea-bicolor, caudatum-bicolor*, *kafir-bicolor, durra-bicolor*, *guinea-caudatum*, *guinea-kafir*, *guinea-durra*, *kafir-caudatum*, *durra-caudatum* and *kafir-durra*. They can be differentiated by mature spikelet traits as well as head type properties. Kafir and its hybrid races are majorly contributed by most of the SADC countries, with exception of Zimbabwe that has all the five basic and 10 hybrid races (Gopal Reddy *et al*., 2006).

According to Serna-Saldivar and Rooney (1995), sorghum varieties and cultivars can be grouped into four categories on the basis of utilisation. They are grain sorghum, forage sorghum, grass or Sudan sorghum and broomcorn. The grain sorghum group can be further classified into different categories, which are based on kernel characteristic differences. These kernel characteristics include grain size, shape, pericarp colour, testa, and endosperm texture (Rooney and Miller, 1982). Based on grain colour and the presence of condensed tannins, sorghum cultivars can be classified either as white-tan, red/yellow, or brown (tannin) sorghum (Serna-Saldivar, 2010). According to the United States Grain Standards, grain sorghum are classified as non-tannin, tannin and mixed sorghum (Waniska, Rooney and McDonough, 2004). This is based on the presence or absence of pigmented testa in the kernel (Rooney and Serna-Saldivar, 2003). In southern Africa, only Botswana, South Africa and Zimbabwe have in place grading and standards systems for sorghum (Taylor and Duodu, 2009). In South Africa, sorghum cultivars are classified based on malting quality in terms of malt diastatic power (total amylase activity), but there is no specification system developed for milling quality.

2.3 SORGHUM GRAIN STRUCTURE AND CHEMICAL COMPOSITION

2.3.1 Kernel structural attributes

Sorghum has a naked kernel (caryopsis) with a 1000 kernel weight varying from 5 to 80 g (Serna-Saldivar and Rooney, 1995). The kernel consists of three key parts: the pericarp (outer covering), the endosperm (starch-rich storage tissue) and the germ (embryo). The relative proportion of these parts varies based on the influenced of genetic and environmental factors (Rooney and Miller, 1982). The following kernel attributes differentiate varieties of sorghum from another: pericarp colour and thickness, presence or absence of pigmented testa, endosperm texture and colour (Beta, Rooney, Marovatsanga and Taylor, 1999). Sorghum varieties having pigmented testa layer are known to contain condensed tannins (Awika and Rooney, 2004; Beta *et al*., 1999), such varieties of sorghum are classified as tannin sorghum. The presence of pigmented testa layer is determined by the presence of $\boldsymbol{B_1\_B_2\_}$ genes.

The sorghum pericarp compared to that of maize is more bran-like, and contains starch granules in the cells (Taylor and Duodu, 2009). Sorghum varieties with a thick pericarp possess three to four mesocarp cell layers containing small starch granules (Serna-Saldivar and Rooney, 1995). Pericarp thickness is controlled by the *Z* gene, which also contributes to the kernel appearance (Rooney and Serna-Saldivar, 1991). The following kernel structural attributes such as size, shape, hardness and germ placement have influence on sorghum grain quality with regard to processing properties, food and feed quality (Rooney and Miller, 1982), as well as the kernel colour attributes (Taylor and Duodu,2009). The sorghum kernel colour attribute is mostly influenced by the type of polyphenolic pigments present in the pericarp. They are genetically determined. The colour attribute can also be environmentally modified as a result of weathering.

2.3.2 Sorghum grain chemical attributes

The proximate composition of sorghum grain is both genetically and environmentally influenced (Serna-Saldivar and Rooney, 1995). Sorghum contains a number of phytochemicals such as phenolic compounds, phytosterols and policosanols (Awika and Rooney, 2004). The polyphenols in sorghum comprise two main groups: phenolic acids and flavonoids. The level of these phenolic compounds contained in particular sorghum cultivars is genetically and environmentally influenced (Dicko, Gruppen, Traore, Voragen and van Berkel, 2006; Dykes and Rooney, 2006), which leads to cultivars with varying grain quality attributes. According to Dykes and Rooney (2006), all varieties of sorghum contain phenolic acids, while most varieties contain flavonoids and the varieties with pigmented testa contain condensed tannins. Pigmented sorghum varieties possess anthocyanins, because they are majorly responsible for grain pericarp colour attributes (Wrolstad, 2004).

The common types of anthocyanins in sorghum are 3-deoxyanthocyaninssuch as apigeninidin and luteolinidin, which lack an OH group in the C-3 position (Awika, Rooney and Waniska, 2004). According to studies conducted by Awika *et al*. (2004), levels of extractable anthocyanins in sorghum vary with cultivar. Black sorghum has more than twice the level in red and brown sorghums. The tannin in tannin sorghum distinguishes sorghum from other cereal grains (Taylor and Duodu, 2009). Sorghum cultivars with a prominent pigmented testa contain condensed tannins, which comprise proanthocyanidins and procyanidins. Condensed tannins are genetically determined due to presence of B_1-B_2 genes (Serna-Saldivar and Rooney, 1995). Sorghum also contains pro-deoxyanthocyanidins such as pro-luteolinidins and pro-apigeninidins (Dicko *et al*., 2006).
Sorghum grain like other cereals is primarily made up of starch. The starch component of sorghum grain is about 60-77% (average of 73.7%) (Serna-Saldivar, 2010). The normal sorghum starch has between 23-30% amylose, while the waxy sorghum type contains less than 5% amylose (i.e. more than 95% amylopectin) (Serna-Saldivar and Rooney, 1995). This variation with regard to amylose/ amylopectin ratio is genetically influenced. Beta and Corke (2001) noted significant influence of environmental factors on the following sorghum starch properties: pasting, textural and thermal properties. Beta, Corke, Rooney and Taylor (2001) reported that polyphenol content as well as the kernel structure of sorghum varieties has an influence on starch properties. They stated that starch coloration might have resulted from complex formation and oxidative reactions with the polyphenols present.

2.4 PRIMARY USES OF SORGHUM IN SOUTHERN AFRICA AND QUALITY ATTRIBUTES NEEDED

2.4.1 Sorghum Meal and Flour

Sorghum meal and flour with coarse and fine particles respectively, are produced through dry milling (Taylor and Duodu, 2010). They both have unique areas of application. Sorghum meal is utilised in porridges and flour for baked products. The dry milling process involves abrasive removal of the pericarp and germ and then physical separation of the dry milled fractions (Rooney and Serna-Saldivar, 1991). In southern Africa, sorghum grain is mostly utilised in traditional foods such as fermented and unfermented, thin and thick porridges (Murty and Kumar, 1995). These stiff and fermented porridges are common in South Africa, while the unfermented type is common in Botswana, Malawi, Zambia and Zimbabwe. Taylor and Emmambux (2008) reported dumplings (called Dinkqwa in South Africa) as another product produced using sorghum meal and flour.

2.4.1.1 Quality attributes required in porridge-making

The milling quality of sorghum grain is majorly affected by endosperm hardness, which is influenced by the adhesion of the starch and protein components of the endosperm (Taylor and Duodu, 2010). The sorghum kernel attributes preferred in sorghum meal for porridge-making are thick pericarp and corneous endosperm texture, because they are easier to hand-decorticate (Rooney and Serna-Saldivar, 1991) and also give a higher yield of sorghum endosperm meal (Serna-Saldivar, 2010). The following quality parameters are important with regard to the porridge-making application of sorghum: colour, texture and keeping quality (Rooney, Earp and Khan, 1982). According to Lee, Pedersen and Shelton (2002), consumers prefer porridges with relative firmness and non-sticky quality, as well as good keeping quality.

The endosperm starch property of the grain is another factor that influences the porridge making quality of sorghum cultivars (Taylor, Dewar, Taylor and von Ascheraden, 1997). According to Murty and Kumar (1995), the porridge colour quality preferred is white or yellow porridge. In southern Africa, tannin and non-tannin sorghum may be mixed together and utilised in porridge making (Awika and Rooney, 2004). The tannin sorghums contribute natural and attractive dark colour, and antioxidants to the porridge (Dykes and Rooney, 2006).

2.4.1.2 Methods of analysis of quality attributes

The tannin property of sorghum grain can be qualitatively determined by using the chlorox bleach test (Taylor and Duodu, 2009). This test is to differentiate tannin sorghum from non-tannin sorghum. The tannin sorghum will give a pronounced black colour due to the oxidation of the pigmented testa. The non-tannin sorghum reflects a light yellowish colour. Taylor and Duodu (2009) noted that this test can give false results with regard to non-tannin sorghum that might have experienced weathering. The grain colour attribute is mostly evaluated based on visual examination (Taylor and Duodu, 2009). Selection criteria for suitable sorghum cultivars with good milling and porridge-making qualities are based on the evaluation of kernel hardness attributes and endosperm starch properties (Taylor *et al*., 1997). This is due to their influence on the final porridge quality, as stated above.

According to Taylor and Duodu (2010), sorghum kernel hardness is related to kernel density. The latter can be determined by test weight (hectolitre weight). The kernel hardness property can be determined directly by using the Tangential Abrasive Dehulling Device (TADD). Test procedures as described by Taylor and Duodu (2009) can be followed. As mentioned, endosperm starch characteristics include amylose content and pasting properties (such as pasting peak viscosity (PPV) and set-back viscosity (SBV)). These starch attributes of the grain contributes to its porridge-making quality in terms of stiffness and keeping quality. The pasting properties can be measured using the Rapid Visco Analyser (RVA) (Taylor *et al*., 1997; Lee *et al*., 2002). The test procedures described according to AACC Method 61-02 Determination of the Pasting Properties of Rice with RVA can be applied (American Association of Cereal Chemists (AACC) International, 2000). Amylose content of the starch can be evaluated based on iodine binding capacity method described by Juliano, Perez, Blakeney, Castillo, Kongseree, Laignelet, Lapis, Murty, Paule and Webb (1981). According to Bao, Cai and Corke (2001), a more rapid technique of measuring starch properties such as amylose content, RVA pasting attributes, textural and thermal properties has been developed based on Near-infrared reflectance spectrometry (NIRS). It is sufficiently accurate for multi-sample selection screening.

2.4.2 Animal feed

Sorghum is high in starch and this makes it a good feed source for livestock. This is because starch serves as the primary energy source in ruminant animal diets, which is required for high level of production (Theurer, 1986). Feed efficiency in non-tannin sorghum is about 95% the feeding value of that of yellow dent maize (Serna-Saldivar, 2010). A feeding value between 80 and 85% was reported for tannin sorghum compared to maize by Streeter, Wagner, Owens and Hibberd (1989), which requires the animals to feed more in order to produce the same amount of weight gain. According to these authors, though evidence is limited, the lower feeding value of sorghum compared to maize could be linked to effects of grain endosperm type impacting on sorghum digestibility in the animal. Their studies on the effect of sorghum cultivar differences showed that starch digestibility is higher in waxy endosperm than normal endosperm varieties. Similar results were reported by Rooney and Serna-Saldivar (2000) with regard to protein digestibility, which is high in waxy type sorghum. Sorghum, when compared to maize is generally slightly higher in protein but lower in energy and protein digestibility (Serna-Saldivar, 2010). The difference between waxy sorghum and normal sorghum may be due to it possessing a weaker protein matrix compared to the tough sub-aleurone protein-rich layer in normal sorghum cultivars.

2.4.2.1 Quality attributes required

Feed quality parameters that contribute to efficiency of feed utilisation (feed value) in animal feeding with sorghums are as follows: feed conversion, digestibility, as well as energy and protein value of the feed (Kamalzadeh, van Bruchem, Koops, Tamminga and Zwart, 1997; Campling, 1991; Owens, Zinn and Kim, 1986). All these quality parameters can be influenced by the grain quality properties. Condensed tannin content of the grain alters the efficiency of sorghum feed utilisation, due to tannin interaction with grain proteins and hydrolytic enzymes of the digestive tract (Taylor and Duodu, 2009). This leads to low digestibility in tannin sorghum cultivars. The starch in sorghum grain has low digestibility compared to maize (Taylor and Emmambux, 2010). This contributes to lower energy value which has been linked to the following grain quality attributes. Sorghum grain starch has smaller and more compact starch granules (Serna-Saldivar, 2010), as well as a tough protein matrix and the inhibiting effect of tannins (where present) on enzymatic hydrolysis of starch (Taylor and Emmambux, 2010). The effect of protein quality of sorghum cultivars on energy and protein digestibility was reported by

Sullivan, Knabe, Bockholt and Gregg (1989). They noted that cultivars with improved protein quality gave higher nutritional value. Therefore, sorghum cultivars with less hard endosperm textural properties coupled with high protein quality is best suitable as animal feed. The lysine quality of sorghum protein is a major factor of consideration in monogastric animal feed formulation (Amira, 1992). Feed formulation with lysine-deficient sorghums required supplementing with synthetically produced amino acids in order to balance the rations (Amira, 1992). The recent availability of improved sorghums with high lysine content will improve sorghum utilisation in poultry and pig feeding.

2.4.2.2 Methods of analysis of quality parameters

According to Theurer (1986), starch digestibility is the major animal feed quality parameter of cereal grains. As noted by Huhtanen and Sveinbjornsson (2006), starch is the major energy yielding component of cereal grains. These authors evaluated different methods that can be applied in estimating starch digestibility and digestion kinetics of the feed in animals. They found that starch digestibility and digestion kinetics parameters can be estimated by mechanistic modeling of the actual rumen environment. This is an *in situ* technique and the procedure is described by Huntington and Givens (1995). Pedersen, Milton and Mass (2000) recommended a more precise and rapid technique, which can be applied by feed grain breeders in evaluating changes in grain digestion parameters. This is a twelve-hour *in vitro* procedure based on rate of starch disappearance. The analysis only measures dry matter digested. Protein quality with regard to lysine content of the grain can be analysed based on the AACC Method 07-01 Measurement of Acid-Stable Amino Acids (AACC International, 2000). Protein digestibility of the grain can be determined using an *in vitro* assay employing mammalian digestive proteolytic enzyme pepsin, as described by Hamaker, Kirleis, Butler, Axtell and Mertz (1987).

2.4.3 Alcoholic and non-alcoholic beverages

In southern Africa, sorghum is applied as malt in processing of both alcoholic and non-alcoholic fermented beverages (Rooney and Serna-Saldivar, 2003), as well as adjunct (source of starch) in beer brewing (Mackintosh and Higgins, 2004). An example of non-alcoholic beverage produced using sorghum which is produced in Zimbabwe, is mahewu (Taylor and Emmambux, 2008). Sorghum malt is added to provide fermentable sugars and to slightly hydrolyse the product. Sorghum is used as malt and adjunct in the production of opaque beers (Taylor and Duodu, 2010; Taylor and Dewar, 2001). Across sub-Saharan Africa, sorghum is widely utilised in the production of traditional alcoholic beverages (Taylor, 2003), with slight variations in quality and processing from one country or region to another. Examples of the common sorghum beers produced from malted sorghum in Africa are opaque beer and pito (cloudy beer) (Palmer, 1992).

2.4.3.1 Quality attributes required

The following sorghum grain attributes are required for adjunct utilisation in lager beer brewing. They are light colour, bland flavour, and low oil content and high extract levels (Rooney and Serna-Saldivar, 1991). The starch gelatinisation temperature property of the grain also determines cultivar selection for use as adjunct in beer brewing (Gomez, Obilana, Martin, Mazvamuse and Monyo, 1997). Taylor and Duodu (2010) noted that sorghum grain with a very high uniform germination under malting conditions will yield malt of good quality. The following malt quality parameters determine sorghum malt suitability in beer brewing. They are diastatic power (DP) (amylase activity), free amino nitrogen (FAN) content and extract yield (Taylor and Duodu, 2009). However, the following cultivar related factors have been identified that limit sorghum utilisation in clear beer brewing. They are incomplete saccharification, low wort filterability and inadequate FAN (Ezeogu, 2007).These problems may be attributed to the nature of sorghum grain structure and its chemical composition.

Incomplete saccharification is due to incomplete starch hydrolysis and low production of fermentable sugars. Beta and Corke (2001) reported that the gelatinisation temperature of sorghum grown in southern Africa is between 67 and 73˚C, which is far higher than that of barley (51-60˚C). Sorghum cultivars vary in the amylose/amylopectin ratio of their starches, resulting in waxy (69.6˚C), heterowaxy (71.1˚C) and normal types (71.1-73.3˚C) (Del Pozo-Insfran, Urias-Lugo, Hernandez-Brenes and Serna-Saldivar, 2004). According to Matsuki, Yasui, Kohyama and Sasaki (2003), chain length of the amylopectin molecules influences the gelatinisation temperature as well. Longer chain length results in higher gelatinisation temperature. This high gelatinisation temperature may also result due to the complex endosperm matrix protein structure of the grain. It was reported by Duodu, Taylor, Belton and Hamaker (2003) that sorghum kafirin storage protein polymers contain complex disulphide-links. These may lead to inaccessibility of the starch granules to amylases, leading to incomplete saccharification. Notwithstanding the above, Taylor *et al*. (2006) noted the possibility of selecting and breeding sorghum varieties with lower gelatinisation temperature.

Evans and Taylor (1990) studied effect of cultivar differences of cultivars grown and malted under similar conditions on their proteinase and carboxypeptidase activities. They reported significant differences in terms of the FAN content of the malt. Similar results were reported by Demuyakor and Ohta (1993). They compared malting properties of traditional and agronomically improved sorghum varieties in Ghana. All the varieties tested varied significantly in their malt quality attributes.

2.4.3.2 Methods of analysis of quality parameters

Starch gelatinisation temperature of the grain can be determined based on the procedure described by Gomez *et al*. (1997). The principle of this test is based on the loss of birefringence and the temperature at which this occurs correspond to gelatinisation temperature. Determination of extract yield level can be analysed based on the procedure described in EBC Method 6.6 Extract Content of Maize: Enzymatic Method (EBC, 1998). This method is more applicable to sorghum, due to its high starch gelatinisation temperature compared with barley (Taylor and Duodu, 2009). The following methods of DP and FAN analyses are approved standard method in southern Africa. Determination of malt DP is based on the SABS Method 235 (Taylor and Duodu, 2009). This method is more suitable to apply in cultivar selection for malting and brewing end-use. The difference between this method and EBC method is the extraction solution, which is 2% peptone solution in order to prevent tannin inactivation of malt enzymes. The FAN analysis of the malt is based on method described by Morall, Boyd, Taylor and Van der Walt (1986), in turn based on the EBC Ninhydrin Method 4.10 FAN of Malt by Spectrophotometry (EBC, 1998). The difference is the extraction condition that is strongly acidic using trichloroacetic acid (Taylor and Duodu, 2009). This prevents proteolysis during extraction.

2.5 SORGHUM MALTING AND BREWING PROCESSES

2.5.1 Sorghum Malting

Malting serves as the basis of producing sorghum malt, which used in opaque beer (traditional sorghum beer) and clear beer brewing. The quality attributes of sorghum malt that can be produced depend on the following factors: the influence of sorghum type and variety used (Letsididi, Bulawayo, Kebakile and Ezeogu, 2008; Serna-Saldivar, 2010), as well as the malting procedures and conditions applied (Evans and Taylor, 1990; Dewar, Taylor and Berjak, 1997a, b; Dewar, Orovan and Taylor, 1997). Table 2.2 shows a comparison between sorghum grain and malt quality attributes and other cereal grains. Due to differences in morphological attributes between sorghum and barley grain (Agu and Palmer, 1998), this has led to adjustment in sorghum malting and brewing processing procedures compared to barley. For example, sorghum required higher germination temperature (Serna-Saldivar, 2010) in order to produce malt of optimal quality close to that of barley (Agu and Palmer, 1998).

Table 2.2: Grain and Malt Properties of Barley and Sorghum (Modified from Daiber and Taylor, 1995)

Properties	Barley	Sorghum	
Grain properties		Normal	Tannin sorghum
Gelatinisation temp. range (˚C)	51-60	68-78	68-78
Lipids (%)	2.9	3.3	3.3
Tannins	Very low	Absent	High
Malt properties			
Optimum malting temp. (˚C)	14-18	24-28	24-28
Malting loss (%)	7	10-20	10-20
DP (SDU[a] / g malt)	150-200	20-60	20-60
α-Amylase (% of DP[b])	18-50	60-80	60-80
Extract at 60˚C	High	Medium	Low
Extract at 45-70˚C	High	High	Medium
Effect of GA[c]	High	Absent	Absent

a: Sorghum diastatic units, b: Degree of polymerisation, c: Gibberellic acid

2.5.1.1 Malting Processing Steps

Malting is a process of germinating the grain in moist air under controlled conditions in order to activate hydrolytic enzymes in the grain (Taylor, Dewar and Joustra, 2005). This process involves three principal steps: steeping, germination and drying.

Steeping-This step permits uptake of moisture into the grain (hydration) by soaking in water and moisture content after this step about 33-35 % (wet weight basis) (Taylor and Dewar, 1992). It initiates activation of enzymes required for metabolic activities during germination stage. Depending on the cultivar type, steeping may require certain pre-treatment. Pre-treatment with dilute formaldehyde solution (0.04-0.08 %) can be applied to tannin sorghum cultivars (Beta, Rooney, Marovatsanga and Taylor, 2000). The use of dilute alkali solution (NaOH) is considered a safer treatment than formaldehyde at early stage to eliminate toxicity effect (Dewar, Orovan and Taylor, 1997). This is to inactivate tannin to prevent interaction with protein and activated enzymes in the grain.

Germination-This step involves seedling growth, which is characterised by emergence of embryonic shoot and roots. Biochemical interpretation of this process implies mobilisation of the endogenous hydrolytic enzymes such as amylases and proteases in the grain (Taylor and Dewar, 1992). The function of the amylases is to hydrolyse the malt starch and adjunct during mashing (Taylor *et al*., 2005). The protease activity hydrolysed protein, which produces FAN in the malt.

Drying-This step is required majorly to reduce the water activity of the malted grain, in order to prevent mould growth and any other metabolic losses in the malted grain (Beta and Dzama, 1997). Traditionally, germinated grain dried in thin layers in the sun. Industrially, grains are subjected to high volume of heated air (about 50^{o}C) to dry the malt and this process in sorghum beer brewing ensures shelf-stable malt with high level of amylase activity (Taylor and Dewar, 1992).

2.5.2 Brewing with Sorghum

Sorghum grain utilisation in beer brewing can be as adjunct (generally lager/clear beer), or as sorghum malt in traditional opaque sorghum beer and lager beer. In southern Africa, the opaque sorghum beer industry is the major commercial large-scale user of sorghum (Daiber and Taylor, 1995).

2.5.2.1 Traditional brewing process

Traditional sorghum beer processing steps include: sorghum malting, cooking of the adjunct into slurry, mashing, souring (lactic acid fermentation),coarse mash filtration and alcoholic fermentation (Murty and Kumar, 1995; Daiber and Taylor, 1995). The final product has an alcohol content of 2-4%, w/v, lactic acid (0.3-0.6%), total solids (4-10%) and pH (3.3-3.5) (Murty and Kumar, 1995; Daiber and Taylor, 1995). One industrial process applied in the production of opaque beer is referred to as the Reef Process, as shown in Figure 2.1 (Novellie and de Schaepdrijver, 1986). Taylor and Emmambux (2008) noted the possibility of dhurrin (cyanogenicglucoside) formation in the shoots and roots of malted sorghum. The dhurrin formed can be reduced to a safe level by adequate drying temperature of 30^{o}C and above (Aniche, 1990), shoots and roots removal (Traore, Mouquet, Icard-Verniere, Traore and Treche, 2004) as well as through the processes of traditional fermentation involved in the brewing process (Ahmed, Mahgoub and Babiker, 1996).

Sorghum malt is the most important ingredient in opaque beer brewing in most of the SADC countries, while others depends on food-grade commercial enzymes as sources of hydrolytic enzymes (Taylor, 2003). This beer is rich nutritionally may be regarded more as a food than an alcoholic beverage. This is due to its good content of vitamin, minerals, protein and carbohydrates resulting from malting and brewing (Daiber and Taylor, 1995). The lactic acid fermentation stage in the process gives the beer sour taste. Low pH condition results in incomplete starch hydrolysis to soluble sugar and gives the beer characteristic opaque and viscous property (Daiber and Taylor, 1995). A major factor limiting distribution of opaque beer is its short shelf-life, a maximum of 7 days (Daiber and Taylor, 1995). This is due to its active fermenting state, which affects flavour and mouthfeel (Briggs, Boulton, Brookes and Stevens, 2004) due to the activity of yeast and lactic acid bacteria.

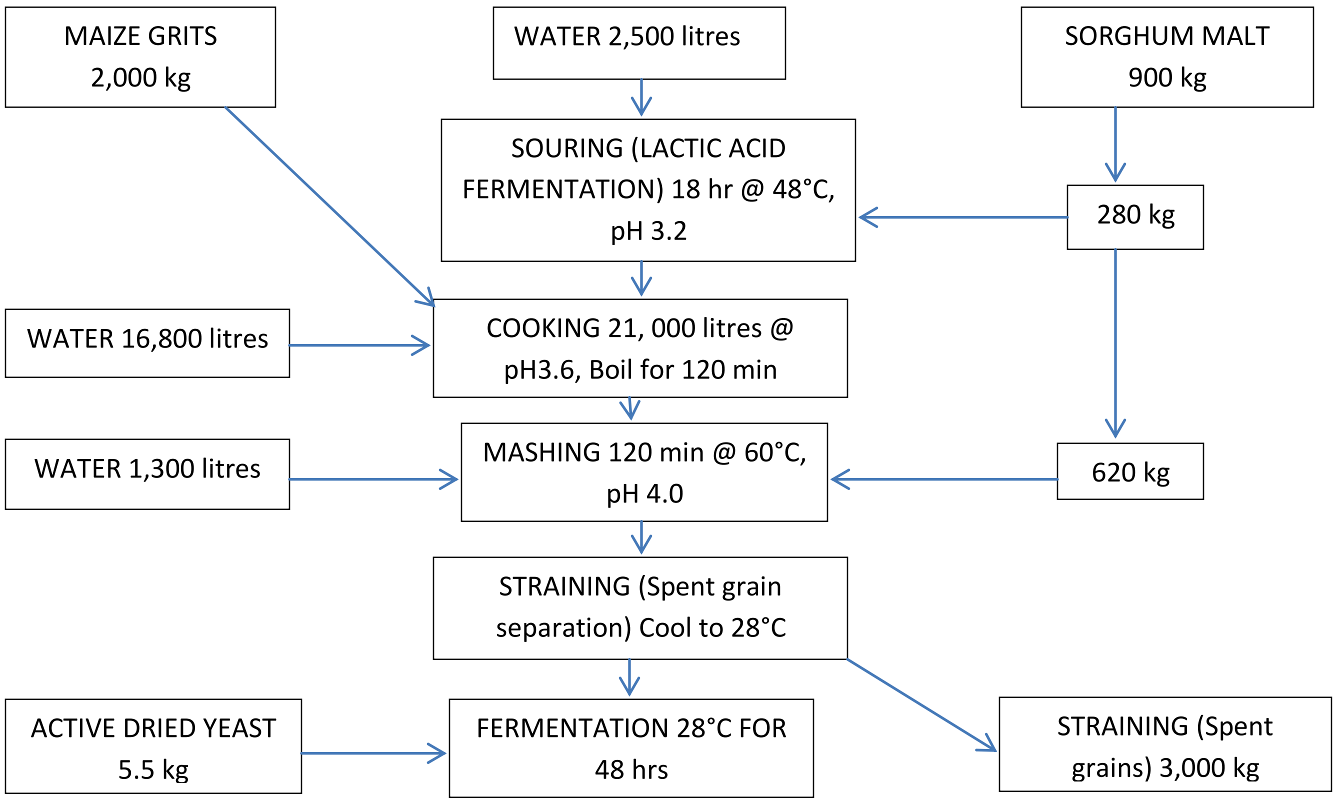

Figure 2.1: Principles of the production of opaque beer by the Reef-type brewing process (Novellie and de Schaepdrijver, 1986).

2.5.2.2 Clear beer brewing process

Sorghum clear beer brewing processes involves using sorghum malt and/or sorghum grits or unmalted whole grain (adjunct), with addition of amylase and other commercial enzymes (Rooney and Serna-Saldivar, 1991; Taylor and Emmambux, 2008). Sorghum grain serves as a good source of starch, because of its high starch content (approx. 73.7%) (Serna-Saldivar, 2010; Mackintosh and Higgins, 2004). Palmer (1991) noted that demand for creamy-white or white grain sorghum will increase because of their application in clear beer brewing. This may be due to grain characteristics of these types of sorghum cultivars, which makes them suitable with regard to extract yield and beer quality. The processing steps involved in clear beer brewing distinguish it from opaque beer (Figure 2.2). They involve hopping which is not in opaque beer brewing (Taylor and Dewar, 2001) and this adds characteristic bitterness to clear beer. It also involves carbonation, clarification and pasteurisation. Pasteurisation gives a long shelf-life to clear beer (up to one year), compared to opaque beer that is still in active state of fermentation, resulting in it short shelf-life (Serna-Saldivar, 2010).

According to Serna-Saldivar (2010), brewing adjuncts are carbohydrate-rich materials and hydrolysed to fermentable sugars by activities of amylase enzymes in the malt or commercial enzymes. They serve as malt replacement to provide fermentable sugars (Palmer, 1992), but not as enzymes. The products of brewing adjunct hydrolysis by malt amylases are as follows: linear and branched dextrins, maltotriose, maltose and traces of glucose. Careful selection of sorghum cultivars with corneous endosperm, as well low starch gelatinisation temperature is best for sorghum application as brewing adjunct (Palmer, 1992). According to Taylor *et al*. (1997), their work shows that South African sorghums have lower starch gelatinisation temperature (between 63.5 and 69.7˚C), compared to values recorded in the literature, which were 71.7-79.7˚C (Serna-Saldivar and Rooney, 1995).

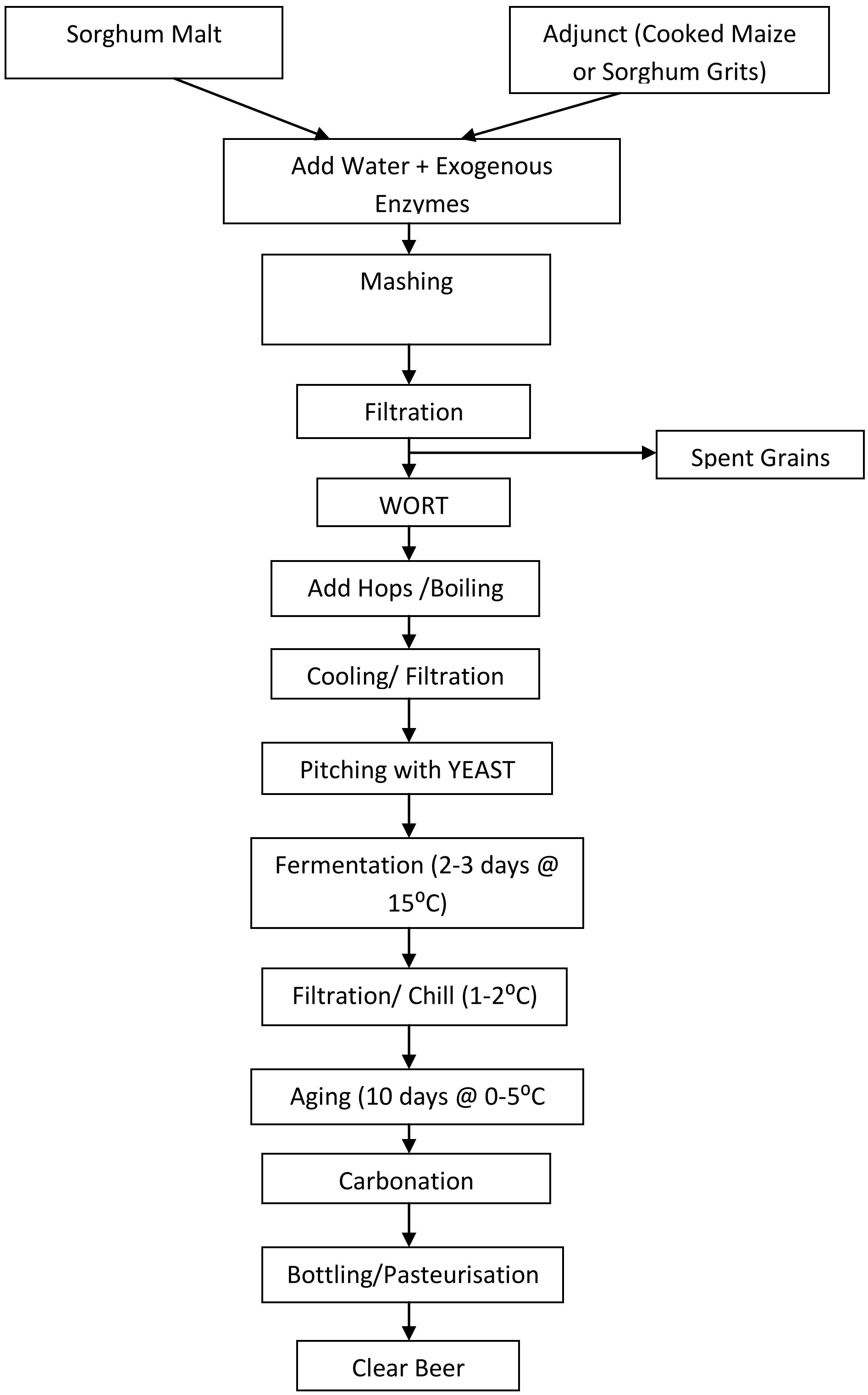

Figure 2.2: Brewing process for the production of clear lager sorghum beer (Adapted from Rooney and Serna-Saldivar, 1991)

2.6 CONCLUSIONS

The above review of the sorghum grain crop in southern Africa reveals that large scale production and utilisation of sorghum in the region is still evolving. A major limitation to sorghum utilisation is as a result of ineffective adoption of the improved sorghum varieties and cultivars available in the region. Information regarding plant characteristics, grain quality properties, processing and end-use attributes of these improved cultivars is very important in order to boost sorghum production and utilisation. This will also enable diversification of sorghum utilisation in food, malting and brewing, as well as animal feed application. This is because most common areas of sorghum application have been in porridge making and traditional sorghum beer (opaque beer) brewing production.

Sorghum application in malting and brewing processing in southern Africa has been majorly limited to production of opaque beer, while its inclusion in the production of clear beer in the region is still evolving. Limitations to sorghum utilisation in clear beer brewing are due to poor malt quality, as well as poor wort quality obtained from sorghum. These problems result due to sorghum grain structural and biochemical attributes. These attributes are both cultivar and cultivation environment dependent. Improvement regarding malt quality parameters had been extensively evaluated with respect to malting procedures and conditions. This has contributed positively to sorghum suitability in clear beer brewing. Therefore, there is need for more comprehensive characterisation of the available improved sorghum varieties and cultivars in southern Africa, with emphasis on their adjunct quality for clear beer brewing. This should ultimately bring about improvement in competitiveness and profitability of sorghum production and utilisation in southern Africa.

3. HYPOTHESES AND OBJECTIVES

3.1 HYPOTHESES

a. Effective utilisation of the available improved sorghum varieties and cultivars in southern Africa by farmers, processors and consumers will be dependent on detailed information about the qualities of the available improved varieties and cultivars. According to Kayode, Adegbidi, Linnemann, Nout and Hounhouigan (2005), optimisation of sorghum breeding programmes, cultivation and utilisation on a commercial level are majorly determined by availability of adequate information. Availability of information has been reported to be a major problem in sorghum competitiveness and profitability with respect toutilisation of improved cultivars (Chisi, 2003).

b. Sorghum types will have significantly different adjunct brewing quality properties due to variations in their grain structural and composition attributes. Differences in grain quality attributes affect brewing efficiency (Agu, Okenchi, Aneke and Onwumelu, 1995) and beer quality, due to the influence of environmental and breeding factors on composition and processing traits of sorghum (Rooney, 2007). Montanari, Floridi, Marconi, Tironzelli and Fantozzi (2005) noted that lager beer brewing property in terms of wort fermentability depend on wort composition properties.

3.2 OBJECTIVES

1. To collate agronomic and plant trait information, and grain and end-use quality attributes of improved sorghum varieties and cultivars in southern Africa in order to develop a well organised and accessible database
2. To determine the effects of different sorghum types on wort quality produced from unmalted sorghum grain mashed with exogenous enzymes
3. To determine the effects of tannin inactivation and of malting on wort quality produced from sorghum grain mashed with exogenous enzymes

4. RESEARCH CHAPTERS

4.1 DEVELOPMENT OF A DATABASE ON THE QUALITY ATTRIBUTES OF RELEASED IMPROVED SORGHUM VARIETIES AND CULTIVARS IN SOUTHERN AFRICA

ABSTRACT

Lack of information about the available sorghum types has majorly limited production and utilisation of sorghum in southern Africa. A database of released and available improved sorghum varieties and cultivars was compiled for eight countries in southern Africa. This information will enable selection of suitable cultivars with higher grain yield and good grain quality attributes, in order to improve the adoption rate. The database provided the following information: yield potential; agronomic and production requirements; plant and grain quality traits; end-use quality attributes with reference to malting and brewing. Nineteen improved open-pollinating varieties (OPV) and 30 hybrid (H) cultivars of sorghum are available in these countries of southern Africa, of which 16 are white tan-plant types, while others are red and purple plant types. These improved sorghums have higher yield potentials with good agronomic properties compared to the traditional landraces. The OPVs have early to medium maturity, while Hs are medium to late maturity. The high tannin cultivars (type III) are mostly Hs. The majority of these improved sorghums are characterised by having uniform grain size and intermediate to corneous endosperm texture. High grain yield potentials of these improved sorghum varieties and cultivars can improve the level of sorghum production in southern Africa. Available grain quality information is limited and it can only be applied to a limited extent with respect to specific area of end-use, such as beer brewing.

4.1.1 INTRODUCTION

Sorghum is one of the important cereal crops on the African continent, because Africa production represents about 44% of the world production in 2009 (FAO, 2011). In southern Africa, sorghum plays a major role in development and in the culture of the black people in the region (Taylor, 1995). It is mainly utilised for food and beverages, such as malt for production of opaque beer and sorghum meal for porridges (South African Sorghum Section 7 Committee, 2007). Sorghum has high drought-tolerance, as well as the ability to withstand poor soils and high temperature conditions where maize struggles (Serna-Saldivar, 2010). The crop also requires relatively low agronomic inputs during growth (ICRISAT/FAO, 1996). The South African Sorghum Section 7 Committee (2007) noted the need for improving the level of sorghum competitiveness and profitability in the region, by recommending the use of improved sorghum varieties and cultivars in order to ensure high yield and better grain quality attributes, as well as application of good agronomic inputs such as irrigation and fertilisation.

Despite the large number of improved sorghum varieties and cultivars already released in the region, the level of sorghum production is still very low compared to the rest of the continent. The recent sorghum production statistics for Africa reflected that southern Africa production represents 1.2% of the total production in Africa in 2009 (FAO, 2011). Low sorghum productivity is mainly due to the system of farming, which is generally still primitive (Taylor, 2004). The farmers largely farm manually and depend only on traditional, low yielding sorghum varieties (ICRISAT/FAO, 1996). Low productivity may be one of the limiting factors to end-use diversification and large-scale application of sorghum in southern Africa. Adoption rate of the available improved sorghum varieties and cultivars has been identified to be very low (Chisi, 2003), which contributes majorly to low production due to the use of low yielding traditional varieties (Taylor and Taylor, 2009). This has been attributed to a lack of adequate information and dissemination regarding these improved sorghum cultivars (Heinrich and Mgonja, 2002) both to producers and processors.

Sorghum grain quality attributes such as structural and chemical composition have significant influence on end-use application. According to Taylor and Duodu (2010), the following are the emerging end-use applications of sorghum in the Africa: instant infant foods, instant porridges, expanded snack foods, lager beer and stout brewing, and formulated dog food. Application suitability of the improved sorghum varieties and cultivars with regard to these new areas of end-use depend on their grain quality properties (Obilana, 2004). This author noted that comprehensive grain quality characterisation is an important complementary activity of breeding programmes, in order to assess both processing and utilisation quality of the improved sorghum cultivars. The present study therefore developed a database on the quality attributes of improved sorghum varieties and cultivars in southern Africa.

4.1.2 MATERIALS AND METHODS

4.1.2.1 Materials

Southern African Development Community (SADC) countries where improved sorghum varieties and cultivars have been released include: Botswana, Malawi, Mozambique, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe. A total of 51 released improved sorghum cultivars were included in the database. Nineteen was open-pollinated varieties (OPV).They were as follows: Mahube, Mmabaitse, Segaolane, Pilira 1 (ICSV 1), Mamonhe, MRS 13 (SDSV 1513), MRS 94 (SDSV 1594), Tegemo, Pato, Kuyuma, Sima, ZSV-15 and -12, WP-13, SV-2 (ICSV 88060), SV-3 (NL 499), and SV-4 (NL 330). The last two OPV were multiple-country released and they are Macia (also known as Phofu or SDS 3220), and ICSV 112 (has other names depending on the country of release). Hybrid cultivars included are 26: BSH 1 (SDSH 48), MMSH-375, 413, 1257, & 625, ZWSH-1, BANJO, MR BUSTER (also known as Mafia), OVERFLOW, NS-5511, 5655, and 5751, PAN-8625, 8609, 8564, 8247, 8706W, 8648W, 8407, 8017, 8474, 8657, 8816, 8677, 8507, and 8488.

The following information were provided in the database: cultivar yield potentials sourced from Mgonja, Obilana, Chisi, Saadan, Ipinge, Mpofu, Chintu, Setimela, Pali-Shikhulu, and Joaquim (2005), Obilana (1998), Chisi (Personal communication), and Booyens (Personal communication); plant characteristics and production requirements obtained from Mgonja *et al*. (2005), Chisi (Personal communication), Booyens (Personal communication), and the Pannar Seed website; grain and milling quality characteristics information obtained from Gomez, Obilana, Martin, Mazvamuse and Monyo (1997), Mgonja *et al*. (2005), Booyens (Personal communcation), Chiremba (2008, 2009), Chiremba (Personal communication), Van Loggerenberg (2001), Pannar Seed website, and Chisi (Personal communication); available malting and brewing quality attributes data obtained from Gomez *et al*. (1997), Chiremba (2007 and 2009), Chiremba (Personal communication), Booyens (Personal communication), and Van Loggerenberg (2001).

4.1.2.2 Methods

The information database spreadsheets of the improved sorghum varieties and cultivars were comprised of three categories. Table 1 contains yield and plant characteristics: grain yield potential (expressed in ton per ha), panicle and panicle exsertion (length of the panicle expressed in cm), days to 50% heading, days to 50% flowering, length of maturity, plant height (expressed in m), plant colour, rainfall requirement (expressed in mm), as well as general remarks. Table 2 has information on grain quality attributes: grain size fractions (percentage of small to medium, to large kernels), glume colour and traits, grain colour, 1000 kernel weight, percent floaters, Tangential Abrasive Dehulling Device (TADD) dehulling loss, grain texture, milling yield in percentage, water absorption, Agtron reflectance value (wet/dry), flour colour, testa (seed coat) presence or absence, and tannin content (expressed in % CE (g catechin equivalents per 100 g)). Table 3 contains malting and brewing quality characteristics data: germination count after 24, 48 and 72 h, water uptake, malting and total loss, malt Diastatic Power (DP), malt Free Amino Nitrogen (FAN), and grain extract content or yield.

4.1.2.2.1 Grain colour, endosperm texture and hardness determination

These attributes were determined visually and the procedures followed as described by Gomez *et al*. (1997). The kernel colour classification was as described by Gomez *et al*. (1997) using the following colour descriptors: white, yellow, red, brown, gray or a combination. The endosperm texture was classified as follows: > 75% mostly corneous and hardness scored 5, 50% corneous or floury and hardness scored 3, and < 25% mostly floury and hardness scored 1.

4.1.2.2.2 Grain size fraction, 1000 kernel weight and percent floater determination

Grain size determination was based on size distribution and percentage of small (≤ 2.6 mm), medium (4.0-2.6 mm) and large (> 4.0 mm) kernel composition. The procedure was that described by Gomez *et al*. (1997). Thousand kernel weight determinations were based on the weight of 1000 kernels counted. Determination of percent floaters was that described by Gomez *et al*. (1997). This is based on the proportion of kernels that float in a solution of a given density and high floater values correspond to high proportion of floating soft kernels.

4.1.2.2.3 Tannin content determination

Tannin content was determined quantitatively by the vanillin-HCl method. This method gives accurate determination of tannin content in the samples. The assay procedure followed was that described by Gomez *et al*. (1997) and the results expressed as percent catechin equivalents (g CE/100 g grain).

4.1.2.2.4Determination of milling quality parameters

Dehulling loss determined using the Tangential Abrasive Dehulling Device (TADD) and percent milling yield were the milling quality parameters determined. The procedures followed were described by Gomez *et al*. (1997).

4.1.2.2.5 Malting quality determination

The Germinative Energy (GE) attribute was determined by methods described by Gomez *et al*. (1997) and Chiremba (2009). The method used by Chiremba (2009) is according to ICC Draft Standard 174 for Determination of GE of Sorghum grain (ICC, 2008). Malt quality in terms of DP and FAN were determined based on SABS Method 235 and EBC Ninhydrin Method 4.10 FAN of Malt by Spectrophotometry (EBC, 1998), respectively. The procedure of analysis was described by Chiremba (2009).

4.1.3 RESULTS AND DISCUSSION

Some 19 improved open-pollinating sorghum (OPV) and 30 hybrid (H) cultivars are available in the SADC region (Table 4.1.1 to 4.1.3). Most of the PAN and NS hybrid cultivars are released and cultivated in South Africa, while the rest are in other SADC countries such as Botswana, Lesotho, Namibia, Zambia, and Zimbabwe.

4.1.3.1 Grain yield (tons/ha)

Table 4.1.1 shows that the potential grain yield of the hybrids (H) is between 2.0 and 11.0 tons per ha, while that of OPVs is between 1.5 and 8.0 tons/ha. Thus, the grain yield potential of the Hs is higher than that of the OPVs. This shows a significant improvement in grain yield potential of the improved sorghum OPVs and Hs, in comparison with traditional landraces, which usually have very low yield potential, less than 0.8 tons/ha (FAO, 2004). The following specific cultivars within the two categories show highest potential grain yield. They are SV-3 (NL 499) (OPV) and MMSH-375, 413, 1257 (Hs) (3.8-8.0, 6.0-10.0/11.0 tons/ha), respectively. Others are the PAN series, which includes PAN 8564, 8738, 8407, 8816, 8677 and 8507 (Hs) (2-10 tons/ha). The data correspond with the point noted by House, Osmanzai, Gomez, Monyo and Gupta (1995) that hybrid sorghum cultivars always produce higher grain yield than their parent varieties.

Table 4.1.1: Plant characteristics and yield potentials of improved sorghum varieties and cultivars

Single-country	Variety name	H/OPV[A]	Grain yield (t/ha)	Panicle size and type[B]	Panicle exsertion[C] (cm)	Days to 50% Heading (days)	Days to 50% Flowering (days)	Maturity[D] (days)
BOTSWANA	BSH1 (SDSH 48)	H	3.5-5.5	SC, M/L	F/3.0-8.0	65-68		125-130 (M)
	MAHUBE (SDS 2583)	OPV	1.5 - 3.0	SC, L /FL Elliptic with awns	E/LP, 18.0-30.0	45-50		90-100 (VE)
	MMABAITSE	OPV	1.5-3.5	C, M/Cylindrical	G/14.0-18.0	65-75		120-125 (M/L)
	SEGAOLANE	OPV						
	SEPHALA							
MALAWI	PILIRA 1 (ICSV 1)	OPV	2.0-4.0	SC, M/Elliptic	VG/15.0-25.0	58-60		110-115 (M)
MOZAMBIQUE	MAMONHE	OPV	1.5-3.0	O, L, drooping branches	VG/18.0-25.0		80-85	135 (L)
SWAZILAND	MRS 13 (SDSV 1513)	OPV	3.0-5.0	C, L/Elliptic	VG/15.0-20.0	75-85		120-125 (M/L)
	MRS 94 (SDSV 1594)	OPV	3-4.5.0	C, L/Cylindrical	VG/15.0-20.0	75-85		125-130 (M/L)
TANZANIA	TEGEMEO	OPV	2.5-4.0	SC, M	G/10.0-15.0	80-85		135-140 (M/L)
	PATO	OPV	3.0-5.0	SO, M/Short bulky	F/6.0-10.0	80-90		140-150 (M/L)
ZAMBIA	KUYUMA	OPV	2.0-5.0/3.0-5.0	SC/O, M/L, B/E	FG/9.0-12.0	65-70		125-130 (M/L)/100-110 (E)
	SIMA	OPV	2.5-3.5/4.0-6.0	O, M/L	F/3.0-8.0	75-85		130-135(FL)/110-120 (E/M)
	ZSV-15	OPV	3.0-6.0/3.0-7.0	SC, L/B	G/10.0-15.0	65-70		115-120 (E/M)/110-120 (E/M)
	ZSV-12	OPV	2.0-6.0	SC, L/B	F/3.0-5.0	80 - 85		130-155 (L)
	WP-13	OPV	2.0-5.0[2]/3.0-6.0	SC, L/B	G/5.0-10.0	80-90		130-150 (L)/145-170 (L)
	MMSH-375	H	3.0-9.0/6.0-10.0	SC & Large	G/5.0-10.0	65-70		120-130 (M)/110-120 (E/M)
	MMSH-413	H	4.0-8.0/6.0-11.0	SC & Large	G/5.0-10.0	65-70		115-125 (E/M)/110-120 (E/M)
	MMSH-1257	H	4.0-9.0/6.0-10.0	SC, L/B	G/10.0-15.0	75-79		120-125 (M)/110-125 (E/M)
	MMSH-1365	H	3.0-7.0/5.0-9.0	SC, Large	G/5.0-10.0	70-80		115-125 (M)
	MMSH-625	H	4.0-8.0/5.0-9.0	SC, L/B	G/5.0 -11.0	75-80		125-130 (M)
	MMSH-1324	H	3.0-6.0	SC, M/L	G/5.0-12.0	60-70		110-115(E)

Continuation: Table 4.1.1

Single-country	Variety name	H/OPV[A]	Grain yield (t/ha)	Panicle size and type[B]	Panicle exertion[C] (cm)	Days to 50% heading (days)	Days to 50% flowering (days)	Maturity[D] (days)
ZIMBABWE	SV-2 (ICSV 88060)	OPV	2.5-4.5	SC, M	G/10.0-16.0	58-62		110-115 (E/M)
	SV-3 (NL 499)	OPV	3.8-8.0	SL, M	G/10.0-16.0	62-68		112-124 (E/M)
	SV-4 (NL 330)	OPV	3.5-9.0	SL, M/L	G/10.0-16.0	62-68		113-127 (E/M)
	ZWSH-1	H	5.0-9.0	SC & Large	G/15.0-20.0	70-75		120-125 (M)
SOUTH AFRICA	NS 5511	H						
	PAN 8625	H		C				135-142 (M/L)
	PAN 8609	H	4.0 - 8.0	SC	G/10.0-16.0		80-85	135-140 (M/L)
	PAN 8564	H	4.0 - 10.0	R/OP	G/10.0-16.0		72 -78	140-145 (L)
	PAN 8738	H	4.0 - 10.0	C	G/10.0-15.03		80-85	135-140 (M/L)
	PAN 8247	H	3.0 - 8.0	C	VG/10.0-17.0		73-76	125-130 (M/L)
	BANJO	H						
	NS 5655	H						
	OVERFLOW	H						
	PAN 8706W	H	3.0 - 9.0	C			80-85	130-140 (M/L)
	PAN 8648W	H	2.0 - 8.0	C	G/10.0-15.0		72 -78	130-140 (M/L)
	NS 5751	H	3.0 - 9.0	SC			75- 80	135-140 (M/L)
	MR BUSTER	H	4.0 - 9.0				72 -78	135-140 (M/L)
	PAN 8407	H	3.0 - 10.0	SC	VG/10.0-16.0		75-80	135-140 (M/L)
	PAN 8017	H	3.0 - 9.0	C	G/10.0-15.0		72 -78	135-140 (M/L)
	PAN 8474	H	4.0 - 9.0	C	G/10.0-16.03		75-80	140-145 (L)
	PAN 8657	H	2.0 - 9.0	SC	G/10.0-16.0		74-78	135-140 (M/L)
	PAN 8816	H	2.0 - 10.0	SC	VG/10.0-16.0		80-85	140-145 (L)
	PAN 8677	H	3.0 - 10.0	SC	G/10.0-13.0		72 -78	140-145 (L)
	PAN 8127	H	3.0 - 9.0	C	G/10.0-14.01		75- 80	135-140 (M/L)
	PAN 8507	H	2.0 - 10.0	SC	VG/10.0-16.0		80-85	140-145 (L)
	PAN 8488	H	3.0 - 9.0	C	VG/10.0-17.0		72 -78	135-140 (M/L)

Continuation: Table 4.1.1

Multiple-country	Variety name	H/OPV[A]	Grain yield (t/ha)	Panicle size and type[B]	Panicle exsertion[C] (cm)	Days to 50% heading (days)	Days to 50% flowering (days)	Maturity[D] (days)
BOTSWANA	MACIA SDS 3220	OPV	3.0-6.0	SC, L/B	G/10.0-15.0	60-65		115-120 (E/M)
MOZAMBIQUE	MACIA SDS 3220							
NAMIBIA	MACIA SDS 3220							
TANZANIA	MACIA SDS 3220							
ZIMBABWE	MACIA SDS 3220							
MALAWI	ICSV 112 (PIRIRA 2)	OPV	2.0-6.5	SC, M/L	VG/12.0-20.0	70-80		115-125 (M)
MOZAMBIQUE	ICSV 112 (CHOKWE)							
SWAZILAND	ICSV 112 (MRS 12)							
ZIMBABWE	ICSV 112 (SV-1)							

Continuation: Table 4.1.1

Single-country	Variety name	H/OPV[A]	Plant height[E] (m)	Plant colour	Production &adaptation[F] recommendation (mm rainfall)	Remarks[G]
BOTSWANA	BSH1 (SDSH 48)	H	1.3-1.6 (SD)	Tan	S/ 250-750	DT
	MAHUBE (SDS 2583)	OPV	0.9-1.0 (D)	Purple	VS/ 200-600	SG
	MMABAITSE	OPV	1.3-1.7 (SD)	Purple	S/ 250-750	
	SEGAOLANE	OPV				
	SEPHALA					
MALAWI	PILIRA 1 (ICSV 1)	OPV	1.4-1.7 (SD)	Tan	I/ (H/H)/ 400-850	TSB
MOZAMBIQUE	MAMONHE	OPV	1.9-2.1 (ST)	Tan	I/L (750-950)	
SWAZILAND	MRS 13 (SDSV 1513)	OPV	1.5-1.7 (SD)	Purple	I/ 400-850	Yield[a]
	MRS 94 (SDSV 1594)	OPV	1.7-1.9 (ST)	Purple	I/ 400-850	RSS, RLB
TANZANIA	TEGEMEO	OPV	1.4-1.7 (SD)	Tan	I/L (450-850)	
	PATO	OPV	1.9-2.4 (ST/T)	Purple	I/ 400-800	
ZAMBIA	KUYUMA	OPV	1.5-1.7 (SD)	Tan	I/ 450-900	GDR/EA/LRA
	SIMA	OPV	1.9-2.5 (T)/(M/T)	Tan	I/ 450-900	MDR
	ZSV-15	OPV	1.2-1.5 (D/SD)	Tan		GDR/LRA
	ZSV-12	OPV	1.4 -2.0 (ST/T)	Purple	I/ 450-900	SPPS/GRSA/GRA/HRA
	WP-13	OPV	1.8-2.5 (ST/T)	Purple	I/L 800-1000	PPS/GRSA/HRA
	MMSH-375	H	1.3-1.5 (D/SD)	Red	I/ 450-900	VWAHP/GDR/EDM
	MMSH-413	H	1.2-1.5 (D/SD)	Red	I/ 450-900	WAHP/GDR
	MMSH-1257	H	1.5-2.0 (SD/ST)	Tan	I 450 - 900	HPT/WA/GDR
	MMSH-1365	H	1.0 -1.5 (D/SD)	Red	S/I 400-950	HY/ADA/GDR/SG
	MMSH-625	H	1.5-2.0(SD/ST)	Red	S/I 400-950	GDR/ADA/EDM
	MMSH-1324	H	Medium	Tan	S 400-700	HY/ADA/GDR/EA

Continuation: Table 4.1.1

Single-country	Variety name	H/OPV[A]	Plant height[E] (m)	Plant colour	Production &adaptation[F] recommendation (mm rainfall)	Remarks[G]
ZIMBABWE	SV-2 (ICSV 88060)	OPV	1.4-1.6 (SD)	Tan	S/ 250-750	DT/Yield[a]
	SV-3 (NL 499)	OPV	1.1-1.6 (SD)	Tan	(S/I)300-900	Yield[b]
	SV-4 (NL 330)	OPV	1.14-1.82 (SD)	Tan	(S/I)300-900	Yield[b]
	ZWSH-1	H	1.9-2.2 (ST)	Tan to purple	I/ 400-850	
SOUTH AFRICA	NS 5511	H				
	PAN 8625	H	1.2-1.3 (D/SD)	Purple	I/ 400-1500	B/P, EU/S, HST
	PAN 8609	H	1.12-1.15 (D)	Purple	I/ 400-1500	HS, IC
	PAN 8564	H	1.3-1.35 (D/SD)	Purple	I/ 400-1500	CEP, DR, GCT, TSB, HPS
	PAN 8738	H	1.0-1.5 (D to SD)	Purple	I/ 400-1500	DT, SG, ADA, GDR
	PAN 8247	H		Purple	I/ 400-1500	DT, SG, ADA, GDR
	BANJO	H				
	NS 5655	H				
	OVERFLOW	H				
	PAN 8706W	H	1.4 -1.6 (SD)	Tan	I/ 400-1500	SG, ADA
	PAN 8648W	H	1.0-1.3 (D)	Tan	I/ 400-1500	SG, ADA
	NS 5751	H			I/ 400-1500	
	MR BUSTER	H			I/ 400-1500	
	PAN 8407	H	1.3-1.6 (D to SD)	Purple	I/ 400-1500	CEP, DR, GCT, TSB, HPS
	PAN 8017	H	1.4 -1.6 (SD)	Purple	I/ 400-1500	DT, GDR, RLB
	PAN 8474	H	1.0-1.3 (D)	Purple	I/ 400-1500	CEP, DR, GCT, TSB, HPS
	PAN 8657	H	1.0-1.3 (D)	Purple	I/ 400-1500	DT, SG, GDR
	PAN 8816	H	1.12-1.17 (D)	Purple	I/ 400-1500	B/P, ES, VGS, LDT, HST
	PAN 8677	H	1.3-1.5 (D to SD)	Purple	I/ 400-1500	CEP, DR, GCT, TSB, HPS
	PAN 8127	H	1.4 -1.6 (SD)	Purple	I/ 400-1500	DT, SG, GDR
	PAN 8507	H	1.0-1.3 (D)	Purple	I/ 400-1500	DT, SG, GDR
	PAN 8488	H	1.4 -1.6 (SD)	Purple	I/ 400-1500	DT, DRA, RLB

Continuation: Table 4.1.1

Multiple-country	Variety name	H/OPV[A]	Plant height[E] (m)	Plant colour	Production &adaptation[F] recommendation (mm rainfall)	Remarks[G]
BOTSWANA	MACIA SDS 3220	OPV	1.3-1.5 (D to SD)	Tan	S/ 250-750	DT, SG
MOZAMBIQUE	MACIA SDS 3220					
NAMIBIA	MACIA SDS 3220					
TANZANIA	MACIA SDS 3220					
ZIMBABWE	MACIA SDS 3220					
MALAWI	ICSV 112 (PIRIRA 2)	OPV	1.5-1.8 (SD)	Tan	I/ 400-850	Yield[a,]
MOZAMBIQUE	ICSV 112 (CHOKWE)					SSB
SWAZILAND	ICSV 112 (MRS 12)					
ZIMBABWE	ICSV 112 (SV-1)					

A:

OPV: Open pollinated variety, H: Hybrid

B:

M/L- Medium to large, L/FL- Long/Fairly large, M- Medium, L/B-Large & Bulbous, B/E- Bulbous & Elliptic
SC- Semi-compact, C- Compact, O- Open, SO- Semi-open, SC/O- Semi-compact to open, SL- Semi-loose, R/OP: Round open panicle

C:

F- Fair, E- Excellent, VG- Very good, G- Good, FG- Fairly good

LP- Long peduncles

D:

M- Medium, VE- Very early, E/M- Early to medium, M/L- Medium to late, FL- Fairly late, L- Late

E:
SD- Semi-dwarf, D- Dwarf, ST- Semi-Tall, ST/T- Semi-Tall to Tall, D/SD- Dwarf to Semi-Dwarf, SD/ST- Semi-Dwarf to Semi-Tall

F:

Type of season: S-Short, VS-Very Short, S/I- Short to intermediate, I- Intermediate, I/L- Intermediate to long

Type of area: H/H- Hot and humid

Continuation: Table 4.1.1

G:
DT: Drought tolerant, SG: Stay green trait, TSB: Tolerant to stem borer, SSB: Susceptible to stem borer, RSS: Resistant to sooty stripe, RLB: Resistant to leafy blight

a: Yield depends on crop management, b: Yields depend on crop management and rainfall
GDR: Good disease resistance, EA: Except for anthracnose, MDR: Moderate disease resistance, EDM: Except for downy mildew, GRA: Good resistance to anthracnose

LRA: Widely adapted to low rainfall areas, HRA: Adaptation to high rainfall areas, ADA: Adapted to dry areas

PPS: Photo-period sensitive, SPPS: Semi-photo period sensitive, HY: High yield
GRSA: Good resistance to soil acidity, HPT: Widely adapted high potential tan, WA: Wide adaptation, VWAHP: Very widely adapted high potential, WAHP: Widely adapted high potential

Saadan, Mgonja and Obilana (2000) studied the effect of multiple environment and year/season on sorghum cultivars. The results of their work reflected some variations in the parameters measured, which included grain yield potential. They concluded that the differences based on location and year/season of planting for the grain yield was not significant. However, influence of environment and yearmay explain the reason for the differences in grain yield potentials recorded for the following cultivars MMSH 375, 413 and 1257 (H), as well as Sima (OPV) by Chisi (Personal communication) and Mgonja *et al*. (2005).

4.1.3.2 Plant characteristics

The database information regarding the plant attributes of these improved cultivars includes the following (Table 4.1.1): Head/panicle characteristics and exsertion, days to 50% heading, maturity length, plant height and plant colour. These help in understanding the agronomic requirements needed to be applied to ensure good yield and grain quality.

House *et al*. (1995) reported heading in sorghum develops between 6 and 10 days before flowering, while sorghum generally flowers between 55 and 70 days in tropical climates. Based on the information in the database, these improved OPVs and Hs can be classified into early, intermediate and late heading. Mahube (SDS 2583) (OPV) has the shortest days to 50% heading and maturity 45-50 and 90-100 days, respectively. This implies that it is an early heading and very early maturing cultivar. ZSV-12 and WP-13 (OPVs) both have very late maturity 140-160 and 145-170 days, respectively. Late maturity may be attributed to late heading. For example, 50% heading in WP-13occur from 80-90 days of planting, as reported by Mgonja *et al*. (2005), which also has late maturity as mentioned above. Among the Hs, MMSH-1324 has early maturity (110-115 days), while PAN 8564 and 8816 both have very late maturity (140-145 days). The Table shows that all the PAN series have medium to late maturity. This may be attributed to late occurrence of 50% flowering, which ranges between 72 and 85 days after planting. The rest of the improved varieties and cultivars are either early to medium, or medium to late maturity.

From the database, it is noticeable that there were significant differences in maturity recorded for both Kuyuma and Sima (OPVs). Chisi (Personal communication) noted Kuyuma maturity to be early (100-110 days), while Mgonja *et al*. (2005) reported it to be medium to late (125-130 days). For Sima, maturity is between 110 and 120 days (early to medium) as noted by Chisi (Personal communication), while Mgonja *et al*. (2005) reported fairly late maturity (130-135 days). These variations may be attributed to effect of interaction between genotype and environment (G x E) (Araus, Slafer, Royo and Serret, 2008). According Mgonja *et al*. (2005), released improved sorghum varieties in SADC were multiple released by individual countries at different years and influence of environment on individual genotypes differ. Timing of flowering is a major attribute that relate to adaption of cultivars to growth conditions and then contributes to the overall crop performance (Passioura, 2002). This may further explained the reason for the differences in maturity reported for Kuyuma and Sima from the two sources.

Sorghum plant height ranges widely, between 0.9 and 2.5 m. Mahube (SDS 2583) (OPV), PAN 8609 and 8816 (H) are classified as dwarf plant types (0.9-1.0 and 1.12-1.15/1.17 m), respectively. These cultivars are suitable for mechanised farming with regards to harvesting. The following are referred to as semi-tall to tall plant types: Pato, Sima and WP-13 (1.9-2.4, 1.9-2.5 and 1.8-2.5 m), respectively. The rest can be grouped as dwarf to semi-dwarf, semi-dwarf, semi-dwarf to semi-tall and semi-tall. Plant colour is also diverse, ranging from white tan to pigmented plant type (either purple or red). There is an anomaly cultivar ZWSH-1 (H), which is described as tan to purple. The PAN series are mostly purple, with the exception of PAN 8706 and 8648, identified as white tan-plant type. The following Hs are the only red plant type cultivars: MMSH-375, MMSH-413, MMSH-625 and MMSH-1365.

Mahube (SDS 2583) has the shortest season with minimum rainfall requirement of 200-600 mm. BSH1 (SDSH 48) H, SV-2 (ICSV 88060) OPV and Macia (OPV multiple country released) have short season with rainfall requirement of 250-750 mm. Mamonhe and WP-13 both OPVs, have the highest rainfall requirement and classified as intermediate to long season, with rainfall requirements of 750-950 mm (Obilana, 1998) and 800-1000 mm (Chisi, Personal communication), respectively. The same trend was reported for the PAN series with very high rainfall requirement (400-1500 mm), but classified as intermediate season. The other cultivars are short to intermediate or intermediate season. Pilira1 (ICSV 1) (OPV), requires hot and humid environment with rainfall requirement of 400-850 mm (Obilana, 1998).

General remarks regarding these cultivars are that MRS 13 (SDSV 1513), ICSV 112 and SV-2 (ICSV 88060) grain yield potential depend on good crop management. Yield potential of SV-3 (NL 499) and SV-4 (NL 330) depend on combination of good crop management and rainfall, as noted by Mgonja *et al*. (2005). BSH 1, SV-2 and Macia are drought-tolerant cultivars (Obilana, 1998). Most of the cultivars have good disease resistance with exception of specific diseases that they are susceptible to, such as stem borer (ICSV 112), anthracnose (Kuyuma and MMSH-1324), and downy mildew (MMSH-375 and 625).

4.1.3.3 Grain quality attributes

According to Gomez *et al*. (1997), the grain quality properties given in Table 4.1.2 are very important in determining processing properties and product end-use quality and they were defined as follows. Glume trait determines grain threshability, which affects both processing and product quality. Grain colour plays a major role in influencing product end-use colour quality. Grain size in terms of distribution and uniformity determines milling quality properties. Kernel weight and percent floaters gives an indication of grain density and they contribute to milling quality attributes with regards to milling yield. Dehulling loss influences milling yield quality of the cultivar as affected by other grain quality factors such as pericarp thickness and grain hardness. Endosperm texture based on the grain hardness influences both processing and end-use quality attributes. Water absorption property of the grain gives indication regarding hardness, which influences milling and malting quality. Milling yield is important in determining processing suitability especially for milling as affected by endosperm textural attributes. Agtron reflectance value gives an indication of colour properties of the dry milled sorghum grain, as well as when the milled grain is hydrated. Tannin in terms of presence of testa and tannin content both influence processing properties and product end-use quality. The information provided can be used in quality classification, development of grading system and setting of quality standards of these improved sorghum varieties and cultivars, as noted by Obilana (2004).

The tannin property of sorghum grain in terms of tannin content is an essential grain quality parameter because of the negative effect tannins have on end-use and nutritional quality due to interaction with nutrients such as protein (Emmambux and Taylor, 2003). The tannin contents of the tannin cultivars range from 4.0 to 8.13 g CE/100 g. They include PAN 8625, 8474, 8677 and 8507; NS 5511 and 5751; MRS 94; MMSH-375 and 413. Based on the sorghum classification system in South Africa (South African Department of Agriculture, 2008), PAN 8625, 8677, 8507, NS 5511 and 5751 are classified as GH (grain sorghum malting class, high tannin). The PAN series that are non-tannin cultivars are classified as GM (grain sorghum malting class, non-tannin). They have good malting quality in terms of diastatic power (Chiremba, 2009). Mahube, Mmabaitse and MRS 13 cultivars have trace level of tannin (between 0.3 and 0.5 g CE/100 g). The rest of the improved cultivars are tannin-free.

The non-tannin and the cultivars with trace levels of tannin lacked a pigmented testa. ZWSH-1 has brown specks/spots on the grain pericarp. This may be attributed to the presence of fragmented testa, which is caused by recessives gene b_1 and b_2 (House *et al*., 1995). The presence of a pigmented testa is due to B_1 and B_2 gene dominance and the testa colour is determined by the presence of either *tptp* or *Tp* genes (Rooney and Miller, 1982). Testa with *tptp* genes gives purple colour, while *Tp* genes result in brown coloured testa. A combination of Spreader gene (*S*-) with B_1 and B_2 results in grain with brown pericarp colour (House *et al*., 1995; Rooney, Earp and Khan, 1982). Tannin sorghums classified as Type III are those with testa and spreader (B_1-B_2-*S*-) (Waniska, Rooney and McDonough, 2004). From the database, the following are high tannin sorghum with brown grain colour: MRS 94 (OPV), MMSH-375 and 413, PAN 8625, 8677 and 8507 (H). The presence of purple specks in Pato (OPV) grain colour could be attributed to presence of the *Pb*- gene, which causes such purple spots in the pericarp colour (Rooney and Miller, 1982).

Glume threshability is an important grain quality trait in crop selection for processing and end-use purposes and glume free-threshing property is genetically determined (Sood, Kuraparthy, Bai and Gill, 2009). Pirira 1, ZSV-15, WP-13, MMSH-375, 413 and 1275, SV-2, 3 and 4, as well as most of the PAN series are characterised with excellent and good threshability. A total of eight, mostly PAN cultivars, are characterised to have large kernel size fraction (>4.0 mm). Large kernel size contributes to having high milling yield because of higher level of starchy endosperm (Lee, Pedersen and Shelton, 2002). The rest of these improved sorghum cultivars have higher percentage of medium kernel size fraction (2.6-4.0 mm), with the exception of Tegemo and Sima (OPV), which are described as having large to medium kernel size fraction ratio (46.5/53.3% and 61.2/38.2%), respectively. This implies that the majority of these improved cultivars have uniform grain size, apart from the three that have mixture of large and medium size kernels. This high level of kernel size uniformity of these improved cultivars implies their milling quality suitability. According to Gomez *et al*. (1997), grain size uniformity affects particle size distribution because uniform size results in milled product with uniform particle size distribution.

Table 4.1.2: Grain Quality Characteristics of Improved Sorghum Varieties and Cultivars

Single-country	Variety name	H/OPV[A]	Grain size fraction[B] (%)	Glume colour	Glume traits[C]	Grain colour[D]	1000 Kernel weight (g)	Floaters (%)	TADD Dehulling loss[E] (4 mins) (%)	Endosperm texture[F] (Scale:1-5)[G]	Milling yield[H] (%)
BOTSWANA	BSH1 (SDSH 48)	H	M/96.8	Straw		C/W	21.0	47	12.7	4.4 (C/H)/4.5	E /84.8
	MAHUBE (SDS 2583)	OPV	Mostly large	Dark red		Red				3.0 (FH)	FG /72.0
	MMABAITSE	OPV	M	Black		White				2.8 (IH)	Av /70.0
	SEGAOLANE B	OPV	M/92.5			C/W	22.2	29	12.5	4.4	84.0
	SEPHALA										
MALAWI	PILIRA 1 (ICSV 1)	OPV	Medium to large	Straw	I/ET	C/W				3.9 (C/H)	E /83.0
MOZAMBIQUE	MAMONHE	OPV	Medium (broad)	Dark red		White				P/H	F
SWAZILAND	MRS 13 (SDSV 1513)	OPV	M/97.3	Light red	I	Red	16.6	49	14.2	2.8-3.0 (IH)/4.3	F/70/83.1
	MRS 94 (SDSV 1594)	OPV	M/99.3	Straw	I	Brown	20.0	100	39.6	2.0-2.8 (S/I)/2.1	P/ < 65/58.7
TANZANIA	TEGEMEO	OPV	Medium	Straw		Pearly, C/W				3.5 (C/H)	FG/78.0
	PATO	OPV	Bold	Black	VC	C/W, purple specks				3.7 (C/H)	E /88.0
	P9406										
	P9405										
ZAMBIA	KUYUMA	OPV	M/97.8	Straw		(C/W)/White	18.9	42	14.0	3.7(C/H)/3.9	VG/83.8
	SIMA	OPV	L/M/61.2/38.2	Straw		C/W,Y/W	31.1	19	12.6	2.8 (C/FH)/3.9	E/85.6
	ZVS-15	OPV	Medium	Straw	I/ET	C/W/white				C/H	E (80)
	ZVS-12	OPV									
	WP-13	OPV	Medium	Purple	I/ET	Chalky white				1.8-2.0 (S)	G
	MMSH-375	H	M/99.1	Red	I/ET	Brown	18.6	96	19.2	2.45 (MS)/2.0	G(85)/78.3
	MMSH-413	H	M/94.4	Brown	ET	Brown	20.1	100	21.3	2.45(C/MS)/1.2	E(90)/76.7
	MMSH-1257	H	M/89.8	Straw	ET	C/W,Y/W	23.9	71	18.5	3.0(C/MH)/3.7	E(85)/79.8
	MMSH-625	H									
	MMSH-1324	H									

Continuation: Table 4.1.2

Single-country	Variety name	H/OPV[A]	Grain size fraction[B] (%)	Glume colour	Glume traits[C]	Grain colour[D]	1000 Kernel weight (g)	Floaters (%)	TADD Dehulling loss[E] (4 mins) (%)	Endosperm texture[F] (Scale:1-5)[G]	Milling yield[H] (%)
ZIMBABWE	SV-2 (ICSV 88060)	OPV	M/95.9	Straw	I/ET	C/W	21.6	55	33.6	3.6 (C/H)/2.9	G(70)/64.1
	SV-3 (NL 499)	OPV	Medium	Straw	I/ET	C/W				3.5 (C/H)	G(70)
	SV-4 (NL 330)	OPV	Medium to bold	Straw	I/ET	White				C/H	G(70)
	ZWSH-1	H	M/95.5	Brown		C/W/BS,C/Y/W	17.2	75	15.4	3.4 (C/FH)	G(82)/81.7
SOUTH AFRICA	NS 5511	H					25.7±2.3/22.2				
	PAN 8625	H	Medium	Purple	GT	Brown	25.2±2.3			4.3 (C/H)	
	PAN 8609	H	Large	Red	GT	Red	29.5±3.5			5 (C/VH)	
	PAN 8564	H	Large	Red	ET	Red	26.5±3.1/22.8			3.2 (C/FH)	
	PAN 8738	H	Medium	Straw	GT	Red	25.2±2.3			3.9 (C/H)	
	PAN 8247	H	Large	Straw	GT	Red	33.1±4.0			4.1 (C/H)	
	BANJO	H									
	NS 5655	H					27.5±4.6/22.2				
	OVERFLOW	H									
	PAN 8706W	H	Medium	Straw	ET	White	25.2±2.3			3.8 (C/H)	
	PAN 8648W	H	Medium	Straw	ET	White	25.2±2.3			4.2 (C/H)	
	NS 5751	H								3.9 (C/H)	
	MR BUSTER	H									
	PAN 8407	H	Large	Red	GT	Red	26.5±3.1			3.6 (C/H)	
	PAN 8017	H	Large	Red	GT	Red	26.5±3.1			4.2 (C/H)	
	PAN 8474	H	Medium	Red	ET	Red	29.5±3.5			3.8 (C/H)	
	PAN 8657	H	Large	Red	GT	Red	29.7±3.6			3.8 (C/H)	
	PAN 8816	H	Large	Straw	ET	Red	27.3±2.3			4.1 (C/H)	
	PAN 8677	H	Medium	Purple	GT	Brown	29.5±3.5			3.9 (C/H)	
	PAN 8127			Purple	GT					2.9 (C/FH)	
	PAN 8507	H	Medium	Purple	ET	Brown	25.2±2.3			3.9 (C/H)	
	PAN 8488	H	Medium	Red	ET	Red	29.1±2.9			4.1 (C/H)	

Continuation: Table 4.1.2

Multiple-country	Variety name	H/OPV[A]	Grain size fraction[B] (%)	Glume colour	Glume traits[C]	Grain colour[D]	1000 Kernel weight (g)	Floaters (%)	TADD Dehulling loss[E] (4 mins) (%)	Endosperm texture[F] (Scale:1-5)[G]	Milling yield[H] (%)
BOTSWANA	MACIA SDS 3220	OPV	M/99.3	Straw	I/ET	C/W, White	16.8	65	17.2	3.8(C/H)/3.6	E/80/80.1
MOZANBIQUE	MACIA SDS 3220										
NAMIBIA	MACIA SDS 3220										
TANZANIA	MACIA SDS 3220										
ZIMBABWE	MACIA SDS 3220										
MALAWI	ICSV 112 (PIRIRA 2)	OPV	L/M, 14.7/85.3	Straw	I/ET	C/W, White	25.1	40	10.4	4.7 (C/VH)/4.2	E/85/87.0
MOZAMBIQUE	ICSV 112 (CHOKWE)										
SWAZILAND	ICSV 112 (MRS 12)										
ZIMBABWE	ICSV 112 (SV-1)										

Continuation: Table 4.1.2

Single-country	Variety name	H/OPV[A]	Water absorption[I] (%)	Agtron Reflectance value[J] (dry)	Agtron Reflectance value[J] (wet)	Flour colour	Testa (seed coat)	Tannin content[K] ≈% (g ce/ 100 g)	Remarks[L]
BOTSWANA	BSH1 (SDSH 48)	H	11.0	76.3	56.7	White[2]	Absent	0	
	MAHUBE (SDS 2583)	OPV				Pink/White	Absent	VL/0.5	
	MMABAITSE	OPV				White	Absent	VL/0.5	
	SEGAOLANE B	OPV	4.8	72.4	52.1				
	SEPHALA								
MALAWI	PILIRA 1 (ICSV 1)	OPV				White	Absent	0	
MOZAMBIQUE	MAMONHE	OPV				White	Absent	0	
SWAZILAND	MRS 13 (SDSV 1513)	OPV	4.6	56.2	33.7		Absent	VL/0.3	
	MRS 94 (SDSV 1594)	OPV	4.3	58.3	34.5		Present	VH/4	
TANZANIA	TEGEMEO	OPV				White	Absent	0	
	PATO	OPV					Absent	0	
	P9406								
	P9405								
ZAMBIA	KUYUMA	OPV	9.4	74.4	55	White	Absent	0	EMP
	SIMA	OPV	6.9	76.4	56.2	White	Absent	0	
	ZVS-15	OPV				White	Absent	0	EGQ
	ZVS-12	OPV							
	WP-13	OPV					Absent	0	
	MMSH-375	H	8.2	59	32.2		Present	VH/4	MTC
	MMSH-413	H	7.8	56.9	32.5		Present	VH/4.5	HTC/EMA
	MMSH-1257	H	12.5	76.2	57.2	White	Absent	0	
	MMSH-625	H							
	MMSH-1324	H							GGQ

Continuation: Table 4.1.2

Single-country	Variety name	H/OPV[A]	Water absorption[I] (%)	Agtron Reflectance value[J] (dry)	Agtron Reflectance value[J] (wet)	Flour colour	Testa (seed coat)	Tannin content[K] ≈% (g ce/ 100 g)	Remarks[L]
ZIMBABWE	SV-2 (ICSV 88060)	OPV	11.5	76.3	57.4	White	Absent	0	
	SV-3 (NL 499)	OPV				White	Absent	0	
	SV-4 (NL 330)	OPV				White	Absent	0	
	ZWSH-1	H	10.6	74.5	55.2	Off-white	Absent	0	
SOUTH AFRICA	NS 5511	H					Present	8.11±0.12/GH	
	PAN 8625	H				Pink	Present	8.13±0.23/GH	HMQ
	PAN 8609	H				Pink	Absent	N/GM	HMQ
	PAN 8564	H				Pink	Absent	N/GM	GMQ/HMQ
	PAN 8738	H				Pink	Absent	N/GM	
	PAN 8247	H				Pink	Absent	N/GM	
	BANJO	H						N	
	NS 5655	H						N/GM	
	OVERFLOW	H						N	
	PAN 8706W	H				White	Absent	N	GG/MQ
	PAN 8648W	H				White	Absent	N	
	NS 5751	H					Absent	GM	
	MR BUSTER	H							
	PAN 8407	H				Pink	Absent	N	
	PAN 8017	H				Pink	Absent	N	
	PAN 8474	H				Pink	Absent	Y	
	PAN 8657	H				Pink	Absent	N/GM	
	PAN 8816	H				Pink	Absent	N/GM	HMQ
	PAN 8677	H				Pink	Present	8.11±0.12/GH	
	PAN 8127								
	PAN 8507	H				Pink	Present	8.11±0.12/GH	
	PAN 8488	H				Pink	absent		

Continuation: Table 4.1.2

Multiple-country	Variety name	H/OPV[A]	Water absorption[I] (%)	Agtron Reflectance value[J] (dry)	Agtron Reflectance value[J] (wet)	Flour colour	Testa (seed coat)	Tannin content[K] ≈% (g ce/ 100 g)	Remarks[L]
BOTSWANA	MACIA SDS 3220	OPV	14.3	75.3	54.3	White	Absent	0	
MOZANBIQUE	MACIA SDS 3220								
NAMIBIA	MACIA SDS 3220								
TANZANIA	MACIA SDS 3220								
ZIMBABWE	MACIA SDS 3220								
MALAWI	ICSV 112 (PIRIRA 2)	OPV	7.4	72.6	52.2	White	Absent	0	
MOZAMBIQUE	ICSV 112 (CHOKWE)								
SWAZILAND	ICSV 112 (MRS 12)								
ZIMBABWE	ICSV 112 (SV-1)								

A- OPV: Open pollinated variety, H: Hybrid

B- L: Large (%>4.0 mm), M: Medium (%2.6-4.0 mm), S: Small (%<2.6 mm)
C- (I: Inconspicuous, VC: Very conspicuous, ET: Easily threshed)[2], (ET: Excellent threshability, GT: Good Threshability)[5]
D- (C/W: Creamy-white, P/W: Pinkish-white, Y/W: Yellowy-white, C/W/BS: Creamy-white with brown speckles, C/Y/W: Creamy-yellow-white)
E- TADD (Tangential abrasive dehulling device) use in determining dehulling loss (%) indication of grain hardness (harder grain results in low dehulling loss implies higher milling) yield.
F- (C/H: Corneous/Hard, C/VH: Corneous/Very hard, C/FH:Corneous/Fairly hard, C/MH: Corneous/Medium hard, C/MS: Corneous/Medium soft, FH: Fairly hard, MS: Medium soft, S: Soft, S/I: Soft to intermediate, IH: Intermediate hardness, P/H: Pearly/Hard)[2]

G- (Scale: 1 - floury/soft, 3 - intermediate, & 5 - corneous/hard)[1]

H- (E: Excellent, VG: Very good, G: Good, FG: Fairly good, Av: Average, F: Fair, P: Poor),
I- Water absorption (%) amount water absorbed in a given time (determine conditioning of the grain before dehulling and milling)
J- Agtron reflectance value measure of whiteness of milled sample (High value means white, Low value means dark)

Continuation: Table 4.1.2

K- (VL: Very low, VH: Very high, Y: Yes, N: No, GM: Non-tannin malting type, GH: Tannin malting type, ce: catechin equivalent)
L- (GG/MQ: Good grain & milling quality suitable for flour production, HMQ: High malting quality, EMP:Excellent milling properties, EGQ: Excellent grain quality, GGQ: Good grain quality, MTC: Moderate tannin content, HTC: Higher tannin content, EMA: Excellent malting attributes)

Thousand kernel weight (TKW) of these improved cultivars ranges between 16.6 and 35.6 g. The cultivars with TKW above 30 g include Pato, Sima (OPV) and PAN 8247 and 8389 (H), while the cultivars with the lowest TKW are MRS 13, ZWSH-1 and Macia. According to Gomez *et al*. (1997), sorghum cultivars with TKW >20 g are suitable for milling. This is due to correlation between TKW and the grain hardness, which results in good milling quality attributes. The TKW data reported by Chiremba (2009) for NS 5511 and 5655, and PAN 8564 cultivars were higher than that of Van Loggerenberg (2001). This may be attributed to differences due to growing season. Percent floater is an indication of grain density, the higher the percent floaters the lower the density (Kirleis and Crosby (1982). MRS 94 and MMSH-413 as well as MMSH-375 have very high percent floaters, 100 and 96%, respectively. This may be attributed to their high tannin content and mostly floury endosperm texture. The cultivars with the lowest percent floaters are Tegemo (15%) and Sima (19%). This implies that these latter cultivars have high grain density. This may be attributed to their grain endosperm texture, which is mostly corneous, as well as high proportion of large kernel size fractions in Sima.

Sorghum kernel endosperm textural properties reflects it hardness attributes, which is based on relative proportion of corneous to floury endosperm (Chandrashekar and Mazhar, 1999; Rooney and Miller, 1982). Sorghum grain hardness is an important grain quality parameter. This is because of it influences processing properties and end-use quality suitability (Taylor, Dewar, Taylor and Von Ascheraden, 1997). Cultivars with endosperm texture ranging from intermediate to corneous are considered to be suitable for milling (Gomez *et al*., 1997). They are hard and have low dehulling losses. Rami, Dufour, Trouche, Fliedel, Mestres, Davrieux, Blanchard and Hamon (1998) suggested suitable types of utilisation based on sorghum endosperm textural attributes: corneous grains for thick porridges, intermediate type for boiled rice-like products, malting and brewing and the floury ones for fermented breads.

ICSV 112, BSH-1 and MRS 13 scored very high on the scale (4.7, 4.5 and 4.3), respectively of Gomez *et al*. (1997). This characterised them as having corneous and hard grain endosperm texture. MRS 13 was scored between 2.8 and 3.0 on the scale (Mgonja *et al*., 2005), which means intermediate to corneous endosperm. WP-13, an OPV scored lowest on the scale (1.8-2.0) (Mgonja *et al*., 2005), while Gomez *et al*. (1997) reported MMSH 413 (H) to score 1.2. This indicates soft grain endosperm texture (floury). However, Mgonja *et al*. (2005) reported MMSH

413 as floury to intermediate endosperm texture (2.45). A similar trend was noted for Sima, which was reported a floury to intermediate by Mgonja *et al*. (2005) and slightly corneous by Gomez *et al*. (1997). The rest of the cultivars are scored between 2.0 and 4.0. This implies that their grain texture is either floury to intermediate, or intermediate to corneous. All the PAN cultivars have endosperm textures ranging from intermediate to corneous, with the exception of PAN 8609 which is entirely corneous. The differences in grain hardness data for MRS 13 and MMSH 413 reported by Gomez *et al*. (1997) and Mgonja *et al*. (2005) may be due to effect of year/season differences.

Most of these improved sorghum OPVs and Hs can be classified as mixed endosperm texture sorghum. This is based on ICC Draft Standard 176 (ICC, 2008) recommendations that >10 and < 90% floury, or intermediate or corneous sorghum grains should be grouped as mixed endosperm. Rooney and Miller (1982) noted that sorghum cultivars with a higher proportion of corneous endosperm give higher milling yield. This may be attributed to influence of grain endosperm hardness as it affects dehulling loss (Gomez *et al*., 1997).For example, ICSV 112 which scored 4.7, has the least dehulling loss (10.4%) with excellent milling yield (87.0%). MRS 94 with the highest dehulling loss (39.6%) has poor milling yield (58.7%). There are some correlations between kernel size, TKW, grain density and grain texture, with regards to milling quality attributes. According to Van Loggerenberg (2001), grain TKW is positively correlated with grain texture, while grain density is negatively correlated. This type of correlation was shown by the MRS 94, MMSH-375 and MMSH-413 cultivars. These cultivars are high-tannin cultivars, characterised by a high proportion of floury endosperm (Waniska, Poe and Bandyopadhyay, 1989), which results in low TKW and very high percent floaters (low grain density).

According to Kirleis and Crosby (1982), the relationship between TKW and grain density is directly proportional, that is high TKW implies high grain density but low percent floaters and vice versa. The Sima cultivar reflected this relationship between the above parameters, which is high TKW and very low percent floaters, resulting in high milling yield (85.6 %). The effect of kernel size uniformity and grain hardness based on endosperm texture shows somewhat in the milling yield. Pilira 1, Sima and Mahube have medium to large and mostly large kernel size, respectively. However, Pilira 1 and Sima both have intermediate to corneous endosperm texture, which may have resulted in higher milling yield. According to Munck, Bach Knudsen and Axtell

(1982), large grain size with less hardness results in cracking, which leads to low milling yield. This may have contributed to lower milling yield in Mahube cultivar in comparison to the other two cultivars.

Sorghum grain water absorption property also gives an indication about grain endosperm texture, through measuring the level of water penetration (Gomez *et al*., 1997), which in turn has an influence on milling and malting processing. MRS 94 and 13 have the lowest water absorption level (4.3 and 4.6%, respectively), while Macia has the highest level of water absorption (14.3%). Sorghum floury endosperm comprises loosely packed cells with small voids in between and low protein (Rooney and Miller, 1982). This attribute increases the rate of water absorption in floury endosperm compared to corneous endosperm.

Agtron reflectance determination is a measure of the colour quality of grain flour, based on the degree of whiteness/darkness (Gomez *et al*., 1997). This can be expressed as on both dry and wet flour bases. The wet Agtron reflectance value gives an indication of colour quality expected in the product end-use application. The following cultivars have high Agtron reflectance values in the range of 76.2-76.4 (dry) and 56.2-57.4 (wet): BSH1, Sima, MMSH-1257 and SV-2. These data correspond with their visual grain colour, which is creamy-white. The cultivars with the lowest Agtron values are MRS 13 and 94, MMSH-375 and 413, ranging between 56.2 and 59.0 (dry) and 32.2-34.5 (wet). Their low Agtron values for both dry and wet correspond with their visual grain colour, which is either red or brown, and their high tannin content. Generally, the wet Agtron value is lower than dry, due to reduction in light reflection. The differences in flour lightness data recorded for Macia, BSH 1 and Segaolane B cultivars as shown in the database, are as a result of differences in the principle of the two methodologies applied. The Agtron reflectance value is slightly lower than L-value of the flour.

The resultant flour colour quality of the above cultivars is a reflection of their overall grain colour. They all have white pericarp, due to absence of colour pigments, while PAN cultivars and Mahube with red grain colour attributes produced pink and pinkish-white flour, respectively. The flour colour quality of cultivars with colour pigments could be attributed to oxidative interactions between colour pigments especially anthocyanins present in the grain with the starch components during milling (Beta, Corke, Rooney and Taylor, 2001), as well as possibility of pieces of broken pericarp in the flour and migration of colour pigment into the endosperm. Van

Loggerenberg (2001) noted that grain with good colour attributes will produce milled products with good colour quality. Flour colour quality can be improved with appropriate processing procedures. For example, the level of abrasion required to produce acceptable colour depends on whether the grain has a pigmented pericarp (Van Loggerenberg, 2001).

4.1.3.4 Malting and brewing quality attributes

The following quality parameters in the database (Table 4.1.3) are important in determining suitability of the sorghum cultivars in malting and brewing processes. Their measurement is based either on analyses carried out during malting or on the final malt produced (Van Loggerenberg, 2001). They are Germinative Energy (potential of the grain to germinate during malting), water uptake (level of hydration of the grain during steeping), Diastatic power (DP) (based on the total amylase activity of the malt), Free Amino Nitrogen (FAN) and extract yield/content.

All the tannin cultivars (PAN 8625, 8389, 8474, 8677, 8229 and NS 5511) have very high water uptake during steeping, between 44.0-50.0%. The reason for high level of water uptake in tannin cultivars is because they have high proportion of floury endosperm texture (Waniska *et al*., 1989). The level of water uptake recorded for the tannin cultivars corresponds with the level of water uptake reported for barley grain (44-46%) (Agu and Palmer, 1998). These non-tannin cultivars (PAN 8564, 8816, 8247 and NS 5655) have water uptake ranging from 39.0 to 43.0%, which is slightly higher than the level normally absorbed by most non-tannin sorghums during steeping (33-35%) (Chiremba, 2009). The slightly high level of water uptake in the above non-tannin cultivars is due to their endosperm texture, which is intermediate to corneous. The rest of the cultivars have water uptake range between 33.8 and 35.5%, which falls within the level normally associated with sorghum grain (33-36%) (Evans and Taylor, 1990).

Table 4.1.3: Malting and Brewing Quality Characteristics of Improved Sorghum Varieties and Cultivars

Single-country	Variety name	H/OPV[A]	Germination count[B] (24 h) (%)	Germination count[B] (48 h) (%)	Germination count[B] (72 h) (%)	Water uptake[C] (%)	Malting loss[D] (%)	Total loss[E] (%)	Malt Diastatic Power (DP)[F] (SDU/ g)	Malt FAN[G] (mg FAN/100 g)	Grain extract content[H] (%)
BOTSWANA	BSH1 (SDSH 48)	H	88	99			12.8	18.2	31.2		
	MAHUBE (SDS 2583)	OPV									
	MMABAITSE	OPV									
MALAWI	PILIRA 1 (ICSV 1)	OPV									
MOZAMBIQUE	MAMONHE	OPV									
SWAZILAND	MRS 13 (SDSV 1513)	OPV	37	65			11.0	13.0	15.3		
	MRS 94 (SDSV 1594)	OPV	27	48			10.5	11.4	7.5		
TANZANIA	TEGEMEO	OPV									
	PATO	OPV									
	P9406										
	P9405										
ZAMBIA	KUYUMA	OPV	98	99			17.9	28.3	40.4		
	SIMA	OPV	97	98			15.6	20.9	20.7		
	ZVS-15	OPV									
	ZVS-12	OPV									
	WP-13	OPV									
	MMSH-375	H	74	90			13.3	21.2	40.2		
	MMSH-413	H	85	94			13.2	23	38.2		
	MMSH-1257	H	84	89			13.5	17.4	27.9		
	MMSH-625	H									
ZIMBABWE	SV-2 (ICSV 88060)										
	SV-3 (NL 499)										
	SV-4 (NL 330)										
	ZWSH-1										
	NS 5511										

Continuation: Table 4.1.3

Single-country	Variety name	H/OPV[A]	Germination count[B] (24 h) (%)	Germination count[B] (48 h) (%)	Germination count[B] (72 h) (%)	Water uptake[C] (%)	Malting loss[D] (%)	Total loss[E] (%)	Malt Diastatic Power (DP)[F] (SDU/ g)	Malt FAN[G] (mg FAN/100 g)	Grain extract content[H] (%)
SOUTH AFRICA	NS 5511	H		82.7±6.1	93.0±3.0	41.2±1.8/45.0/39.6	16.8±0.8		46.6±8.7/63.0	122±33	70.7
	PAN 8625	H		88.3±4.7	94.1±3.7	40.9±1.5/44.0	19.1±4.4		49.1±8.4/65.0)	129±43	46.4
	PAN 8609	H		79.6±8.5	92.7±2.1	35.0±2.1/42.0	18.5±1.8		43.1±6.4/46.0	124±34	73.1
	PAN 8564	H		85.0±7.7	95.2±2.7	33.4±1.9/40.0/36.4	17.0±2.0		40.3±6.2	130±39	
	PAN 8247	H		78.7±9.0	92.8±2.6)	33.8±1.6/40.0	17.7±1.2		42.6±6.2/41.0)	114±25	74.3
	BANJO	H							25.0		75.0
	NS 5655	H		87.5±4.5	95.9±1.9	36.5±2.4/39.0/38.8	18.2±1.1		39.1±7.6/38.0	123±31	74.5
	OVERFLOW	H							27.0		74.3
	PAN 8706W	H									
	PAN 8648W	H							26.0		75.3
	NS 5751	H									
	MR BUSTER	H									
	PAN 8407	H							24.0		72.7
	PAN 8017	H							38.0		72.6
	PAN 8474	H							44.0		63.6
	PAN 8657	H		80.2±5.4	92.2±3.4	34.8±1.8	18.5±2.0		45.0±5.7/46.0	119±27	74.2
	PAN 8816	H		84.0±4.8	91.8±2.8	36.8±1.7/43.0	18.3±0.9		43.4±6.7/49.0	121±33	74.2
	PAN 8677	H							60.0		67.8
	PAN 8507	H		85.6		35.5	16.1		71.0		63.4
	PAN 8488	H		81.7±8.9	90.7±5.9	35.1±1.3	19.7±3.7		37.8±5.1	113±34	
Multiple-country											
BOTSWANA	MACIA SDS 3220	OPV	93	98			15.4	23.9	42.6		
MOZAMBIQUE	MACIA SDS 3220										
NAMIBIA	MACIA SDS 3220										
TANZANIA	MACIA SDS 3220										
ZIMBABWE	MACIA SDS 3220										
MALAWI	ICSV 112 (PIRIRA 2)	OPV	94	95			16.1	25.9	31.3		
MOZAMBIQUE	ICSV 112 (CHOKWE)										
SWAZILAND	ICSV 112 (MRS 12)										
ZIMBABWE	ICSV 112 (SV-1)										

Continuation: Table 4.1.3

A- OPV: Open pollinated variety, H: Hybrid
B- Germination count (%) after 24, 48 and 72 h determine the viability of the grain (< 65% not suitable to malt the grain)

C- Water uptake (%) measure of grain hydration after steeping
D- Malting loss (%) given as difference between initial grain weight and dry malt weight divided by initial grain weight
E- Total loss (%) given as difference between initial grain weight and polished malt (kernels minus external roots and shoots) weight divided by initial grain weight
F- Malt DP measure of combined activities of α and β- amylases (SDU/ g malt: Sorghum Diastatic Units per gram of malt dry basis)
G- Malt Free- Amino Nitrogen (FAN) consist of amino acids and peptides (Minimum of 110 mg FAN/ 100 g dry basis) (including external roots and shoots) in the malt suitable for brewing

H- Grain extract content measure of grain starch content and availability (% Dry basis)

The water uptake during steeping data reported varies for some cultivars. This may be due to differences in sample sources, as well as the season/year the samples were analysed. These variations could also be linked with the methodology applied. The values reported by Van Loggerenberg (2001) for PAN 8564, NS 5511 and NS 5655 are slightly lower than those of Chiremba (2007). The higher water uptake reported by Chiremba for 2007 compared to the 2009 season may be due to effect of seasonal variations. Water uptake is very important in cultivar application with regards to malting and brewing. According to the findings of Dewar, Taylor and Berjak (1997a), sorghum malt quality is directly linked to the level of water uptake during steeping. This is because the water absorbed initiates metabolic activity in the grain during germination.

As stated, GE indicates grain germination ability during malting. It is a rough guide to the level of endogenous hydrolytic enzymes mobilised in the grain (Taylor and Dewar, 1992). BSH1, Kuyuma, Sima, Macia, ICSV 112, SV-2, MMSH-413 and 375 have germination counts after 48 h ranging from 90 to 99%. The GE for most of the PAN and NS cultivars were determined after 72 h and range from 90.7 to 97.0%. MRS-13 and 94 (OPVs) have the lowest germination count (GE after 48 h) and no information is available regarding their GE after 72 h. According to Gruwel, Yin, Edney, Schroeder, MacGregor and Abrams (2002), seed viability can be attributed to genetics, pre-harvest effects, and mechanical damage during harvesting and handling, storage conditions and microbial attack. These factors may be responsible for the low GE reported for MRS-13 and 94 (65 and 48%), respectively. Taylor and Duodu (2009) noted that about 90% germination count is recommended to ensure good malt quality.

Malting loss is directly inversely linked with GE and it is also influenced by germination conditions applied during malting process (Agu and Palmer, 1996). Malting loss is due to metabolic and leaching losses during malting (Owuama, 1997). This is as a result of dry matter loss through carbon dioxide and water produced, due to carbohydrate utilisation during malting process. MRS 13 and 94 have the lowest malting loss (10.5 and 11.0%). Low malting loss in MRS-13 and 94 may be linked to their low GEs, based on the relationship between malting loss and GE as stated above. PAN 8488 has the highest malting loss (19.7%). However, total malting loss is expressed as malting loss plus the loss of mass due to removal of the shoots and roots (Gomez *et al*., 1997). MRS 13 and 94 cultivars have the least loss (11.4 and 13%), while Macia, ICSV 112 and Kuyuma have the highest total loss (23.9, 25.9 and 28.3%), respectively. The data obtained by Van Loggerenberg (2001) and Chiremba (2007) are lower than the values obtained for the analysis conducted by Chiremba (2009) for the same cultivars. This may be attributed to effect of season/year.

Diastatic power (DP) is the most important sorghum malt quality parameter, which determines sorghum suitability in malting and brewing (Taylor, 2003). DP is the combined activity of α- and β-amylase synthesised in the malted grain (Raschke, Taylor and Taylor, 1995). These authors reported that minimum DP between 28 and 30 SDU/g malt has been set as the standard for sorghum cultivars in malting and brewing application. Among the OPVs, Kuyuma and Macia have DP as high as 40.4 and 42.6 SDU/g, respectively. The other OPVs (MRS 13 and 94, Sima and SV-2) with exception of ICSV 112 having DP value of 31.3 SDU/g have DPs below the recommended standard. No information is available regarding DPs of OPVs: Mahube, Mmabaitse, Pilira 1, Mamonhe, ZVS-12 and 15, WP-13, SV-3 and -4.

In South Africa, DP is the criterion used in categorising sorghum cultivars into groups (Chiremba, 2009). The groups are GL- non-malting and non-tannin, GM- malting and non-tannin and GH- malting and high-tannin. Table 4.1.3 shows that the GH group has the highest DP, ranging between 53.0 and 65.0 SDU/g, followed by GM group ranging from 33.4-53.0 SDU/g and the GL group ranges between 28.3 and 36.0 SDU/g. PAN 8127 and 8507 are tannin sorghums that are yet to be approved. Both have very high DP (64.0 and 71.0 SDU/g), respectively. PAN 8488, 8043 and 8141 are also not yet approved but are non-tannin sorghums, with DPs between 48.0 and 58 SDU/g. It is not known why tannin sorghums produce malt with high DP. However, it could be because the level of water uptake is higher than that of non-tannin cultivars, as mentioned above. Thus, as a result of adequate hydration, enzymic activities would be maximised during malting, as mentioned by Agu and Palmer (1998).

The variations in data reported for the DPs of the following cultivars may be as a result of season/year differences. They are NS 5511, PAN 8564, 8229, 8657, 8677, 8389 and 8625, which all have higher DP values for the year 2010 than 2009. But cultivars such as PAN 8247, 8806, 8648, 8474, 8568 and 8488, as well as Banjo, NS 5655 and Overflow have lower DP values.

Malt FAN is also an important parameter that determines sorghum malt quality suitability in beer brewing. This is because FAN level determines the activity of yeast during fermentation process, as the source of amino acids for effective growth and functionality (Chiremba, 2009; Lekkas, Stewart, Hill, Taidi and Hodgson, 2007). FAN is produced through the activity of proteases, which are mainly activated in the grain during malting process (Evans and Taylor, 1990). FAN data is only available for some of the PAN and NS cultivars. The minimum level of FAN in the malt suitable for sorghum beer (opaque beer) brewing is 110 mg FAN/100 g (Chiremba, 2009). The highest level of FAN was recorded for NS 5511 (GH) with 140 mg FAN/100 g, followed by PAN 8625 (GH) and 8564 (GM) having FAN level of 129 and 130 mg FAN/100 g, respectively. The other cultivars have FAN levels above the recommended minimum level and they are all non-tannin cultivars, except PAN 8389 which is a tannin cultivar type. Their level of FAN ranges between 113 and 124 mg FAN/100 g.

The high level of FAN in GH cultivars could again be attributed to their floury endosperm texture, which permits high water uptake as mentioned above in high tannin cultivars. This effect may have resulted in more protease activity in malt. The FAN value recorded for NS 5511 by Chiremba (2009) is lower than that by Van Loggerenberg (2001). PAN 8564 and NS 5655 FAN levels have higher values (Chiremba (2009) than those of Van Loggerenberg (2001). Again, the most likely reason for the difference is a seasonal effect on the samples analysed.

Malt extract yield/content is the estimate of fermentable sugars and dextrins that can be obtained when the malt is mashed (Briggs, Hough, Stevens, and Young, 1981). Malt extract is the most important single parameter that determines barley malt suitability in beer brewing, because it is directly related to the of level of starch hydrolysed by the amylases, as well as to starch content and availability, which in turn are influenced by protein content and composition of the grain (Taylor and Duodu, 2009). According to Janes and Skerritt (1992), protein content of the grain negatively correlates with malt extract yield. From the data, all the tannin sorghum cultivars give malt extract yields below 70.0%, except NS 5511 (70.7%). The non-tannin cultivars give higher malt extract yield, above 70.0%.

Low extract yield in tannin sorghum cultivars can be attributed to tannin interaction with starch and amylase enzymes during brewing (Waniska *et al*., 2004). This may limit tannin sorghum cultivars' suitability as adjunct/starch source in brewing. Pre-treatment of high-tannin sorghum with sodium hydroxide (NaOH) effectively detoxifies and reduces tannin content of the grain to zero (Beta, Rooney, Marovatsanga and Taylor, 2000). This is probably achieved through oxidative reaction between NaOH and phenolic groups, as a result of opening and rearrangement of the phenolic ring structure (Cilliers and Singleton, 1990). Therefore, this would result in oxidative polymerisation of condensed tannins (Porter, Hrstich and Chan, 1986). This process could be applied in utilisation of tannin sorghums as brewing adjuncts.

4.1.4 CONCLUSIONS

The available improved OPV and H sorghums with their high grain yield potential can improve the level of sorghum production in southern Africa region. OPV and H sorghums with white grain colour, hard endosperm texture and absence of tannins make them suitable for milling and end-use application in porridge products. PAN and NS (Hs) are suitable for utilisation in malting due to their high DP potential. Therefore they could serve as suitable replacement for barley in lager beer brewing.

The above shows that even the limited amount of quantitative and qualitative information available in SADC on the improved OPV and H sorghum cultivars can be applied to a certain extent in grouping them in relation to their processing and end-use qualities. This information could also be utilised in developing a grading system, as well as the setting of quality standards that could be used in selecting these improved OPV and H sorghums for specific end-uses. However, further and more complete quality characterisation of these improved varieties and cultivars is very necessary, for effective selection of these improved sorghums for specific area of application.

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4.2 SELECTED IMPROVED SORGHUM VARIETIES AND CULTIVARS RELEASED IN SOUTHERN AFRICA: GRAIN QUALITY ATTRIBUTES AND THEIR EFFECTS ON WORT QUALITY PROPERTIES

ABSTRACT

Five different sorghum types: white tan-plant, white non-tan plant, red non-tannin, white tannin (type II), and red tannin (type III) were evaluated for the effects of their grain quality traits on their wort quality attributes in a whole grain and commercial enzymes mashing process. The non-tannin sorghum types had mostly corneous to intermediate endosperm and the tannin sorghum types were characterised as floury endosperm, as expected. The protein content of the sorghum types between 6.90 and 15.10 g/100 g slightly correlated with wort FAN ($p<0.1$, r =0.511). Grain tannin content was up to 4.53 g catechin equivalents/100 g, which contributed significantly to the high level of total phenols in the tannin sorghums. The tannin property correlated significantly and negatively with wort extract ($p<0.001$, r =-0.846), fermentable sugars ($p<0.001$, r = -0.810) and FAN ($p<0.1$, r = -0.498). This can be linked to tannin inactivation of the exogenous enzymes during mashing, resulting in poor wort quality attributes in the tannin sorghum types. Tannin inactivation by steeping in dilute NaOH solution did not consistently improve wort quality. Contrary to expectations, tannin still remained significantly and negatively correlated with wort quality attributes, except for slightly lower correlation coefficients. Malting the sorghum types combined with exogenous enzymes mashing yielded great improvement in wort quality. The wort quality attributes of the red non-tannin sorghums ranged as followed: extract (75.9-80.9); FAN (42.2-104.9 mg/l); total fermentable sugars (9.51-10.73 g/100 ml). The red non-tannin sorghums have potential as adjunct in lager beer brewing due to their similar wort quality attributes to white tan-plant sorghums.

4.2.1 INTRODUCTION

Sorghum is used in lager beer brewing in the form of malt and/or raw sorghum (adjunct) (Mackintosh and Higgins, 2004). Sorghum as the primary ingredient in lager beer brewing has been successfully developed in Nigeria (Agu and Palmer, 1998), East Africa, especially Uganda (Mackintosh and Higgins, 2004), southern Africa and the USA (Taylor, Schober and Bean, 2006). The successful research that led to these developments covered the following areas: enzymes in sorghum malting, sorghum malting, and sorghum brewing technology (Taylor and Dewar, 2001; Owuama, 1997). However, identification of sorghum types with specific grain characteristics suitable for sorghum brewing remains a major area of concern (Agu, Okenchi, Aneke and Onwumelu, 1995; Taylor *et al*., 2006). This may be attributed to lack of studies that systematically look into different types of sorghums, with the aim of understanding their mashing properties and wort quality attributes as applied to lager beer brewing.

Larson and Erbaugh (2007) recommended the use of improved sorghum cultivars in clear (lager) beer brewing. However, application suitability of the different types of sorghum available depends on their grain quality attributes (Obilana, 2004). Sorghum grain structural and chemical composition properties are the main factors that influence their end-use. Determination of sorghum grain quality properties as influenced by cultivar differences has been highlighted as one of the means of improving sorghum brewing quality potentials (Ezeogu, 2007). The following grain quality attributes were highlighted by Mackintosh and Higgins (2004) as required specifications for sorghum grain suitable for brewing purposes: excellent starch content (>72%), protein content (10.0% ±1.0), fat content (3.5%±0.5) and tannin (<1%). They also make particular reference to small grain size attribute, as it negatively influences the above mentioned grain composition quality with exception of tannin content.

Mashing of malted sorghum in lager beer brewing produces the high level of Free Amino Nitrogen (FAN) needed to ensure efficient buffering capacity and optimum yeast performance during fermentation (Bajomo and Young, 1993; Palmer, 1989). However, a low level of fermentable sugars is produced in sorghum malt mashing, which has been attributed to low diastatic power (DP) (amylase activity) in the malt (Agu and Palmer, 1998). Sorghum malt mashing requires addition of exogenous enzymes in order to increase the wort composition in terms of the level of total fermentable sugars. Sorghum application in the form of raw grain in place of malted grain has been considered as a more logical and cost-effective approach (Taylor *et al*., 2006; Mackintosh and Higgins, 2004). Bajomo and Young (1993) reported that application of a suitable mashing regime developed for sorghum with minimal use of heat stable α-amylase and proteolytic enzymes produces a level of hot water extract yield that is commercially acceptable. Wort quality attributes is another factor that play a major role in determining suitability of the available improved sorghum cultivars in lager beer brewing. Bamforth (2001) noted that the influence of cultivar differences due to sorghum type is a major cause of variability in wort composition. The objective of this study was therefore to systematically identify which of the types of sorghum that are grown in southern and eastern Africa are suitable as adjunct for sorghum lager beer brewing with exogenous enzymes.

4.2.2 MATERIALS AND METHODS

4.2.2.1 Materials

Fourteen improved sorghum varieties and cultivars, mainly southern Africa types, were selected based on their grain type. Red, Tannin (type III): PAN 3860 and NS 5511 (Hs); Red, Non-tannin: PAN 8564, NK 283, SNK, and MR BUSTER (Hs); White, Tan-plant: Orbit and BSH1 (Hs), Macia and KAT 369 (OPVs); White, Not tan-plant: Mmabaitse and Kanye Standard (OPVs); White, Tannin (type II): Feterita (Sudan) and Tannin white sorghum (Zimbabwe) (OPVs). The whole sorghum grain samples were milled using a hammer mill (Falling Number AB, Huddinge, Sweden) fitted with a 1.0 mm opening screen. The flour samples were stored in zip-lock type polythene bags at 6-8ºC until analysis.

The commercial enzyme preparations used were Cerezyme 2X Sorghum and Fungamyl 4000 BG, which were kindly donated by Novozymes SA (Pty) Ltd, Marlboro, South Africa.

4.2.2.2 Methods

<u>**Pre-treatments**</u>

Steeping- Tannin was inactivated by steeping the tannin sorghums (PAN 3860, NS 5511, Feterita and Tannin white sorghum (Zimbabwe)) in 0.2% (w/v) NaOH solution for six hours (1 part NaOH solution and 1 part grain) and rinsed with water and steeped in water for another six hours. The steeped grain samples were oven dried at 50˚C for 7-8 hours.

Malting- Two sorghum varieties were selected for malting, Macia and Tannin white sorghum (type II). The laboratory malting method applied was according to Taylor, Dewar, and Joustra (2005). Malt was dried at 50ºC, after which the roots and shoots were removed by putting the whole malt grains in a coarse mesh nylon bag and rubbing to break the roots and shoots off, and sieve through the mesh. Macia malt and White Tannin malt had Diastatic Power of 11 and 21 Sorghum Diastatic Units (SDU)/g (peptone extract method), respectively.

4.2.2.2.1 Mashing

Mashing of milled sorghum samples were conducted using a BRF mashing bath (Brewing Research Foundation, Nutfield, UK). Flour samples (100 g dry weight basis) were mixed with 318 ml distilled water containing 222 mg/l calcium chloride (80 ppm) in pre-weighed mashing beaker and pre-heated to 50ºC, to give a grist/liquor ratio of approximately 1:3. At a pH between 5.6 and 5.8, Cerezyme 2X sorghum (0.159 g) was added and followed by a protein rest for 30 min., at 50ºC. The mash was cooked at 85ºC for 45 min and cooled down to 58ºC. Freshly prepared Fungamyl 4000 BG (0.159 g) was added to the mash (pH 5.5) and mashed at 58ºC for 60 min. The mash was heated to 72ºC and rested for 15 min or until starch negative as tested by iodine. The mash temperature was raised to 78ºC. The mash was cooled down and weighed. The weight was then made up to 450 g with distilled water. The wort was filtered using cheese cloth and the wort filtrate centrifuged at 2714 g for 10 min., at 4ºC. The clarified wort stored frozen at -18ºC.

4.2.2.2.2 Analyses

<u>Grain quality attributes</u>

Grain size- by using sieves with screen opening sizes of 4.0 mm and 2.36 mm, according to Gomez, Obilana, Martin, Mazvamuse and Monyo (1997).

1000 kernel weight- determined based on the weight of sound 1000 kernels counted.

Hectolitre (Test) weight- by using a 500 ml cup according to AACC Official Method 55-10 (American Association of Cereal Chemists (AACC) International, 2000) and expressed in kg/hl.

Endosperm texture- by visual estimation of the grain endosperm texture according to ICC Draft Standard 176 (ICC, 2008).

Moisture content- determined according to AACC Method 44-15A (AACC International, 2000).

Protein content- by combustion analysis according to AACC Method 46-30 (AACC International, 2000).

Tannin content- by using the modified Vanillin-HCl method of Price, Van Scoyoc and Butler (1978). The tannin content was expressed in mg Catechin Equivalents (CE)/g.

Total phenol content- by using Folin-Ciocalteu method of Singleton and Rossi (1965). The total phenol content was expressed in mg CE/g.

Wort quality attributes

Wort Extract- by refractometry and expressed in ºBrix, and by specific gravity as described in European Brewery Convention Method 6.6 (EBC, 1998).

Wort FAN- by ninhydrin colorimetry method according to the European Brewery Convention Method 8.8.1 (EBC, 1987).

Wort Bitterness- by European Brewery Convention Method 9.6 Bitterness (EBC, 1987). Pure *iso*-octane was used as reference standard to zero the instrument.

Wort fermentable sugar spectrum- by European Brewery Convention Method 8.5 Fermentable Carbohydrates (EBC, 1987). A high-performance liquid chromatograph (HPLC) fitted with refractive index detector and Rezex RHM-Monosaccharide column: 300 x 7.8 mm, Rezex H+ (8%) Monos. (Phenomenex, Torrance, CA) was used.

Wort colour- wort samples were filtered through kieselguhr and colour determined by tristimulus colorimetry method, using a Minolta colorimeter (Chroma Meter CR-400, Konica Minolta Sensing, Japan) in L* a* b* values.

4.2.2.3 Statistical analysis

All experiments were repeated at least once. Data were analysed by one-way analysis of variance (ANOVA). Significant differences among the means were determined by Fischer's least significant difference (LSD) test ($p<0.05$). Pearson correlations were performed to determine relationships between all the parameters measured.

4.2.3 RESULTS AND DISCUSSION

As stated, five different types of improved sorghum varieties and cultivars were used: Red Tannin (type III) (2), White Tannin (type II) (2), Red Non Tannin (4), White Tan-plant (4) and White non Tan-plant (2). This was to determine the most suitable sorghum type(s) for application as adjunct in lager beer brewing, based on their unique grain quality attributes as they influence wort quality properties.

4.2.3.1 Grain quality attributes

All 14 sorghum varieties and cultivars had a very high percentage of medium size fractions, ranging between 85.4 and 99.9% (Table 4.2.1). Sorghum type had no influence on their grain size attribute. The grain size data correspond with results reported by Gomez *et al*. (1997). The thousand kernel weight (TKW) property for all the sorghum types ranged from 16.7 to 31.9 g. TKWs of Macia and BSH1 (white tan-plant type) were lower than reported by Gomez *et al*. (1997) (16.8 and 21.0 g), respectively, while PAN 8564 (red non-tannin sorghum) and NS 5511 (type III tannin sorghum) (26.5 and 25.7 g), respectively were higher than reported by Chiremba (2009). These variations may be due to cultivation environmental factors affecting the grain quality attributes. The white tan-plant and red non-tannin sorghum types were characterised by having a high proportion of corneous endosperm, as expected. This is because corneous endosperm serves as defence mechanism against mould and possible insect attack in non-tannin sorghum types (Waniska, Poe and Bandyopadhyay, 1989). The white non-tan plant sorghum types had intermediate to floury endosperm and the tannin sorghum types had a high proportion of floury endosperm. Grain hardness based on relative proportions of corneous to floury endosperm of these sorghum types shows that most of the non-tannin sorghum types had hard endosperm texture, with the exceptions of Mmabaitse (white, non tan-plant) and PAN 8564 (red, non-tannin) with intermediate to soft endosperm texture. Both the type II and III tannin sorghum types had floury endosperm texture, as expected. This is because condensed tannins in tannin sorghum grains serve as defence mechanism against mould attack (Waniska *et al*., 1989).

Table 4.2.1: Grain physical quality attributes of the sorghum cultivars

Sorghum Type	Sorghum cultivar	Grain size (relative %)			Test weight (kg/hl)	1000 kernel weight (g)	Grain Endosperm Texture (relative %)		
		Small (<2.36 mm)	Medium (2.36-4.0 mm)	Large (>4.0 mm)			Corneous	Intermediate	Floury
White Tan-plant	**BSH1**	0.8^{ab}	98.4^{defg}	0.5^{abc}	76.4^{e}	31.2^{i}	90.0^{g}	5.0^{a}	5.0^{abc}
	Orbit	0.7^{ab}	98.1^{def}	1.1^{bcde}	72.6^{c}	29.7^{h}	55.0^{d}	42.5^{g}	2.5^{ab}
	KAT 369	0.3^{ab}	98.3^{def}	1.6^{de}	77.5^{f}	29.1^{h}	80.0^{ef}	10.0^{ab}	10.0^{c}
	Macia	0.9^{ab}	98.9^{efg}	0.0^{a}	78.1^{fg}	20.3^{c}	52.5^{cd}	40.0^{fg}	7.5^{bc}
White non Tan-plant	**Mmabaitse**	0.0^{a}	99.9^{g}	0.0^{a}	69.6^{a}	23.2^{d}	7.5^{b}	45.0^{gh}	47.5^{f}
	Kanye Std.	0.4^{ab}	97.6^{de}	1.9^{e}	71.9^{bc}	31.9^{j}	5.0^{ab}	77.5^{i}	17.5^{d}
Red non-tannin	**PAN 8564**	9.2^{d}	89.4^{a}	0.0^{a}	71.3^{b}	16.7^{a}	10.0^{b}	52.5^{h}	37.5^{e}
	NK 283	4.0^{c}	93.8^{c}	1.5^{de}	74.1^{d}	26.7^{g}	85.0^{fg}	15.0^{bc}	0.0^{a}
	SNK	0.3^{ab}	99.4^{fg}	0.3^{ab}	73.6^{d}	24.3^{e}	47.5^{c}	42.5^{g}	10.0^{c}
	MR Buster	1.3^{b}	97.2^{d}	1.4^{cde}	78.5^{g}	29.1^{h}	77.5^{e}	20.0^{cd}	2.5^{ab}
White tannin (type II)	**Feterita**	3.6^{c}	91.9^{b}	4.2^{f}	69.3^{a}	24.1^{e}	0.0^{a}	27.5^{de}	72.5^{h}
	Tannin White	0.4^{ab}	99.3^{efg}	0.0^{a}	72.2^{c}	23.0^{d}	0.0^{a}	27.5^{de}	72.5^{h}
Red tannin (type III)	**NS 5511**	1.2^{ab}	98.3^{def}	0.0^{a}	72.2^{c}	19.3^{b}	7.5^{b}	42.5^{g}	47.5^{f}
	PAN 3860	3.7^{c}	95.2^{c}	0.8^{abcd}	71.8^{bc}	25.5^{f}	5.0^{ab}	32.5^{ef}	62.5^{g}

Mean values in the same column but with different letters are significantly different ($p<0.05$)

Grain protein content ranged between 6.9 and 15.1 g/100 g (Table 4.2.2). Macia (white tan-plant) had the lowest protein content, while Feterita (type II tannin) had the highest protein content. Non-tannin sorghum types with corneous endosperm are reported to have higher protein content than tannin sorghum types with floury endosperm (Ioerger, Bean, Tuinstra, Pedersen, Erpelding, Lee and Herrman, 2007). Differences in protein content can be attributed to the influence of cultivation environmental factors. According to Buffo, Weller and Parkhurst (1998), growing conditions in terms of moisture and temperature determine the relative proportions of starch to protein deposited in the sorghum kernel. Tannin content ranged from 0 to 45.3 mg/100 mg and the total phenol content ranged between 4.4 and 89.5 mg/100 mg. Protein and tannin contents of the tannin sorghum types in this current study correspond with data for tannin sorghum cultivars analysed by Neucere and Sumrell (1980), as well as the endosperm texture attribute. The type III tannin sorghum types had very high total phenol content, more than twice the levels in the type II tannin and non-tannin sorghum types. Similar results were reported by Kobue-Lekalake, Taylor and De Kock (2007). This is due to their red pericarp and high tannin content. The red non-tannin sorghum types had higher levels of total phenols compared to the white tannin sorghum types, due to colour pigments present in their red pericarp, which according to Awika and Rooney (2004) contributes to the level of extractable phenols.

Table 4.2.3 correlates the grain quality attributes. Percent corneous endosperm significantly and negatively correlated with both intermediate ($p<0.05$, r = -0.640) and floury endosperm ($p<0.001$, r = -0.846). Test weight positively correlated with corneous endosperm ($p<0.001$, r =0.808) and negatively with floury endosperm ($p<0.01$, r = -0.706). The high negative correlation coefficient between corneous and floury indicates a predominance of corneous endosperm in the non-tannin sorghum types and floury endosperm in the tannin sorghum types, as shown in Table 4.2.1. Tannin content positively correlated with percent floury endosperm ($p<0.05$, r = 0.532) and total phenol content negatively correlated with corneous endosperm ($p<0.05$, r = -0.539). Floury endosperm has loosely packed cells with voids, which may be due to differences in the level of kafirin polymerisation compared to corneous endosperm with higher level of polymerisation (Mazhar and Chandrashekar, 1995). The negative correlation between total phenols and corneous endosperm is probably linked to the contribution of tannin, as suggested by Waniska *et al*. (1989). Total phenol content correlated highly with tannin content ($p<0.001$, r =0.914), as expected. A similar high positive correlation between sorghum total phenol and tannin ($p<0.001$, r =0.880) was reported by Dicko, Hilhorst, Gruppen, Traore, Laane, Van Berkel and Voragen (2002). The presence of pigmented testa can intensify the level anthocyanidin pigments in the pericarp and testa, which increases the level of extractable phenols (Hahn and Rooney, 1986). The other grain quality parameters were not significantly correlated with each other.

Table 4.2.2: Grain chemical quality attributes of the sorghum cultivars

Sorghum Type	Sorghum Cultivar	Protein Content (g/100 g) Dry weight basis	Tannin Content (CE mg/g) Dry weight basis	Total Phenol Content (mg/g) Dry weight basis
White Tan-plant	**BSH1**	12.95^{j}	0.0^{a}	18.0^{c}
	Orbit	8.55^{d}	0.0^{a}	20.4^{d}
	KAT 369	9.40^{e}	0.3^{abc}	4.4^{a}
	Macia	6.90^{a}	0.1^{ab}	26.8^{ef}
White non Tan-plant	**Mmabaitse**	14.25^{k}	1.8^{abcd}	29.9^{gh}
	Kanye Std	11.25^{i}	1.7^{abc}	21.6^{d}
Red non-tannin	**PAN 8564**	8.20^{c}	2.5^{cde}	31.5^{h}
	NK 283	10.95^{h}	4.0^{de}	17.0^{c}
	SNK	12.80^{j}	2.0^{bcd}	44.9^{i}
	MR Buster	10.50^{g}	2.5^{cde}	12.2^{b}
White tannin (type II)	**Feterita**	15.10^{l}	4.6^{e}	28.7^{fg}
	Tannin White	7.25^{b}	10.4^{f}	25.3^{e}
Red tannin (type III)	**NS 5511**	10.85^{h}	38.2^{g}	79.1^{j}
	PAN 3860	10.25^{f}	45.3^{h}	89.5^{k}

Mean values in the same column but with different letters are significantly different ($p<0.05$)

Table4.2.3: Correlation matrix of sorghum grain quality attributes

	Corneous	Intermediate	Floury	Small	Medium	Large	Test weight	1000 kernel weight	Protein	Tannin
Intermediate	-0.640*									
Floury	-0.846***	0.132								
Small	-0.207	0.072	0.219							
Medium	0.195	-0.033	-0.232	-0.933***						
Large	-0.005	-0.115	0.091	0.068	-0.413					
Test weight	0.808***	-0.486	-0.706**	-0.293	0.319	-0.150				
1000 kernel weight	0.498	-0.228	-0.478	-0.480	0.304	0.382	0.310			
Protein	-0.076	-0.076	0.150	-0.131	-0.026	0.436	-0.383	0.233		
Tannin	-0.448	0.049	0.532*	0.126	-0.057	-0.173	-0.278	-0.287	-0.043	
Total phenol	-0.539*	0.252	0.511	0.165	-0.057	-0.260	-0.403	-0.434	0.069	0.914***

***, **, *** significant at p<0.05, <0.01 and <0.001, respectively**

4.2.3.2 Wort quality attributes

Wort extract yield is the single most important parameter that determines sorghum grain suitability in lager beer brewing (Letsididi, Bulawayo, Kebakile and Ezeogu, 2008). The extract yield of the sorghum types ranged between 63.8 and 84.5% by the specific gravity method and between 70.5 and 90.4% by refractometry (Table 4.2.4). Extract yield results by refractometry were probably higher than by the specific gravity method due to differences in analytical principle involved. The tannin sorghum types, both raw and steeped in NaOH solution, gave the lowest extract, with the exception of the type II Tannin White variety. Low extract yield was probably due to interaction during mashing between condensed tannins and the amylase enzymes, as described by Daiber (1975). Wort extract was highly negatively correlated with tannin content ($p<0.001$, $r = -0.846$) (Table 4.2.5). This shows that the tannin property of the grain had a major negative effect on wort extract. The other sorghum types gave higher levels of extract, due to their non-tannin attribute. The great improvement in extract of about 5% in the malted samples was due to activity of malt amylases combined with the exogenous enzymes added. This finding agrees with results of a study by Agu *et al*. (1995). These authors compared the level of wort extract yield from unmalted sorghum mashed with exogenous enzymes to that of malted sorghum in combination with exogenous enzymes. Wort from raw and NaOH steeped Tannin White sorghum had higher extract than the other tannin sorghum types, similar to the non-tannin sorghum types. This could be due to its low tannin and protein content when compared to the other tannin sorghums (Table 4.2.2).

Wort colour L* value (lightness) ranged from 52.5 to 58.7, a* value (redness-greenness) from 0.1 to 2.7, and b* value (yellowness-blueness) from 1.4 to 7.1 (Table 4.2.4). The sorghum cultivars with high L* value had low a* value (less red), while the cultivars with low L* values showed high a* values (more red). Sorghum type did not seem to affect the wort colour L* value. This may be due to adsorption of the grain colour pigments to the spent grain, as observed. Wort colour a* values differed only slightly among the sorghum types. The tan-plant sorghum type gave lower wort colour a* values than the other sorghum types. This could be due to white tan-plant sorghums containing no anthocyanins and very low extractable phenols compared to the others which had significant levels of phenols and red pericarps. Thewhite tan-plant sorghum type was classified by Awika and Rooney (2004) as having no detectable anthocyanins and very low extractable phenols. Wort colour b* value did not vary with the different sorghum types.

Wort FAN ranged between 31.2 and 196.1 mg/l (Table 4.2.4). The low FAN levels from the raw sorghum samples correspond with results reported by Bajomo and Young (1993, 1994) for wort obtained from 100% raw sorghum. The wort low FAN of most of these sorghum types may be attributed to poor protein hydrolysis during mashing. This is due to endogenous properties of sorghum kafirin protein which contributes to its low digestibility (Zhao, Bean, Ioerger, Wang and Boyle, 2008). In a study carried out by Ng'andwe, Hall and Taylor (2008) sorghum kafirin cross-linking due to disulphide bonding was identified to be a major factor contributing to poor sorghum protein digestibility. The type III tannin sorghum type cultivars gave the lowest FAN levels. This is understandably due to high levels of tannin interaction with proteins and in particular with hydrolytic enzymes (Taylor and Duodu, 2009). Condensed tannins strongly interact with the sorghum prolamin protein (kafirin) to form insoluble complexes, which reduces the protein's digestibility (Emmambux and Taylor, 2003). FAN somewhat negatively correlated with tannin content ($p<0.1$, r =0.498) (Table 4.2.5). Feterita (type II tannin sorghum) illustrates the relationship between tannin and protein with regard to wort FAN quality. Feterita had a FAN level similar to the white tan-plant sorghums, presumably due to its high grain protein and low tannin content (Table 4.2.2). The high level of FAN from raw Mmabaitse (white non-tan plant) and SNK (red non-tannin) may also be linked to their high protein contents coupled with their intermediate to floury endosperm attribute, which permitted higher enzymatic activity. The correlation between wort FAN and grain protein content was also slightly significant ($p<0.1$, r =0.511) (Table 4.2.5), which suggests that high grain protein and endosperm property contribute to higher wort FAN. Malted Macia (white tan-plant) and type II Tannin White had the highest FAN levels. Higher hydrolytic enzyme activities due to proteolytic enzymes in the malt plus the exogenous enzymes added to the mash resulted in significant increase in the production of FAN in the wort, as was found by Taylor and Boyd (1986).

Table 4.2.4: Wort quality attributes from the different sorghum samples

Sorghum Type	Sorghum Cultivar	Extract (%) Dry weight basis		Colour			FAN (mg/l)	Bitterness (BU)	Wort Fermentable Sugars (g/100 ml)				
		Specific Gravity	Refracto-metry	L*	a*	b*			Maltotriose	Maltose	Glucose	Fructose	Total Ferm. Sugars
White Tan-plant (WTP)	**BSH1 (R)**	75.5^{ef}	80.7^{ef}	58.7^{f}	0.1^{a}	3.4^{abcd}	73.5^{g}	1.7^{abcd}	3.96^{bcdef}(41)	3.76^{def}(39)	1.81^{d}(19)	0.14^{c}(1)	9.66^{defg}
	Orbit (R)	81.0^{kl}	86.8^{jk}	56.4^{bcde}	0.7^{abcd}	4.5^{bcdefg}	69.6^{fg}	2.7^{e}	4.08^{bcdef}(45)	3.47^{cd}(38)	1.47^{d}(16)	0.07^{abc}(1)	9.08^{def}
	KAT 369 (R)	79.6^{ijk}	83.4^{fghi}	57.8^{def}	0.1^{a}	2.5^{abc}	62.3^{ef}	1.5^{abc}	3.94^{bcdef}(46)	3.34^{bcd}(39)	1.29^{cd}(15)	0.08^{abc}(1)	8.64^{cd}
	Macia (R)	80.8^{kl}	85.9^{ijk}	55.9^{bcd}	0.5^{abc}	5.5^{cdefg}	65.4^{fg}	3.7^{f}	4.60^{ef}(47)	3.80^{def}(39)	1.39^{d}(14)	0.08^{abc}(1)	9.86^{defg}
White non-tan plant	**Mmabaitse (R)**	76.2^{fg}	80.3^{def}	52.7^{a}	2.7^{k}	5.9^{defg}	139.1^{i}	3.8^{f}	3.78^{bcde}(43)	3.41^{cd}(38)	1.63^{d}(18)	0.05^{ab}(1)	8.86^{cdef}
	Kanye Std (R)	79.9^{jk}	85.9^{ijk}	56.9^{cdef}	1.1^{cdef}	3.5^{abcde}	68.2^{fg}	2.1^{bcde}	4.37^{cdef}(41)	4.63^{hi}(43)	1.72^{d}(16)	0.08^{abc}(1)	10.79^{fgh}
Red non-tannin	**PAN 8564 (R)**	80.9^{kl}	85.5^{ij}	55.1^{bc}	2.3^{ijk}	7.1^{g}	50.2^{cd}	1.7^{abcd}	4.45^{cdef}(46)	3.75^{def}(38)	1.48^{d}(15)	0.09^{abc}(1)	9.77^{defg}
	NK 283 (R)	78.5^{hij}	82.0^{efgh}	55.7^{bcd}	1.4^{efgh}	6.5^{efg}	42.2^{bc}	1.6^{abc}	4.18^{bcdef}(44)	3.63^{de}(38)	1.70^{d}(18)	0.01^{a}(0)	9.51^{defg}
	SNK (R)	75.9^{fg}	81.2^{efg}	56.5^{bcdef}	0.9^{bcdef}	4.5^{bcdefg}	104.9^{h}	1.4^{abc}	4.35^{cdef}(42)	4.40^{fghi}(42)	1.49^{d}(14)	0.13^{bc}(1)	10.36^{defg}
	MR Buster (R)	79.0^{hijk}	85.2^{hij}	57.4^{def}	0.7^{abcd}	3.3^{abcd}	50.7^{cd}	2.3^{cde}	4.72^{f}(44)	4.22^{efgh}(39)	1.72^{d}(16)	0.08^{abc}(1)	10.73^{efgh}
White tannin (type II)	**Feterita (R)**	72.2^{cd}	76.1^{bc}	56.8^{cdef}	0.7^{abcde}	2.0^{ab}	63.9^{fg}	1.6^{abc}	4.04^{bcdef}(46)	3.36^{bcd}(38)	1.22^{bcd}(14)	0.12^{bc}(1)	8.73^{cde}
	Tannin White (R)	77.1^{fgh}	83.5^{fghi}	58.6^{ef}	1.3^{cdefg}	3.9^{abcdef}	43.6^{bc}	1.8^{abcde}	4.26^{cdef}(46)	3.68^{def}(39)	1.20^{bcd}(13)	0.11^{bc}(1)	9.35^{defg}
Red tannin (type III)	**NS 5511 (R)**	70.4^{bc}	74.1^{b}	52.5^{a}	2.4^{jk}	6.7^{fg}	37.4^{ab}	1.0^{a}	3.76^{bcd}(53)	2.65^{b}(38)	0.49^{ab}(7)	0.14^{c}(2)	7.04^{c}
	PAN 3860 (R)	63.8^{a}	70.5^{a}	57.9^{def}	1.3^{defg}	5.4^{cdefg}	31.2^{a}	1.3^{ab}	2.73^{a}(55)	1.79^{a}(36)	0.34^{a}(7)	0.09^{abc}(2)	4.95^{a}
Type II	**Feterita (S)**	73.7^{de}	79.4^{de}	58.7^{ef}	0.8^{abcde}	1.4^{a}	64.2^{fg}	2.3^{cde}	4.51^{def}(47)	3.87^{defg}(40)	1.19^{bcd}(12)	0.12^{bc}(1)	9.62^{defg}
	Tannin White(S)	77.7^{ghi}	84.1^{ghij}	56.4^{bcde}	1.6^{fghi}	3.6^{abcde}	53.4^{de}	2.0^{bcde}	4.36^{bcdef}(49)	3.42^{cd}(39)	1.05^{abcd}(12)	0.10^{bc}(1)	8.83^{cdef}
Type III	**NS 5511(S)**	70.4^{bc}	77.4^{cd}	54.3^{ab}	1.8^{ghij}	5.6^{defg}	51.7^{cd}	2.6^{de}	3.51^{ab}(50)	2.79^{bc}(40)	0.64^{abc}(9)	0.08^{abcd}(1)	7.00^{bc}
	PAN 3860(S)	69.8^{b}	75.9^{bc}	57.3^{cdef}	1.3^{defg}	3.9^{abcdef}	44.2^{bcd}	2.3^{cde}	2.77^{a}(55)	1.75^{a}(35)	0.45^{ab}(9)	0.07^{abc}(1)	5.03^{ab}
WTP	**Macia(M)**	84.5^{m}	90.4^{l}	57.2^{cdef}	0.2^{ab}	5.6^{cdefg}	196.1^{k}	2.2^{bcde}	4.16^{bcdef}(33)	5.12^{i}(41)	2.82^{e}(23)	0.34^{d}(3)	12.43^{g}
Type II	**Tannin White(M)**	81.9^{l}	89.0^{kl}	57.3^{cdef}	2.1^{hijk}	4.9^{bcdefg}	180.4^{j}	1.5^{abc}	3.65^{bc}(32)	4.54^{ghi}(40)	2.80^{e}(25)	0.37^{d}(3)	11.34^{gh}

R = Raw grain; S = NaOH steeped grain; M = Malted grain; Mean values in the same column but with different letters are significantly different ($p<0.05$)

Values in parentheses are percentage proportion of the individual sugars in the total fermentable sugars

Table4.2.5: Correlation matrix of sorghum grain and wort quality attributes

	Corn.	Inter	Floury	Small	Med.	Large	TW	TKW	Prot.	Tannin	TPC	SG	REF	L*	a*	b*	FAN	Bitter	Maltot.	Maltos.	Gluco.	Fruct.
Int.	-.640**																					
Floury	-.846****	.132																				
Small	-.207	.072	.219																			
Med	.195	-.033	-.232	-.933****																		
Large	-.005	-.115	.091	.068	-.413																	
TW	.808****	-.486*	-.706***	-.293	.319	-.150																
TKW	.498*	-.228	-.478*	-.480*	.304	.382	.310															
Protein	-.076	-.076	.150	-.131	-.026	.436	-.383	.233														
Tannin	-.445	.045	.531*	.125	-.056	-.174	-.276	-.284	-.041													
TPC	-.539**	.252	.511*	.165	-.057	-.260	-.403	-.434	.069	.914****												
SG	.404	.137	-.611**	-.066	.075	-.056	.375	.133	-.377	-.846****	-.825****											
REF	.371	.171	-.589**	-.099	.124	-.101	.395	.203	-.450	-.801****	-.785****	.963****										
L*	.229	-.392	-.104	-.125	.064	.205	.343	.524*	-.172	-.138	-.285	.027	.153									
a*	-.594**	.461*	.440	.358	-.220	-.350	-.614**	-.627**	.081	.363	.461*	-.209	-.279	-.767***								
b*	-.177	.275	.032	.405	-.208	-.524*	-.195	-.541**	-.220	.296	.397	-.100	-.167	-.656**	.713***							
FAN	.002	.208	-.140	-.401	.423	-.119	-.183	.079	.511*	-.498*	-.249	.233	.194	-.292	.109	-.073						
Bittern	.032	.233	-.195	-.264	.331	-.208	.080	-.039	-.100	-.440	-.334	.434	.438	-.200	.029	.011	.548**					
Maltot	.242	.109	-.384	-.043	.037	-.019	.307	-.028	-.211	-.624**	-.579**	.685***	.692***	.080	-.113	-.088	.112	.200				
Maltos	.273	.210	-.489*	-.196	.173	.036	.248	.245	.024	-.760***	-.659**	.721***	.757***	.193	-.266	-.277	.363	.239	.800****			
Glucos	.480*	-.039	-.583**	-.095	.058	.065	.269	.392	.142	-.869****	-.814****	.717***	.703***	.144	-.230	-.149	.444	.329	.631**	.769***		
Fruct	-.222	.008	.272	-.094	.109	-.105	-.047	-.166	.138	.277	.375	-.369	-.330	.158	-.074	-.182	-.077	-.379	-.013	-.076	-.230	
TFS	.342	.125	-.519*	-.135	.112	.026	.298	.210	-.020	-.810****	-.729***	.768***	.784****	.162	-.230	-.206	.331	.264	.900****	.959****	.855****	-.080

, **, ***, * significant at p<0.1, <0.05, <0.01 and <0.001, respectively**

Corn.- Corneous, Med- Medium, Prot- Protein, Maltot- Maltotriose, Maltos- Maltose, Gluco- Glucose, Fruct- Fructose

Wort bitterness ranged between 1.0 and 3.8 BU (Table 4.2.4). This result did not follow the expected trend because the level of phenolics in beer contributes majorly to the bitterness attribute (Arnold, Noble and Singleton, 1980; Hough, 1985). However, the trends of the wort bitterness results in this study agree with results of a study carried out by Kobue-Lekalake *et al*. (2007) on sorghum bran infusions. In this present work, the tannin sorghum types have the lowest wort bitterness than the non-tannin samples, especially the white tan-plant and non tan-plant sorghum types. This could be linked to condensed tannin interaction with proteins, forming insoluble complexes (Emmambux and Taylor, 2003; Awika, Dykes, Gu, Rooney and Prior, 2003), during mashing. Another possibility is that the low wort bitterness in the tannin sorghum types may be due to tannin polymerisation during mashing. Noble (2002) reported that an increase in the degree of tannin polymerisation results in a decrease in bitterness.

The sugar profile of the wort gives an indication of the potential fermentable sugar quality attributes of the sorghum types. The level of total fermentable sugars in the wort ranged between 4.95 and 12.43 g/100 ml (Table 4.2.4). The tannin sorghum types gave substantial lower levels of fermentable sugars compared to the non tannin types. This is an indication of tannin inactivation of amylase enzymes during mashing, as reported by Daiber (1975). The correlation between tannin grain content and wort fermentable sugars was highly significant and negative ($p<0.001$, $r = -0.810$) (Table 4.2.5). This confirms that tannin interaction with starch and amylase enzymes leads to poor starch hydrolysis, as suggested by Waniska, Rooney and McDonough (2004). Table 4.2.6 shows a higher correlation between the extract yield and total fermentable sugars ($p<0.001$, $r =0.800$) than with FAN ($p<0.05$, $r =0.518$). This shows that wort extract is predominantly made up of fermentable sugars due to higher level of starch in sorghum grain than protein. The correlation trend observed between FAN and fermentable sugars in this study is due to influences of malting and the tannin property of the grain on wort quality. The level of starch hydrolysis increased as a result of malt amylase and proteolytic enzymes, while insoluble protein complexes due to tannin interaction with protein may have reduced the level of FAN in the wort.

Table 4.2.4 shows that maltotriose had the highest contribution to the total fermentable sugars, except with Kanye Std and the malted samples. This may be attributed to insufficient starch hydrolysis to simple sugars by the amylase enzymes, resulting from cross-link endosperm protein matrix surrounding the starch granules (Taylor *et al*., 2006). Sorghum endosperm contains disulphide bond linked protein complexes (Duodu, Taylor, Belton and Hamaker, 2003). Sorghum grain protein matrix and its interaction with starch (Wong, Lau, Cai, Singh, Pedersen, Vensel, Hurkman, Wilson, Lemaux and Buchanan, 2009) affects sorghum starch functionality, such as gelatinisation and digestion rate compared to other cereals (Chandrashekar and Kirlies, 1988).

Table 4.2.6: Correlation matrix of sorghum wort quality attributes

	Extract Specific Gravity	Extract Refracto-metry	L*	a*	b*	FAN	Bitterness	Maltotriose	Maltose	Glucose	Fructose
Refractometry	0.963****										
L*	0.070	0.163									
a*	-0.212	-0.233	-0.695****								
b*	0.022	-0.038	-0.633***	0.584***							
FAN	0.518**	0.540**	-0.010	-0.016	0.073						
Bitterness	0.222	0.223	-0.150	-0.029	-0.042	0.195					
Maltotriose	0.589***	0.547**	0.076	-0.162	-0.051	0.050	0.099				
Maltose	0.785****	0.797****	0.206	-0.262	-0.089	0.599***	0.075	0.719****			
Glucose	0.734****	0.718****	0.159	-0.122	0.152	0.726****	0.049	0.459**	0.812****		
Fructose	0.316	0.367	0.131	0.035	0.178	0.721****	-0.238	0.014	0.450**	0.673***	
Total Fermentable Sugars	0.800****	0.789****	0.176	-0.206	0.007	0.570***	0.070	0.784****	0.968****	0.883****	0.487**

, **, ***, * significant at p<0.1, <0.05, <0.01 and <0.001, respectively**

4.2.3.3 Effect of tannin inactivation on the wort quality attributes

Tannin inactivation by NaOH steeping only gave a significant increase in extract with the Feterita (type II) and PAN 3860 (type III) tannin sorghums and an increase in FAN from Tannin White, PAN 3860 and NS 5511 tannin sorghum types, and as well an increased wort bitterness from Feterita, PAN 3860 and NS 5511 (Table 4.2.7). Wort fermentable sugars increased in Feterita and decreased in type II Tannin White. Thus, there was not a general improvement in parameters across all the tannin sorghums. These results indicate inconsistency in tannin inactivation of the tannin sorghum types, irrespective of the level of their tannin content. Table 4.2.8 shows the correlation of the NaOH steeped sorghum wort quality with grain quality attributes. Tannin and total phenol content were significantly and negatively correlated with wort extract, contrary to expectation. However, the correlation coefficients were slightly lower than those without tannin inactivation (Table 4.2.5). The implication of these results is that reduction of tannin by steeping in dilute NaOH as described by Beta, Rooney, Marovatsanga and Taylor (2000) was not sufficient to improve wort quality attributes of the tannin sorghum types.

4.2.3.3 Effect of malting on the wort quality attributes

Table 4.2.9 shows that malting resulted in a great increase in wort extract, FAN and fermentable sugars. This is undoubtably due to the combined activity of the malt enzymes and the exogenous enzymes added to the mash. The increased wort extract found in this study correspond with the findings of a study carried out by Agu *et al*. (1995). They compared mashing unmalted sorghums with exogenous enzymes to malted sorghum mashed in combination with exogenous enzyme sorghum. Their results show substantial improvement in wort extract from malted sorghum. These authors recommended adding enzymes to sorghum malt during mashing to improve wort quality. The proteolytic enzymes in malt in conjunction with the exogenous proteases were responsible for huge improvement in wort FAN, as confirmed by Palmer (1989) and Bajomo and Young (1993). The higher proportion of maltose in the malted samples compared to the raw samples could be linked to the activity of β-amylase enzymes in the malt, because β-amylase activity specifically produces maltose during mashing (Taylor *et al*., 2005). Malting significantly reduced wort bitterness in Macia, which may be attributed to phenolics leached out during steeping.

Table 4.2.7: Effect of tannin inactivation on wort quality attributes of tannin sorghum grain (types II and III)

Sorghum cultivar	Treatment	Extract (%) Dry weight basis		Colour			FAN (mg/l)	Bitterness (BU)	Wort Fermentable Sugars (g/100 ml)				
		Specific Gravity	Refracto-metry	L*	a*	b*			Maltotriose	Maltose	Glucose	Fructose	Total Ferm. Sugars
Feterita (Type II)	**Raw**	72.1^{a}	76.1^{a}	56.8^{a}	0.7^{a}	2.0^{a}	63.9^{a}	1.6^{a}	4.04^{a}(46)	3.36^{a}(38)	1.22^{a}(14)	0.12^{b}(1)	8.73^{a}
	Steeped in NaOH	73.7^{b}	79.4^{b}	58.7^{b}	0.8^{a}	1.4^{a}	64.2^{a}	2.3^{b}	4.51^{b}(47)	3.87^{b}(40)	1.19^{a}(12)	0.06^{a}(1)	9.62^{b}
Tannin White (Type II)	**Raw**	77.0^{a}	83.5^{a}	58.7^{a}	1.3^{a}	3.9^{a}	41.1^{a}	1.7^{a}	4.36^{a}(46)	3.68^{a}(39)	1.20^{a}(13)	0.11^{a}(1)	9.35^{b}
	Steeped in NaOH	77.7^{a}	84.1^{a}	56.4^{a}	1.6^{a}	3.6^{a}	52.6^{b}	2.0^{a}	4.26^{a}(49)	3.42^{a}(39)	1.05^{a}(12)	0.10^{a}(1)	8.83^{a}
PAN 3860 (Type III)	**Raw**	63.8^{a}	70.5^{a}	57.9^{a}	1.3^{a}	5.4^{a}	30.4^{a}	1.3^{a}	2.73^{a}(55)	1.79^{a}(36)	0.34^{a}(7)	0.09^{a}(2)	4.95^{a}
	Steeped in NaOH	69.8^{b}	75.9^{b}	57.3^{a}	1.3^{a}	3.9^{a}	44.3^{b}	2.3^{b}	2.77^{a}(55)	1.75^{a}(35)	0.45^{b}(9)	0.07^{a}(1)	5.03^{a}
NS 5511 (Type III)	**Raw**	70.4^{a}	74.1^{a}	52.5^{a}	2.4^{b}	6.7^{b}	37.0^{a}	0.9^{a}	3.76^{a}(53)	2.65^{a}(38)	0.49^{a}(7)	0.14^{b}(2)	7.04^{a}
	Steeped in NaOH	70.4^{a}	77.4^{a}	54.3^{b}	1.8^{a}	5.6^{a}	50.6^{b}	2.6^{b}	3.51^{a}(50)	2.79^{a}(40)	0.64^{a}(9)	0.08^{a}(1)	7.00^{a}

Means for the treatments with different letters are significantly different ($p<0.05$)

Values in parentheses are percentage proportion of the individual sugars in the total fermentable sugars

Table4.2.8:Correlation matrix of sorghum grain and wort quality attributes with dilute NaOH solution steeped tannin cultivars

	Corn.	Inter	Floury	Small	Med.	Large	TW	TKW	Prot.	Tannin	TPC	SG	REF	L*	a*	b*	FAN	Bitter	Maltot.	Maltos.	Gluco.	Fruct.
Int.	-.640**																					
Floury	-.846****	.132																				
Small	-.207	.072	.219																			
Med	.195	-.033	-.232	-.933****																		
Large	-.005	-.115	.091	.068	-.413																	
TW	.808****	-.486*	-.706***	-.293	.319	-.150																
TKW	.498*	-.228	-.478*	-.480*	.304	.382	.310															
Protein	-.076	-.076	.150	-.131	-.026	.436	-.383	.233														
Tannin	-.445	.045	.531*	.125	-.056	-.174	-.276	-.284	-.041													
TPC	-.539**	.252	.511*	.165	-.057	-.260	-.403	-.434	.069	.914****												
SG	.375	.147	-.574**	.027	-.014	-.037	.369	.165	-.472*	-.806****	-.798****											
REF	.269	.230	-.494*	-.029	.039	-.042	.350	.171	-.535**	-.700***	-.700***	.931****										
L*	.321	-.410	-.126	-.064	-.100	.522*	.306	.521*	.083	-.120	-.224	-.037	.011									
a*	-.620**	.446	.489*	.380	-.229	-.375	-.645**	-.599**	.038	.280	.368	-.162	-.200	-.789****								
b*	-.039	.304	-.164	.367	-.165	-.532**	-.092	-.501*	-.258	.050	.183	.158	.077	-.763***	.622**							
FAN	-.098	.228	-.026	-.436	.485*	-.200	-.254	.019	.515*	-.354	-.108	.018	-.052	-.348	.211	.066						
Bittern	-.265	.272	.146	-.230	.281	-.172	-.130	-.259	-.029	.037	.116	-.011	-.024	-.360	.221	.108	.376					
Maltot	.215	.070	-.317	.036	-.115	.213	.236	.005	-.085	-.703***	-.629**	.591**	.631**	.117	-.129	.008	.032	-.113				
Maltos	.243	.208	-.449	-.148	.070	.201	.187	.230	.156	-.774***	-.651**	.587**	.625**	.169	-.234	-.106	.271	-.161	.808****			
Glucos	.512*	-.016	-.641**	-.093	.050	.087	.291	.404	.179	-.841****	-.771***	.635**	.556**	.073	-.159	.100	.320	-.129	.636**	.750***		
Fruct	.045	.008	-.061	-.175	.259	-.302	.204	.030	-.046	-.064	.066	-.054	.052	.269	-.218	-.188	.122	-.269	.145	.186	.117	
TFS	.327	.117	-.494*	-.084	.010	.186	.253	.216	.088	-.837****	-.732***	.653**	.666***	.146	-.202	-.024	.225	-.156	.907****	.958****	.846****	.192

, **, ***, * significant at p<0.1, <0.05, <0.01 and <0.001, respectively**

Corn.- Corneous, Med- Medium, Prot- Protein, Maltot- Maltotriose, Maltos- Maltose, Gluco- Glucose, Fruct- Fructose

Table 4.2.9: Effect of malting on the wort quality attributes of Macia (white tan-plant) and Tannin white sorghum (type II)

Sorghum cultivar	Treatment	Extract (%) Dry weight basis		Colour			FAN (mg/l)	Bitterness (BU)	Wort Fermentable Sugars (g/100 ml)				
		Specific Gravity	Refracto-metry	L*	a*	b*			Maltotriose	Maltose	Glucose	Fructose	Total Ferm. Sugars
Macia	**Raw**	80.8[a]	85.9[a]	55.9[a]	0.5[a]	5.4[a]	65.4[a]	3.7[b]	4.60[b](47)	3.80[a](39)	1.39[a](14)	0.08[a](1)	9.86[a]
	Malted	84.5[b]	90.4[b]	57.2[b]	0.2[a]	5.6[a]	196.1[b]	2.2[a]	4.16[a](33)	5.12[b](41)	2.82[b](23)	0.34[b](3)	12.43[b]
Tannin White	**Raw**	77.1[a]	83.5[a]	58.7[b]	1.3[a]	4.0[a]	43.6[a]	1.8[a]	4.36[a](46)	3.68[a](39)	1.20[a](13)	0.11[a](1)	9.35[a]
	Malted	81.9[b]	89.0[b]	57.3[a]	2.1[a]	4.9[a]	180.4[b]	1.5[a]	3.65[a](32)	4.54[b](40)	2.80[b](25)	0.37[b](3)	11.34[b]

Means for the treatments with different letters are significantly different ($p<0.05$)

Values in parentheses are percentage proportion of the individual sugars in the total fermentable sugars

4.2.4 CONCLUSIONS

This study indicates the tannin property as the major sorghum grain quality attribute that determines suitable sorghum types as adjunct in lager beer brewing. This is due to the negative effect tannin has on wort quality attributes such as extract, FAN and fermentable sugars. The high tannin content of type III tannin sorghum makes it unsuitable. Inactivation of tannins by dilute NaOH steeping does not seem to be suitable because of its inconsistent effect on wort quality. Protein content of the grain is to some extent a grain quality attributes to consider in selecting suitable sorghum varieties and cultivars from the appropriate sorghum type(s) as adjunct in lager beer brewing. This is because high grain protein content has negative effect on wort extract, but contributes positively to FAN quality.

The high wort extract of non-tannin sorghum types makes them most suitable as adjunct in lager beer brewing. Malting produces wort with a great improvement in extract, FAN and fermentable sugars. In view of their good agronomic characteristics, red non-tannin sorghums should be considered as adjunct, because there is no apparent difference in their grain and wort quality attributes compared to the white tan-plant sorghum type. However, further study is necessary in relation to comparative fermentability and final product quality of suitable varieties and cultivars from both white tan-plant and red non-tannin sorghum types. This is to determine any differences in their sensory properties compared to that of white tan-plant sorghums.

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5. GENERAL DISCUSSION

This section provides a critical review of the methods used in this study. The database information is discussed, as well as discussion on the relationship between grain quality attributes of the different sorghum types and their wort quality properties. Finally, it explains the trends observed with regard to grain quality factors that most influenced wort quality attributes and discusses the most suitable sorghum types for sorghum lager beer brewing in southern Africa.

5.1 Methods

The data provided on the available improved sorghum varieties and cultivars in southern Africa were collated from different sources. This meant that different methods coupled with differences in samples analysed were used to generate the data. This did not permit statistical analysis of the data, nor was there control over the quality of the data. Therefore, the information as provided in the database with regard to the improved sorghums can only be applied subjectively.

Concerning the methods of analysis used by the researcher, the effect of sorghum type on grain hardness attribute was determined by visual estimation of the relative proportion of corneous to floury endosperm texture according to ICC Draft Standard 176 (ICC, 2008). According to Rooney and Miller (1982), there is direct correlation between the proportion of corneous and floury endosperm and grain hardness. The main drawback with the method is that it is subject to individual judgment. The Tangential Abrasive Dehulling Device (TADD) is a standard method that can be used in determining grain hardness quality, as described by Reichert, Tyler, York, Schwab, Tatarynovich and Mwasaru (1986). This method of determining endosperm hardness is based on the percent weight of bran and endosperm removed by abrasive milling of kernels, whereby high value implies kernel with soft endosperm due to loss of weight during milling and vice versa with hard endosperm kernel. Application of the TADD in future studies could give more definite results of sorghum hardness and provide more accurate data.

Tannin content of the sorghum types was determined by colorimetric assay using the modified Vanillin-HCl method of Price, Van Scoyoc and Butler (1978). The assumption made was that condensation of the aromatic aldehyde vanillin (4-hydroxy-3-methoxybenzaldehyde) with the sorghum monomeric flavanols and their oligomers forms a red adduct that absorbs at 500 nm

(Dykes and Rooney, 2006). As shown in the Chapter 4.2 results and discussion section (Table 4.2.2), trace levels of tannins were measured in the non-tannin sorghum types, similar to the level in the type II tannin sorghum types. This may be due to interference of non-tannin phenolics, as noted by Waniska and Rooney (2000). Despite the colour blank correction meant to correct for non-tannin pigment interference, the colour blank did not effectively correct for the non-tannin phenolics interference. This may imply inaccurate measurement of tannin content in the sorghum types, as noted by Dykes and Rooney (2006). Deshpande and Cheryan (1986) attributed inaccurate quantification of condensed tannin content to factors like material particle size, solvent type, extraction time and standards used. Catechin was used as standard in this study. Price *et al*. (1978) criticised this because of overestimation of condensed tannin. Despite this limitation, catechin is being widely used as standard in vanillin-HCl assay because of lack of suitable standard due to structural complexity of condensed tannins (Schofield, Mbugua and Pell, 2001).

Total phenolics in the sorghum types were determined using the Folin-Ciocalteu method of Singleton and Rossi (1965). This method is based on the principle of oxidation-reduction reactions. The drawbacks of this assay are due to non-specificity groups of phenols, as well as interference from amino acids (Hahn and Rooney, 1986). Awika *et al*. (2004) noted that the type of extraction solvent used could also interfere with the phenol extracts, which may influenced the level of total phenol determined. In this study, acidified methanol was used for extraction, which was proposed by Lu and Foo (2001) and Awika *et al*. (2004) to be a better extraction solvent compared to aqueous acetone. This is because acidified methanol preserves the extracted phenols in their original state.

The laboratory scale mashing procedure used in this study was very effective in differentiating the sorghum types. According to Owuama (1997), the following factors influence enzyme activities during mashing of sorghum: temperature, pH, time and concentration of the wort. According to Evans, Van Wegen, Ma and Eglinton (2003), a proper balance of temperature required for starch gelatinisation during mashing determines efficiency of starch hydrolysis and the rate of thermal inactivation of enzymes. In this research, efficiency of the mashing condition ensured adequate starch gelatinisation solubilisation, which yielded high levels of extract in all the sorghum types except the tannin types. One of the problems associated with this mashing procedure had to do with clarifying the wort. This problem can be attributed to endosperm cell wall materials released into the wort due to incomplete endosperm degradation in sorghum, as noted by Etokakpan and Palmer (1990). This made it necessary to go through a very tedious filtration process of clarifying the wort for wort colour analysis. The wort samples were first filtered through layer of Kieselguhr. The wort filtrates obtained were filtered through a 0.45 µm membrane filter with the aid of vacuum pump.

It was observed that starch hydrolysis in all the sorghum types was incomplete, based on the iodine test at the end of the mashing process. This was also confirmed during sugar profiling of the wort. The HPLC method detected high levels of dextrins, coupled with a significant higher level of maltotriose than maltose. This means that there was a relatively low level of fermentable sugars in the wort, which ranged up to 10.79 g/100 ml. This problem could be linked to incomplete breakdown of the endosperm structure to expose the starch granules to ensure complete hydrolysis. Montanari *et al*. (2005) noted that with sufficient rest time α-amylase enzymes can breakdown all the dextrins to maltose, glucose and small branched limit dextrins. Bajomo and Young (1992) studied the effect of varying concentration of enzymes added to sorghum mash. They reported that increasing concentration of enzymes in the mash had no significant effect on wort extract, but affected wort composition, such as fermentable sugars and FAN quality. This implies that application of higher concentration of amylase enzymes within the commercially acceptable level and longer rest time for the enzymes during mashing in this study would have given better wort composition quality for these sorghum types.

Determination of wort extract yield using pycnometry required that the procedures were followed carefully because of the sensitivity of the method. Required temperature (20ºC) was carefully followed and other sources of error such as air bubbles being trapped in the pycnometer with the wort sample were eliminated. In this study, the pycnometry method was compared with refractometry method. The major advantage of the refractometry method is that it is a very rapid and non-destructive (Peris-Tortajada, 2004). Also, it requires a very small quantity of the wort for analysis. The only drawback with this method may be due to possible influence of non-sugar soluble solids on the refractometric reading, as reported by Constenla, Lozano and Crapiste (1989). This may explain the reason for higher results by refractometry than by pycnometry.

Wort fermentable sugar profiling was carried out based on the widely accepted standard method of the European Brewery Convention, Method 8.5 Fermentable Carbohydrates (EBC, 1987). Refractive Index (RI) detector system was used in this study, being a universal method for carbohydrate HPLC analysis (Peris-Tortajada, 2004). Drawbacks of RI detection is lack of sensitivity and non-specificity (Peris-Tortajada, 2004), as well as interference from non-carbohydrate compounds on the peak detection (Siouffi, 2000). Sample preparation according to the method procedure was applied to address the influence of non-carbohydrate compounds on the detection of the sugars in the wort. Peris-Tortajada (2004) noted that the problem of non-specificity with RI becomes obvious only when the carbohydrates are present in trace amounts. However, the level of individual sugars down to 0-5% can be quantified with RI detector system. This implies that the levels of the fermentable sugars were accurately quantified in the wort samples in this study. The instrument was required to be re-calibrated with the standards every time wort sugar analyses were carried out, due to influence of change in temperature, pH, pressure and composition of the solvent and sugar standard (Siouffi, 2000; Peris-Tortajada, 2004). This was to ensure that the slope did not drift too much, because any shift in the slope will affect the level of sugars quantified in the wort samples.

Wort bitterness was determined according to European Brewery Convention Method 9.6 Bitterness (EBC, 1987). The assay only quantifies bitterness related to general phenolic compounds, not the actual wort bitterness, as the measurement of the compounds is simply by absorbance at 250 nm. The drawback of this assay is linked to non-specificity, based on its principle. For example, the level of absorbance used in the measurement of the bitterness related phenolic compounds may have contributed. As shown in Chapter 4.2 Results and Discussion section (Table 4.2.4), the tannin sorghum types had lower wort bitterness than the non-tannin sorghum types. This may be attributed to tannin complexation interaction with metal ions, carbohydrates and proteins. The insoluble complexes formed are difficult to extract, as reported by Awika, Dykes, Gu, Rooney and Prior (2003). This could also have limited the effectiveness of this chemical assay in differentiating the sorghum types based on their wort bitterness attribute.

5.2 Approach of updating the improved sorghum database information

Grain quality and end-use quality information available on the improved sorghums provided in Chapter 4.1 Results and Discussion section can be effectively utilised in the selection of suitable sorghums cultivar with regard to milling, while the information is limited in the area of malting and brewing. However, the database can now be updated with new information as generated from the grain and wort quality characterisation study carried out on 14 sorghum varieties and cultivars under five different sorghum types. This information obtained shows that the tannin property of sorghum has the major influence (adverse influence) on the end-use quality parameters considered, important in the sorghum lager beer brewing application (Table 5.1).

5.3 Approach of improving sorghum wort quality from tannin sorghums

Wort extract and fermentable sugars are the main quality factors considered during mashing (Letsididi, Bulawayo, Kebakile and Ezeogu, 2008). The highly negative correlations between tannin and wort extract and with fermentable sugars found in this study show that the tannin property can be used as a major grain quality characteristic to determine suitability of sorghum types as adjunct in lager beer brewing. Figure 5.1 shows the influence of reduced tannin level on wort extract and total fermentable sugars. This was based on considering only tannin sorghums with tannin content up to approximately 1%. Importantly, there were no significant correlations between tannin and wort extract or fermentable sugars when the tannin level was up to approximately 1% compared to the higher tannin level (approximately 4%) found in Type III sorghums. This is probably due to reduced tannin inactivation of the exogenous enzymes. Tannins form complexes with the hydrolytic enzymes and also inactivate the enzymes (Milic, Srdjan and Nada, 1972; Daiber, 1975), which affects the level of starch hydrolysis during mashing. This suggests that low tannin Type II sorghums combined with effective method of tannin inactivation may not adversely affect the extract and wort fermentable sugars levels. Possibly the approach of combining non-tannin sorghum types with tannin type II or low tannin type III sorghum types could be used to achieve a substantial reduction in tannin effect on wort quality.

Table 5.1: Updated Malting and Brewing Quality Characteristics of Improved Sorghum Varieties and Cultivars

Single-country	Variety name	H/OPV[A]	Germination count[B] (24 h) (%)	Germination count[B] (48 h) (%)	Germination count[B] (72 h) (%)	Water uptake[C] (%)	Malting loss[D] (%)	Total loss[E] (%)	Malt Diastatic Power (DP)[F] (SDU/ g)	Malt FAN[G] (mg FAN/100 g)
BOTSWANA	BSH1 (SDSH 48)	H	88	99			12.8	18.2	31.2	
	MAHUBE (SDS 2583)	OPV								
	MMABAITSE	OPV								
MALAWI	PILIRA 1 (ICSV 1)	OPV								
MOZAMBIQUE	MAMONHE	OPV								
SWAZILAND	MRS 13 (SDSV 1513)	OPV	37	65			11.0	13.0	15.3	
	MRS 94 (SDSV 1594)	OPV	27	48			10.5	11.4	7.5	
TANZANIA	TEGEMEO	OPV								
	PATO	OPV								
	P9406									
	P9405									
ZAMBIA	KUYUMA	OPV	98	99			17.9	28.3	40.4	
	SIMA	OPV	97	98			15.6	20.9	20.7	
	ZVS-15	OPV								
	ZVS-12	OPV								
	WP-13	OPV								
	MMSH-375	H	74	90			13.3	21.2	40.2	
	MMSH-413	H	85	94			13.2	23	38.2	
	MMSH-1257	H	84	89			13.5	17.4	27.9	
	MMSH-625	H								
ZIMBABWE	SV-2 (ICSV 88060)									
	SV-3 (NL 499)									
	SV-4 (NL 330)									
	ZWSH-1									
	NS 5511									

Continuation: Table 5.1

Single-country	Variety name	H/OPV[A]	Germination count[B] (24 h) (%)	Germination count[B] (48 h) (%)	Germination count[B] (72 h) (%)	Water uptake[C] (%)	Malting loss[D] (%)	Total loss[E] (%)	Malt Diastatic Power (DP)[F] (SDU/ g)	Malt FAN[G] (mg FAN/100 g)
SOUTH AFRICA	NS 5511	H		82.7±6.1	93.0±3.0	41.2±1.8/45.0/39.6	16.8±0.8		46.6±8.7/63.0	122±33
	PAN 8625	H		88.3±4.7	94.1±3.7	40.9±1.5/44.0	19.1±4.4		49.1±8.4/65.0	129±43
	PAN 8609	H		79.6±8.5	92.7±2.1	35.0±2.1/42.0	18.5±1.8		43.1±6.4/46.0	124±34
	PAN 8564	H		85.0±7.7	95.2±2.7	33.4±1.9/40.0/36.4	17.0±2.0		40.3±6.2	130±39
	PAN 8247	H		78.7±9.0	92.8±2.6	33.8±1.6/40.0	17.7±1.2		42.6±6.2/41.0	114±25
	BANJO	H							25.0	
	NS 5655	H		87.5±4.5	95.9±1.9	36.5±2.4/39.0/38.8	18.2±1.1		39.1±7.6/38.0	123±31
	OVERFLOW	H							27.0	
	PAN 8706W	H								
	PAN 8648W	H							26.0	
	NS 5751	H								
	MR BUSTER	H								
	PAN 8407	H							24.0	
	PAN 8017	H							38.0	
	PAN 8474	H							44.0	
	PAN 8657	H		80.2±5.4	92.2±3.4	34.8±1.8	18.5±2.0		45.0±5.7/46.0	119±27
	PAN 8816	H		84.0±4.8	91.8±2.8	36.8±1.7/43.0	18.3±0.9		43.4±6.7/49.0)	121±33
	PAN 8677	H							60.0	
	PAN 8507	H		85.6		35.5	16.1		71.0	
	PAN 8488	H		81.7±8.9	90.7±5.9	35.1±1.3	19.7±3.7		37.8±5.1	113±34
Multiple-country										
BOTSWANA	MACIA SDS 3220	OPV	93	98			15.4	23.9	42.6	
MOZANBIQUE	MACIA SDS 3220									
NAMIBIA	MACIA SDS 3220									
TANZANIA	MACIA SDS 3220									
ZIMBABWE	MACIA SDS 3220									
MALAWI	ICSV 112 (PIRIRA 2)	OPV	94	95			16.1	25.9	31.3	
MOZAMBIQUE	ICSV 112 (CHOKWE)									
SWAZILAND	ICSV 112 (MRS 12)									
ZIMBABWE	ICSV 112 (SV-1)									

Continuation: Table 5.1

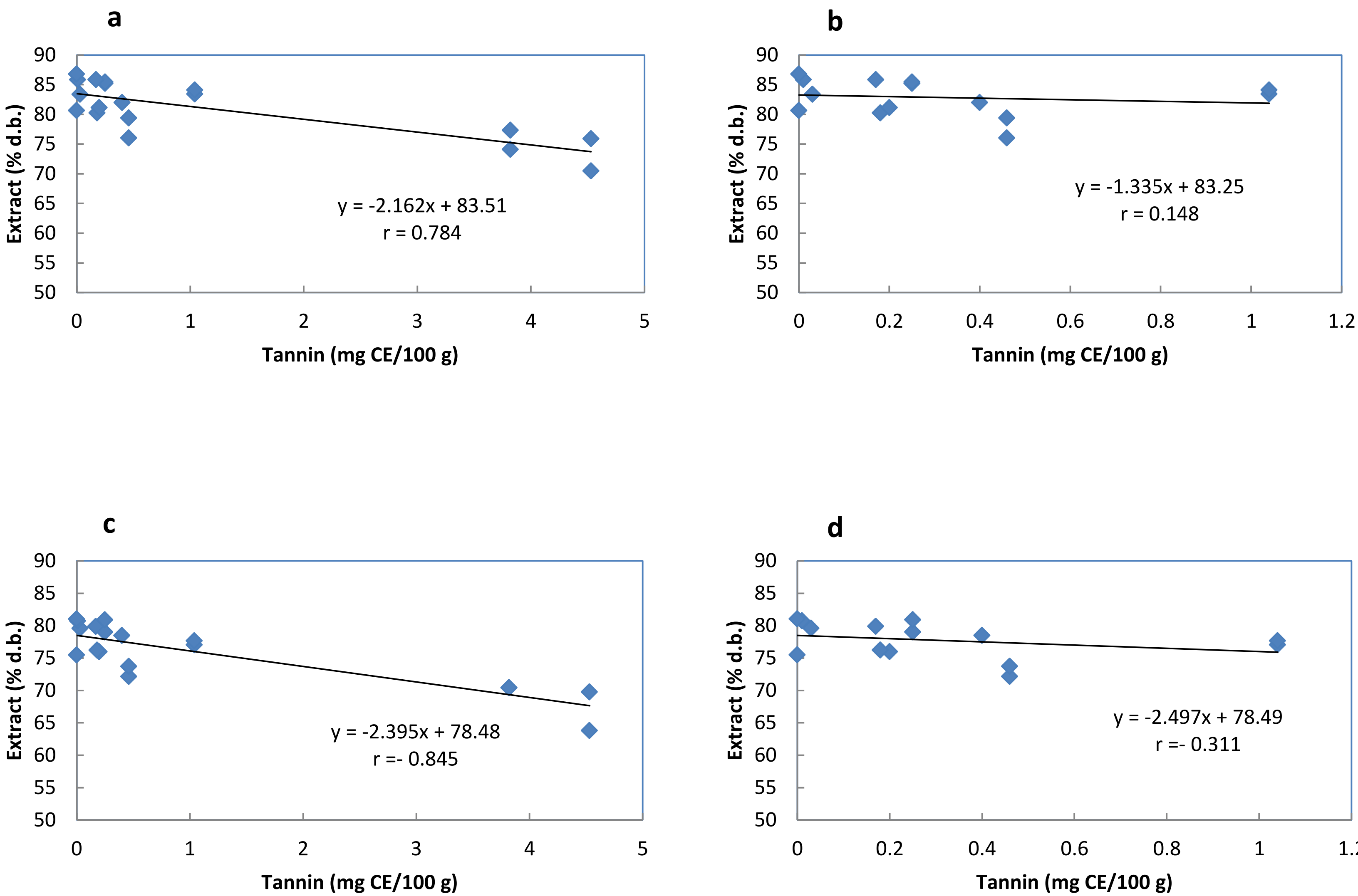
Single-country	Variety name	H/OPV[A]	Grain extract content[H] (%)	Wort extract Specific Gravity (% dry basis)	Wort colour L*	Wort colour a*	Wort colour b*	Wort FAN (mg/l)	Total fermentable sugars (g/100 ml)
BOTSWANA	BSH1 (SDSH 48)	H		75.5	58.7	0.1	3.4	73.5	9.66
	MMABAITSE	OPV		76.2	52.7	2.7	5.9	139.1	8.86
SOUTH AFRICA	NS 5511	H	70.7	70.4	52.5	2.4	6.7	37.4	7.04
	PAN 8625	H	46.4						
	PAN 8609	H	73.1						
	PAN 8564	H		80.9	55.1	2.3	7.1	50.2	9.77
	PAN 8247	H	74.3						
	BANJO	H	75.0						
	NS 5655	H	74.5						
	OVERFLOW	H	74.3						
	PAN 8648W	H	75.3						
	MR BUSTER	H		79	57.4	0.7	3.3	50.7	10.73
	PAN 8407	H	72.7						
	PAN 8017	H	72.6						
	PAN 8474	H	63.6						
	PAN 8657	H	74.2						
	PAN 8816	H	74.2						
	PAN 8677	H	67.8						
	PAN 8507	H	63.4						
	PAN 8677	H	67.8						
	PAN 8507	H	63.4						
	PAN 8488	H							
BOTSWANA	MACIA (SDS 3220)	OPV		80.8	55.9	0.5	5.5	65.4	9.86

Continuation: Table 5.1

A- OPV: Open pollinated variety, H: Hybrid
B- Germination count (%) after 24, 48 and 72 h determine the viability of the grain (< 65% not suitable to malt the grain)

C- Water uptake (%) measure of grain hydration after steeping
D- Malting loss (%) given as difference between initial grain weight and dry malt weight divided by initial grain weight
E- Total loss (%) given as difference between initial grain weight and polished malt (kernels minus external roots and shoots) weight divided by initial grain weight
F- Malt DP measure of combined activities of α and β- amylases (SDU/ g malt: Sorghum Diastatic Units per gram of malt dry basis)
G- Malt Free- Amino Nitrogen (FAN) consist of amino acids and peptides (Minimum of 110 mg FAN/ 100 g dry basis) (including external roots and shoots) in the malt suitable for brewing

H- Grain extract content measure of grain starch content and availability (% Dry basis)


a
Extract (% d.b.)
Tannin (mg CE/100 g)
y = -2.162x + 83.51
r = 0.784
b
Extract (% d.b.)
Tannin (mg CE/100 g)
y = -1.335x + 83.25
r = 0.148
c
Extract (% d.b.)
Tannin (mg CE/100 g)
y = -2.395x + 78.48
r =- 0.845
d
Extract (% d.b.)
Tannin (mg CE/100 g)
y = -2.497x + 78.49
r =- 0.311

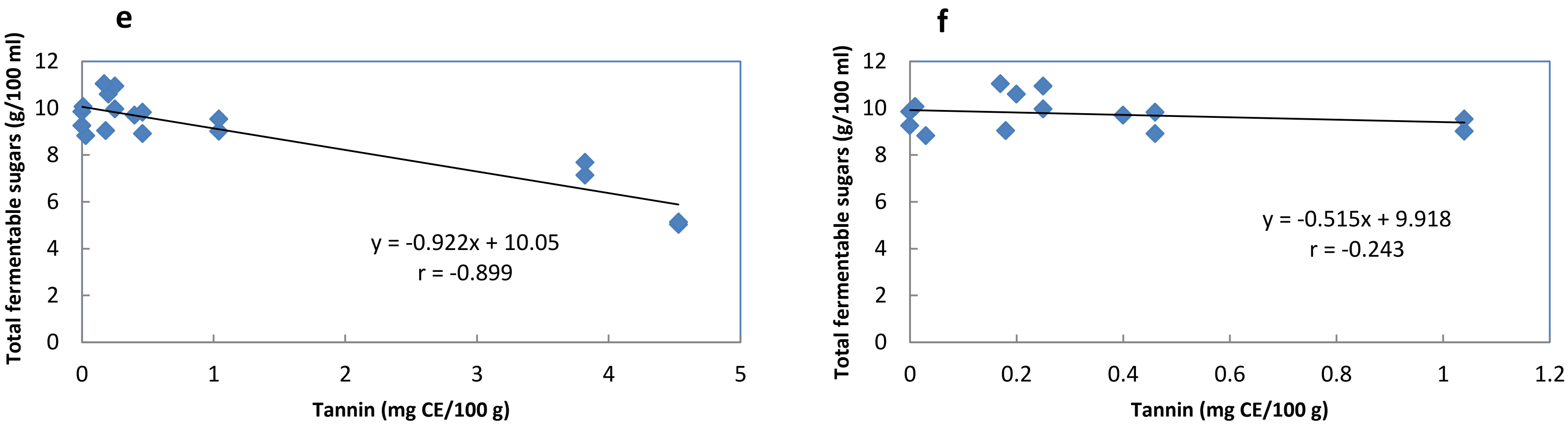


Figure 5.1: Effects of different levels of tannin in sorghum grain on wort extract and total fermentable sugars

a: Wort extract by refractometry including high tannin sorghums

b: Wort extract by refractometry excluding high tannin sorghums

c: Wort extract by specific gravity including high tannin sorghums

d: Wort extract by specific gravity excluding high tannin sorghums

e: Total fermentable sugars including high tannin sorghums

f: Total fermentable sugars excluding high tannin sorghums

5.4 Future work

Based on the potentially suitable wort quality attributes found when using the red non-tannin sorghums as adjunct, there is need for further studies. More comprehensive wort quality analysis of individual red non-tannin sorghum varieties and cultivars available in southern Africa is necessary. This is because wort quality properties in terms of wort composition can affect finished beer quality (Montanari *et al*., 2005). This can be studied by looking at the red non-tannin sorghums wort fermentability and beer brewing quality characteristics. Also, sensory quality study of the wort and beer quality properties is necessary. This is to determine if there will be any differences in the wort and beer quality from red non-tannin sorghum and white tan-plant sorghums.

Tannin sorghums are cultivated due to their agronomic advantages over the non-tannin sorghums (Price, Stromberg and Butler, 1979). Hence, there is need to consider other means of ensuring tannin reduction in tannin sorghum types. For example, tannin reduction in sorghum grain by the decortication method can be considered. Sorghum endosperm can be separated from the bran fraction by decortication (Taylor and Dewar, 2001). This process may remove most of the condensed tannin in the bran and produce sufficiently clean sorghum grits suitable for application as adjunct in lager brewing. This approach may effectively eliminate the negative impact tannin has on wort quality, as it affects extract and fermentable sugars. As mentioned, another approach to reducing effect of tannin on wort quality that can be considered is by compositing the low tannin Type II or even Type III tannin sorghums with the white tan-plant sorghum type at different levels.

6. CONCLUSIONS AND RECOMMENDATIONS

The database of available improved sorghums in southern Africa is the first of its kind. The information provided on agronomic requirements, grain quality characteristics, and malting and brewing quality properties will be of great support to sorghum producers and processors. Also, this information could be utilised in developing a grading system, as well as the setting of quality standards that could be used in selecting these improved OPV and H sorghums for specific end-uses. The database is already posted on the International Sorghum, Millet and Other Grains Collaborative Research Support Program (INTSORMIL) website (www.intsormil.org). This is to make the information widely accessible. There is need for constant updating of the database in order to make it useful in supporting sorghum production and utilisation. The approach used in generating data regarding brewing quality attributes of the selected sorghum types should be adopted to generate more detailed information on malting quality properties, as well as other specific areas of sorghum utilisation.

With regard to the lager beer brewing adjunct quality of different sorghum types, red non-tannin sorghum types have similar wort quality attributes compared to white tan-plant sorghum types. Thus, red non-tannin sorghums have considerable potential as adjunct in lager beer brewing, due to their agronomic advantages. However, there is need for brewing trials with the red non-tannin sorghums, to ensure that their beer quality is the same as that from white tan-plant sorghums. The tannin property of tannin sorghums had huge negative impact on their wort quality attributes. An effective method of tannin reduction is necessary, as tannin inactivation by steeping in dilute NaOH solution did not yield consistent improvement on wort quality properties. Due to agronomic advantages of tannin sorghums, combining low tannin sorghum with white tan-plant sorghum may be considered. Also, reduction of grain tannin content by decortication should be studied in order to produce wort with consistent improved quality from tannin sorghum types.

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8. APPENDIX

Presentation: Poster presentation.

Title: Development of a database on the quality attributes of released improved sorghum varieties and cultivars in southern Africa.

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