STRATEGIES TO IMPROVE YIELD AND QUALITY OF SWEET SORGHUM AS A CASH CROP FOR SMALL SCALE FARMERS IN BOTSWANA

by

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ABSTRACT

Strategies to improve stem yield and juice quality in sweet sorghum were investigated in this study. Seed quality of sixty five accessions (landraces) from Botswana was investigated. Standard germination tests revealed that only 66% of the accessions had germination percentages in excess of 85%. The Accelerated Ageing test showed that only 50%of the 26 accessions had germination percentages above 80%. The results indicated that Botswana sweet sorghum seed quality is generally poor. Seed development and maturity observations demonstrated that maximum seed quality occurred 14 to 17 days after mass maturity (physiological maturity) and this coincided with maximum seed germination. These results suggest that harvesting sweet sorghum seed prior to mass maturity can lower seed quality. Farmers should, therefore be advised to select plants intended for seed harvesting and allow them to mature properly before the seeds are harvested.

Differences in seed colour, shape and compactness of the inflorescences were observed amongst the 65 landraces collected from farmers in Botswana. Ten landraces were characterised and from the results it was evident that there was a range of genetic diversity which can be utilized in the improvement of the crop. Large panicles were characteristic of most sweet sorghum landraces, the effect of tiller, panicle and floret removal on juice quality

was consequently studied. Removal of panicles and florets significantly improved juice quality whilst removal of tillers did not. Selection and breeding of genotypes with small panicles and male sterile varieties may improve juice quality and should be investigated.

Effect of planting date, spacing and nitrogen were investigated. Early planting (October) resulted in increased stem yields but reduced juice quality. A 30 cm intra-row spacing resulted in high stem yields per plant and good juice quality. Nitrogen fertilisation increased stem yield and improved juice quality. On the bases of the results obtained from this study, early planting (October), application of 60 kg N ha^{-1}, and 30 cm intra-row spacing could be recommended for sweet sorghum production in pure stands.

In pure stands yields of more than 37 000 stems (per hectare) of good quality can be attained. These could be sold at an estimated price of P2.00 (R2.25) per stem indicating the potential of sweet sorghum as a cash crop. However, its economic viability depends on the price elasticity in the supply - demand function.

Keywords: Sweet sorghum, small -scale farmers, stem yield, juice quality, seed quality, standard germination test, Accelerated Ageing test, seed development and maturation, mass maturity, landraces, characterisation, panicle removal, floret removal, tiller removal, planting date, spacing, nitrogen.

CHAPTER 1

GENERAL INTRODUCTION

Sweet sorghum (*Sorghum bicolor* L. Moench) belongs to the same species as grain sorghum, grass sorghum and broom sorghum (Doggett, 1970). This sorghum is characterized by abundant sweet juice in the stalks and the height usually ranges from 1.5 m to 3.0 m (Martin, Leonard & Stamp, 1975). A number of reports have shown that sweet sorghum is a potential source of sugar and a multipurpose industrial crop (Cowley & Smith 1972; Ferraris & Stewart, 1979; Inman-Bamber, 1980).

In Botswana sweet sorghum is widely grown by almost every farmer, though on small scale. It is grown mainly for its sweet stems which are chewed as a snack and to quench thirst while working in the fields. It is commonly grown in mixtures of crops such as maize, grain sorghum, cowpea, groundnut and melon (Harris, Fry, Miller & Pain, 1992). The stalks are sold as delicacies at roadside stalls. Hence, the crop has recently attracted interest as a potential cash crop for small scale farmers.

Sweet sorghum is adapted to the climatic conditions of Botswana, which may be described as semi-arid with rainfall mostly confined to the summer months between October and March. Mean annual rainfall varies from 650 mm in the northeast to about 300 mm in the southwest of the country (Harris *et. al*.1992). Average daily maximum temperatures are around 33°C in January and 22°C in July, and the daily minimum average as low as 12°C in January and 5°C in July (Harris, *et al*, 1992).

Frosts are common in winter. Generally, the soils of Botswana are sandy to sandy-loams and low to very low in nutrients and organic matter. The most serious deficiency in Botswana soils is usually phosphate. Due to erratic rainfall, high evaporation and freely draining sandy soils, intra seasonal drought is common. Because of its drought tolerance, sweet sorghum can survive severe droughts and is often an important source of income before harvesting grain sorghum and other surviving crops.

Growers of sweet sorghum are faced with a number of problems in trying to improve the quality of the crop. Poor crop establishment is one of the problems suspected to be due to poor seed quality. Seed harvesting is done when the stems are ready for sale and not necessarily when the seeds have reached physiological maturity. Other problems are low sucrose levels in the juice and lack of uniformity in height and thickness of stems. Farmers have also indicated that the sweetness in the stems is deleteriously affected by late planting, high amounts of organic manure, too much rain and harvesting too early or too late. Since the crop is probably never grown in monoculture systems, the effect of spacing on the quality of the stalks and juice is not known. Poor stem quality caused by either insects or diseases is another important problem in the production of sweet sorghum. Most of these problems result from a lack of knowledge regarding effective cultural practises for this crop.

Since sweet sorghum is seen as a potential cash crop for small scale farmers, more information is needed on the phenology and management of the crop. Such information will help to develop appropriate and affordable cultural practices for improving the quality of sweet sorghum. In this study, the main objective was to

contribute towards improved sweet sorghum production in Botswana through a better understanding of the agronomy of the crop.

The approach was as follows:

(i) The limited amount of available information on sweet sorghum in southern Africa and elsewhere was scrutinized. Most of the published information is from the United States, Australia and India where the crop enjoyed some popularity during the early stages of the twentieth century (Ferraris & Stewart, 1979).

(ii) Germplasm was collected from different parts of Botswana, targeting small scale farmers growing sweet sorghum. During this exercise some information about the crop was acquired from farmers. Sixty-five landraces were collected and seed vigour and quality were tested. The effect of early harvesting on seed quality in sweet sorghum was also investigated.

(iii) A total of ten accessions from the landrace collection were characterized to understand agronomic performance in the field and identify traits which can be used in future improvement programmes.

(iv) Field experiments were conducted to determine the effects of panicle removal (deheading) and tiller removal, planting date, spacing and nitrogen on the stem yield and sucrose concentration of sweet sorghum.

CHAPTER 2

LITERATURE REVIEW

Sweet sorghum belongs to the *Sorghum bicolor* L. Moench species (Harlan & de Wet, 1972). The genus Sorghum belongs to the tribe *Andropogoneae* of the family *Poaceae*. Sweet sorghum and the other cultivated species have a chromosome number of n = 10 and is primarily self-pollinated with about 2 to 5% cross-pollination. It is accepted that cultivated sorghum originated in Africa in the zone south of the Sahara Desert where several closely related wild species are found and the cultivated species are very diverse (Martin, Leonard, & Stamp, 1975).

2.1 CROP USES

Sorghum is a major crop of the world with various uses. The estimated world area of sorghum in 1972 was 40 Mha, the largest areas being in India (16 Mha) and Africa (10.3 Mha). By 1980, sorghum production had spread throughout most parts of the world (Hume & Kebede, 1981). Sorghum grain is used for stockfeed in the New World, Japan and Europe. It provides human food and beer in India and Africa. Sweet sorghum has sweet juicy stems which may be used for forage and silage or to produce syrup. The juicy stems are often chewed as a snack by humans in southern Africa. In China sugar is produced from sweet sorghum (Doggett, 1988). Brazil currently relies on sugarcane for the production of ethanol but cassava and sweet sorghum are also being evaluated as source crops. Sweet sorghum appears to be suitable for the production of alcohol, and researchers have shown that this crop can yield up to 45 tons of biomass per hectare in 110 days. Fermentable solids in the

stalks amount to 2.5 to 5 tons per hectare. One ton of sweet sorghum stalks has the potential to yield 74 litres of 200 proof alcohol (Anonymous, 1996). This shows that sweet sorghum may become an important crop for fuel alcohol production in future. Sweet sorghum bagasse is a suitable source of paper pulp The pulp is used to manufacture kraft paper, newsprint and fibre boards. Currently in France broomcorn stalks are used for paper production. Danish scientists have also made a good panelling using the chips from internodes of sorghum. Similar products are being explored in Zimbabwe as well (Anonymous, 1996).The stems are fed to livestock and is used for fencing, while the plant bases provide fuel for cooking. Sorghum may be grown for forage like the modern Sudan grasses which are developed from wild sorghum.

2.2 CROP DESCRIPTION

Sweet sorghum stems are generally taller (1.5 to 3.0 m) and juicier than grain sorghum. The diameter of the stems varies from 10 mm to 50 mm. The height of the stem depends upon the number of nodes which equals the number of leaves produced. It also depends upon the internode length, peduncle length and panicle length. All these factors contributing to height are under separate genetic control (Doggett, 1988).

The central part of the stalks contains the most sugar, followed by the lower and then the upper parts (Jansen, McClelland & Metzger, 1930). Assimilates in the stems start accumulating during the development of the inflorescence (McBee & Miller, 1982). During this period there is no competition between grain development and sugar accumulation (Lingle, 1987). Before anthesis, sugar accumulation in the stem

becomes the preferential sink at the expense of growth of apical internodes (Massacci, Battistelli & Loreto, 1996). Eastin (1972) reported that after anthesis assimilates generally move down from the leaves for one to four internodes before moving upward in the central stem. The sucrose content increases and once the seed reaches the hard dough stage, sucrose content of the stem is at its maximum (Eastin, 1972; Webster, Benefiel & Davies, 1953; Stokes, Coleman & Dean, 1957; Ventre, 1948). Changes in the assimilates and proportions of sugars in sweet sorghum stems with increasing maturity were observed by Stokes *et al, (*1957) (see Table A2.1 of the Appendix). According to Ventre, Byall & Walton (1939) there is more glucose in the lower portion and more sucrose and starch in the upper part of the stem. Under conducive field conditions plants will maintain their sucrose content for about one month after reaching the hard dough stage (Coleman, 1970; Broadhead, 1972a). On the stem of sweet sorghum there is a single bud at each node. On the lowest nodes these buds may develop to form tillers and prop roots, while those on the upper nodes may produce branches (Doggett, 1988). In sorghum the normal pattern of tiller bud outgrowth in the field is the production of some tillers during the vegetative growth period followed by more extensive tiller production during and after anthesis of the main shoot (Isbell & Morgan, 1982).

Sorghum leaves are similar to corn leaves in shape but generally narrower than those of corn. Sweet sorghum leaves differ from those of grain sorghum with a dull midrib due to the presence of juice in the air spaces of the pitting tissue (Martin *et al*,1975). The total number of leaves on the stalks, including those formed during the seedling stage, ranges from 7 to 27. Leaf number is influenced by temperature and photoperiod. It is reported that leaf number tend to increase with increasing

temperature and increasing daylength (Heskerth, Chase & Nanda, 1969). Leaves vary in their length and usually mature leaves reach a length of 30 to 135 cm and a width of between 1.5 and 13 cm (Dogget, 1988). Like other sorghums, sweet sorghum leaves have numerous bulliform cells near the midrib on the upper side of the leaf. During drought stress these cells result in a longitudinal rolling of the leaf that reduces transpiration and stress associated with wilting (Stoskopf, 1985). Similarly the stomatal closure occurs during drought to reduce transpiration and stress associated with wilting. Stomatal sensitivity, however, is gradually lost after flowering (Ackerson, Krieg & Sung, 1980). As a consequence, the water use efficiency is reduced and drought stress may negatively affect grain filling and development (Premachandra, Hahn & Joly, 1994).

The roots of sweet sorghum are adventitious with numerous branched lateral roots (Doggett, 1988). Roots emerge from the coleoptile node and from several leaf nodes above the coleoptile node, as an individual whorl of roots associated with each node. Root density in two grain sorghum hybrids was found to increase until grain filling, followed by a decline towards maturity (Zartman & Woyewodzic, 1979).

Flower initiation is promoted by short days although not independent of temperature (Wilson & Eastin, 1982). Like other members of the genus, anthesis begins when the peduncle has completed elongation although occasionally flowering starts earlier. The first flower to open is either the terminal one or the second flower of the uppermost panicle branch. During anthesis a typical panicle of sorghum may have an upper region of the spikelets with dried anthers that have dehisced pollen (post flowering), a middle region of the spikelet with yellow-coloured anthers

shedding fresh pollen (flowering) and a basal portion of immature florets (pre-flowering) (Pendleton, Teetes & Peterson, 1994). Flowering may continue over a period of 3 to 15 days depending on the size of the panicle, temperature and the variety, with 6 - 9 days being typical (Ayyangar & Rao, 1931; Quinby, Hesketh & Voight, 1973).

Although there are varietal differences, pollen is shed freely after sunrise and may be delayed on cloudy, damp mornings. The stigmas are receptive for a day or two before blooming of the flower (Maunder & Sharp, 1963). The length of sweet sorghum panicles varies from 2 to 25 cm or more and the width from 2 to 22 cm or more. A single panicle may carry between 800 and 30,000 seeds. Although it is reported that sweet sorghum is self- pollinated, the upper part of the panicle has more outcrosses than the lower part (Maunder & Sharp, 1963).

Seeds from a panicle vary up to 10% in weight according to their position on the panicle. For some hybrids the top kernels are larger, for others the bottom kernels are larger (Weibel, 1982). In grain sorghum physiological maturity is reached at a moisture content of approximately 30 % (Bovey & McCarthy, 1965). It occurs from 25 to 55 days after flowering in tropical zone areas, and from 34 to 70 days in the temperate. The hilum frequently turns dark at about the time the seed reaches physiological maturity (Eastin, Hultquist & Sullivan, 1973). In sweet sorghum the area of the grain covered by glumes at maturity varies from one cultivar to another. Some sweet sorghum cultivars have seeds that remain enclosed by the glumes even after threshing and other cultivars are 25 to 75 % enclosed and easy to thresh (Stoskopf, 1985). The seed colour varies from light brown to black with tannins

usually being present in seeds which are dark in colour.

2.3 CULTIVARS

There are readily available cultivars of sweet sorghum in many sorghum growing areas. Some of these cultivars have been selected and developed as a source of animal feed, for chewing or for syrup and sugar production. In the USA the most common cultivars are those for syrup and sugar production and most of these originated from South Africa, Sudan and Malawi. Various selections have been made from these introductions. Breeding programmes emphasized early maturity, disease resistance and sugar content.

There are considerable varietal differences in sugar content in sweet sorghum (Jonson, Sperow & Mclaren,1961). Delay in juice extraction after the stalks have been harvested is associated with reduction of the sucrose content as it is converted to reducing sugars. The variation that can occur in sugar content and quality with variety, maturity stages and delay in milling have been demonstrated by Stokes *et al*, *(*1957) (see Table A2.1 of the Appendix). Varieties have different rates of converting sucrose to reducing sugars, and the variety with the slowest rate of conversion tends to be the best choice for sugar production such as variety Brawley (see Table A2.2 of the Appendix). Jonson *et al*, (1961)observed that for all varieties, except Brawley, harvested at the soft dough stage, the sucrose had completely inverted to reducing sugars when milled 10 days after cutting. Due to the differences in sugar content it has been possible to classify sweet sorghum into syrup and sugar varieties. According to Coleman (1983) a good syrup cultivar must have the following characteristics:

- ability to produce high yields of medium to large stalks per hectare;

- a high percentage of extractable juice;
- strong erect growth not prone to lodging ;
- excellent juice quality capable of producing high quality syrup;
- resistance to drought and to water logging;
- relatively short growing period;
- resistance to damage by insecticides and herbicides;
- seeds that germinate well and produce vigorous seedlings; and
- adaptation to a wide range of soil and climatic conditions.

Syrup varieties such as Brawley and Sart have strong stalks and will not lodge except under adverse weather conditions (Coleman, 1983). The desirable characteristics of sweet sorghum varieties for sugar production are similar to those of syrup varieties. The differences are that sugar varieties must have extracted juice with high purity of at least 75% sucrose and a low rate of sucrose inversion. The juice of a good variety of sweet sorghum grown under suitable conditions contains 10 to 14 % of sucrose and 13 to 17 % total sugar (Cowley & Lime, 1976). Starch and aconitic acid should not be present or the concentration should be low enough not to interfere with crystallization of sucrose (Coleman, 1983). Rio is a sugar cultivar which was released to farmers in USA in 1965 as a selection from the cross of MN1048 and Rex. Rex was selected in Kansas in about 1891 whilst MN1048 was introduced from equatorial Africa in 1945. Rio is highly resistant to leaf anthracnose, red rot and rust and also tolerant to most of the other important diseases (Coleman, 1983). Characteristics of sweet sorghum varieties for chewing should be the same as the varieties for syrup and sugar production.

There are early maturing and late maturing varieties of sweet sorghum. Late maturing varieties typically mature within 135 to145 days from emergence whilst early maturing varieties mature from 82 days to 124 days after emergence (Ferraris & Stewart, 1979). Late maturing varieties usually have higher yields of stalks per hectare than early maturing ones. It also has been hypothesized that high sugar yields can be expected from late maturing, tall and thick stemmed cultivars with a relatively small grain yield, but large leaf area carried low on the stem (Ferraris, 1981a). Sweet sorghum varieties are open pollinated and hybrids are readily produced. This shows that there is a potential for rapid advances from breeding and selection programmes.

2.4 LODGING

Lodging in sweet sorghum is one of the major problems. Like in most sorghums it is affected by diseases like root and stalk rot, movement of reserves out of the culms into the grain, morphologically thin stalk walls, long internodes, and whether the pith remains strong and alive (Stoskopf, 1985). Lodging can be aggravated by high plant population which reduces stem thickness, drought occurring during ripening, or by wet and windy weather. Identification of the optimum plant population to encourage thicker and stronger stems is necessary. Breeding for lodging resistance would be another challenge. Lodging resistance in some sweet sorghum cultivars is inherited as a single dominant gene and can easily be recovered in a segregating population, such as in cultivar Sart (Coleman & Stokes, 1958). In cultivars like Branders, lodging resistance is due to plants having superior flexible stalks that sway with the wind, and a very good root system that holds the plant erect even under adverse conditions. Some cultivars have strong stalks but brittle nodes and

internodes with excessive heights, such as in cultivar Wiley, which makes them prone to lodging (Coleman & Stokes, 1958).

2.5 ENVIRONMENTAL EFFECTS

Sweet sorghum grows well on a variety of soils from heavy clay to light sandy soils but best growth is achieved on loams and sandy loams. Adequate soil moisture and good drainage are important for good yields, and application of organic matter may improve soil water holding capacity. Soil acidity is seldom important and sweet sorghum can grow within a pH water range of 5.0 to 8.5. A problem with acid soils is that Al, Mn and Fe become toxic and result in ions like P, Zn, Mg, and Mo becoming deficient (Clark, 1982). Generally, sorghum tolerates salinity better than maize (Doggett, 1988). Most of the arable soils of Botswana fit the soil requirements and are suitable for the production of sweet sorghum.

Sweet sorghum is a perennial crop which prefers growing in warm conditions. In frost affected areas sweet sorghum needs to mature before the frost (Webster *et al*, 1953). Sweet sorghum can be grown year round in the tropics and in the subtropics, but in the temperate areas it is managed as a summer crop. The average growing temperature should be between 20 and 35°C, though varietal differences in temperature tolerances occurs (Doggett, 1988). The optimum germination temperature is 23°C (Kanemasu, Bark & Chinchoy, 1975). Therefore planting must be delayed until a soil temperature of 21 to 23°C is reached. Soil temperatures above 45°C inhibit the emergence of seedlings, resulting in poor crop stands (Peacock, 1982). Usually, temperature variation in the soil is responsible for differences in

sorghum emergence and early seedling development (Kassam & Andrews, 1975; Kanemusu *et al*, 1975).

Sweet sorghum is a short day photoperiod sensitive plant, though large genotypic differences exist in daylength requirements for floral initiation (Ferraris & Stewart, 1979). It was reported by Ferraris & Stewart (1979) that mild photoperiod sensitive to virtually insensitive varieties existed in Australia. Varieties originally selected in the USA had a higher critical photoperiod than tropical sorghums (Ferraris & Stewart, 1979), requiring day lengths greater than 11.6 h in order to delay flower initiation (Miller, Quinby & Cruzado, 1968). The range in photoperiod sensitivity in sweet sorghum helps in its adaptation. Early maturing types can be grown in short seasons such as in areas where the growing season is limited by rainfall, temperature or other factors. Another advantage of cultivar differences in photoperiod response is that it provides flexibility in planting time, allowing manipulation of harvest schedules.

Sweet sorghum is well adapted to summer rainfall regions but in theUSA and Australia it has been shown that for commercial yields to be obtained, sweet sorghum requires more humid growing conditions than grain sorghum (Coleman, 1970; Hansen & Ferraris, 1985). However, elsewhere, good yields are realized in areas where rainfall is limited because sweet sorghum is more tolerant to drought than maize (Coleman, 1970; Doggett, 1988). During periods of drought plants remain dormant and resume growth as soon as there is sufficient soil moisture availability. Massaci *et al*, (1996) observed that in sweet sorghum juice quality was not affected by drought although photosynthesis was slightly affected.

2.6 PRODUCTION ASPECTS

Land preparation and planting

Early planting is often recommended as the yield of sweet sorghum in terms of sucrose production tends to decline with delay in sowing (Maheshwari, Prasad, Singh & Sharma,

1974; Inman-Bamber, 1980; Ferraris& Charles-Edwards, 1986b. Land preparation is similar to that used for grain sorghum. Sweet sorghum is propagated either by seed or by setts as in sugarcane (Karve, Ghanekar & Kshirsagar, 1975). In warm and moist conditions sweet sorghum can be regrown as ratoons. Planting is by drill seeding or hill planting into a well prepared seed bed. Plant population studies indicated that populations ranging from 46 000 to 65 000 ha^{-1} were optimum for stem yield and juice quality (Broadhead, Stokes & Freeman, 1963). Broadhead *et al*, (1963) observed that total dry matter and water soluble carbohydrate (WSC) yield increased with increased plant populations from 8 to 16 plants m^{-2} (80-160 000 plants/ha), whilst wider row spacing resulted in taller and thicker stems. Narrower rows resulted in high dry matter content reduced water soluble carbohydrate (WSC) yield, thinner stems which matured unevenly and increase the risk of lodging (Broadhead *et al*, 1963; Martin & Kelleher, 1984; Ferraris& Charles-Edwards, 1986(b). Cowley (1969) reported that sucrose and purity (juice quality) values are not significantly affected by spacing.

Fertilizers

It has been found that under dry conditions fertilizer application is often

uneconomic. This has lead to the incorrect conclusion that sorghum does not respond to fertilizer and can be grown under low fertility conditions. Under adequate moisture conditions sorghum responds very well to fertilizers, particularly to nitrogen. In sweet sorghum it is recommended that fertilizers be applied during planting to promote early growth. Late applications of farm yard manure or fertilizers high in nitrogen may interfere with juice quality (Ferraris & Stewart, 1979). Although moderate levels of soil nitrogen are required for maximum yields, Cowley & Smith (1972) did not find any correlation between nitrogen levels and sucrose content and purity.

Total yield increased with increased nitrogen applications and the increase was experienced in stem dry matter yield rather than increase in sugar content (Ferraris, 1981). High phosphate levels in sorghum juice have been found to affect juice clarification during the processing (Smith, Smith, Romo, Cruz & Griffiths, 1970).

Weed control

Thinning should be done as early as possible before the young plants begin to tiller, usually at 7 to 10 cm in height. Weed control is advisable until canopy closure. Use of herbicides in sorghums is less satisfactory than with many other field crops, as sorghum plants are more sensitive to herbicides (Martin *et al*,1975). Effective control of weeds in the Republic of South Africa was achieved by pre-emergence application of atrazine at the rate of 3 kg ha^{-1} (Inman-Bamber, 1980). Propazine as a pre-emergence herbicide at the rate of 2.2 to 3.6 kg per hectare was used experimentally to control broadleaf and grass weeds in sweet sorghum in Mississippi and Texas and was found to be effective (Freeman *et al*, 1973). The above mentioned rates of

atrazine and propazine herbicides should be lower on lighter soils (Santo & Nalamwar,1991). Post-emergence applications of atrazine, bendioxide and bromfenoxin have also been found to give excellent control of broadleaf weeds but have little effect on grasses (Coleman, 1972; Inman -Bamber, 1980). Cultivation is an important weed control measure as it minimizes weed competition until canopy closure (Cowley, 1969).

Pests and diseases

Sweet sorghum is subject to a range of insects and diseases but there is little published information available on the occurrence or severity of insects or diseases of this crop.

In Botswana there are no serious disease problems experienced either on grain sorghum or sweet sorghum. However, important pests of sorghum in Southern Africa are sorghum aphids (*Melanaphis sacchari*), Lesser false wireworms (*Mesomorphus spp*. larvae), false wireworms (*Somaticus spp*.), sorghum shoot fly (*Anatrichus erinaceus* Loew) and stalk borer (*Busseola fusca*) (van den Berg & Drinkwater (1997). In South Africa Inman-Bamber (1980) observed the chilo borer *(Chilo partellus)* and maize aphids (*Rhopalosiphum maidis)* as common insects of sweet sorghum. In the USA it has been reported that insects of importance are the lesser corn stalk borer *(Elasmopalpus lignosellus)*, sorghum midge (*Stenodiplosis sorghicola)*, sugarcane borer *(Diatraea saccharalis)*, aphids, armyworms (*Spodoptera frugiperda*) and wireworm (*Heteroderes spp)*. Reported seed pests in USA are the grain moth (*Sitotroga cerealella*) and rice weevil (*Sitophilus oryzea)*, (Coleman, 1970).

It is reported that disease resistant varieties have been developed but these are often highly resistant to some diseases and may be susceptible to other diseases. For example, Rio is resistant to rust (*Puccinia purpurea*), leaf anthracnose (*Colletotrichum graminicolla*)and red rots and moderately resistant to downy mildew (*Peronosclerospora sorghi)* whilst Roma is resistant to downy mildew, rust and leaf anthracnose (Cowley & Smith, 1972). In South Africa common diseases of sorghum are covered kernel smut (*Sphacelotheca sorghi*), ergot *(Claviceps africana*), fusarium rot (*Fusarium spp*)and stalk disease complex and antracnose stalk rots (*Colletotrichum graminicola*) (McLaren & Smit, 1996). Maize dwarf mosaic (MDM) and sugarcane mosaic (SCM) virus have been observed occasionally in Mississippi, Georgia, Kentucky and Texas as a destructive disease in fields of sweet sorghum. Rust was commonly found in moist humid areas while anthracnose, zonate leaf spot (*Gleocercospora sorghi*) and other leaf diseases are reported to occasionally develop readily on susceptible varieties.

Downy mildew is reported as an important disease of sweet sorghum in parts of Texas (Coleman, 1970). There are no reports of insecticidal use on sweet sorghum. However, it has been reported that sweet sorghum varieties are sensitive to certain insecticides and defoliants applied to cotton (Coleman & Dean, 1964).

Yields and harvesting

The optimum harvesting period is when the soluble carbohydrate content is at its highest level (Ferraris, 1981b). Broadhead, (1972) reports this period to be between the soft dough and ripe grain stages depending on variety or ripening conditions. As

the stem reaches maturity, total sugars increase, the ratio of reducing sugars to non-reducing sugars changes and the quantity of starch present in the juice increases (Doggett, 1988). Reduction in stem-sugar content occurs after grain ripening. The optimum estimated time of harvesting sweet sorghum should be between the soft dough stage and late dough stage. Varieties such as Wiley can be harvested from as early as flowering time until the seeds are in the dough stage of maturity according to Coleman (1983). Inman-Bamber (1980) and Ferraris (1981b) recommend harvesting at the hard-dough stage because at this stage the sucrose content level is fairly consistent and stems have reached an acceptable quality for milling. Harvesting can be done by hand or by sugarcane or forage harvesters, cutting the plants at the base. Stems harvested 3 to 4 weeks after the seeds had matured, had significantly decreased Brix and sugar values (Broadhead, 1969, 1972).

Literature on sweet sorghum is inconclusive regarding post-harvest changes in sugar content and quality. Broadhead (1969) found that stems of cultivar Rio could be stored outdoors up to 48 hours without a decrease in sucrose content, while Hansen & Ferraris (1985) found that in the first 48 hours sucrose decreased from 34 to 19 % of the dry matter. It is therefore advisable to process sweet sorghum stems within 24 hours of harvesting to retain maximum sucrose content. In Texas experimental plantings of Rio yielded 36 to 45 tonnes of millable stalks per hectare (Broadhead, 1969). According to Coleman (1983), in Texas yields ranging from 45 to 112 t ha^{-1} (fresh mass) were possible. It is possible to obtain yields of sugar that vary between 2.5 to 5.9 t ha^{-1} from the first crop, and from the ratoon crop 1.5 to 5.9 t ha^{-1} (Cowley & Smith, 1972).

In the Republic of South Africa in the Midlands Mistbelt (Dalton) Inman-Bamber (1980) observed stalk yields between 14 and 37 t ha-¹ in a growth period of about five months (see Table A2.3 of the Appendix). In North Queensland, highest sugar yields were obtained from cv. Rio, which produced 3.6 and 1.6 t ha-¹ over 145 and 79 days from the first and ratoon crops respectively (Ferraris, 1981a). Sweet sorghum is also an excellent producer of grain (Hesker, 1966). Grain yield of 5.7 t dry matter per hectare was reported in Ayr, North Queensland (Ferraris, 1981a).

2.7 FUTURE PROSPECTS OF THE CROP IN BOTSWANA

Soil and climatic conditions in most parts of Botswana are suitable for the production of sweet sorghum. The fertilizer requirement of the crop is relatively low with very few pest and disease problems. The major production constraints experienced in Botswana are late planting, poor crop establishment, availability of seed, inferior varieties, droughts and lodging.

Sweet sorghum needs a long growing season and yield declines with late sowing (Broadhead, 1972b). Early planting is generally a problem to farmers because they must wait for adequate rains before attempting to plough. Typically small scale farmers rely on animal draught power or rented tractors which may not be available when farmers are ready to plough. Consequently, early maturing cultivars need to be introduced.

Difficulties in establishing good stands of healthy seedlings in Botswana are associated with unsuitable planting depths and sub-optimal soil moisture levels during germination and emergence. Therefore, high seed quality is a prerequisite.

Botswana farmers keep their own seed which is collected when the stems are ready for sale and not when the seeds have reached physiological maturity. The quality of seed is not monitored because sweet sorghum is considered a minor crop. Cultivar improvement is not a priority. However, harvesting seeds when they are physiologically matured and selection of genotypes for fast germination and seedling growth could improve crop establishment.

Sweet sorghum is susceptible to lodging and this is accelerated by high plant populations which reduce stem thickness (Broadhead et al,1963; Ferraris, 1988). In Botswana farmers typically broadcast seeds when planting. This results in high plant populations in some parts of the field and low crop density in other parts. In sweet sorghum production this encourages lodging and results in low stem yields. Planting in rows at a low population of 6 to 9 plants per metre is suggested as it encourages thicker and stronger stems, with high stem yields, high sucrose production, early maturity and disease and lodging resistance (Ferraris & Stewart, 1979). Currently there are no introduced or improved cultivars in Botswana to provide farmers with a range of varieties adapted to different areas.

Sweet sorghum stalks are sold as delicacies at roadside stalls. These are sold only when they are in season between March and May. Production practices resulting in a longer marketing season and in higher yields of better quality stalks can contribute greatly to the welfare of numerous small scale farmers. However, farmers must be certain of the market demands before increasing production. There are possibilities of developing sweet sorghum into an industrial crop. Sweet sorghum can be processed for sugar and its components can be used for many products (Ferraris &

Stewart, 1979). Should the need arise of industrialising sweet sorghum, then farmers could be encouraged to increase production scales.

CHAPTER 3

QUALITY OF SWEET SORGHUM SEEDLOTS OF BOTSWANA LANDRACES

3.1 ABSTRACT

The seed quality of sixty five sweet sorghum seedlots of Botswana landraces was investigated. The standard germination test was performed on all of the seedlots and the Accelerated Ageing (AA) test was conducted for those seedlots that showed germination percentages around 90%. The standard germination test results indicated that the germination capacity of the seedlots ranged between 0 to 98.5% and only 66% of the seedlots had germination percentages in excess of 85%. Seedlots of landraces X and Gl showed the highest germination capacity of 98.5% and 98 % respectively, whereas seedlots of landraces Kll and Lll showed the lowest germination capacity of 0% and 0.5% respectively. The germination percentage obtained with accelerated aged seeds ranged from 58.0 to 87.8% with the mean 16.1 percentage points lower than that obtained with the standard germination test. Only 13 of the 26 tested landraces had a germination percentage above 80% after accelerated ageing. The results indicated that seed quality of the sweet sorghum seedlots was generally poor. The investigation also showed that the standard germination test results would be more informative when combined with the AA test, but the results need to be correlated with field emergence.

3.2 INTRODUCTION

Poor crop establishment of sweet sorghum is one of the major problems faced by Botswana farmers. It is well known that germination and seedling emergence results from a complex interaction of seed quality and the seedbed environment (Perry, 1983). However, poor crop establishment is often attributed to poor seed quality. Farmers typically use traditional varieties (landraces) and keep their own seed from one season to another. Seed is collected when stems are harvested for sale, often when the seed is between the milk and the dough stages. The immature heads are dried in the sun and threshed under ambient temperatures which could exceed 40°C. The seed is then stored in plastic bags, tins or any other container the farmer finds suitable, under environmental conditions which may not be conducive to seed longevity.

Seed of high quality results in rapid germination, emergence and root and shoot growth during the early stages of development. Hence a prerequisite for successful crop establishment is a seed of high quality because such seed will determine the ability to cope with suboptimal conditions (Halmer & Bewley, 1984; Harris *et al*, 1992).

For a long time seed quality was regarded as having three components which were routinely determined by means of laboratory tests, viz. purity, health and viability (germination) (Perry, 1983). However, seedlots showing a satisfactory performance in these tests do not necessarily produce satisfactory stands in the field. Hence, seed vigour appeared as an additional quality criterion. In this study, viability and vigour are the two components used to assess sweet sorghum landraces for seed quality.

Seed viability (germination) is defined by the Association of Official Seed Analysts (AOSA, 1983) as the emergence and development from the seed embryo of those essential structures which, for the kind of seed in question, are indicative of the ability to produce a normal plant under favourable conditions. Although the standard germination test approximates emergence under optimal field conditions, experience has shown its inadequacy as an indicator of seed performance in conditions which are less than optimum (Byrd & Delouche, 1971; Delouche & Baskin,1973; Tekrony & Egli,1977; Jonson & Wax, 1978; Yeklich & Kulik,1979). Because seed bed conditions are often sub-optimal, farmers require a more reliable indication of the emergence potential of a seed lot. Seed vigour is defined as those seed properties which determine the potential for rapid, uniform emergence and the development of normal seedlings under a wide range of field conditions (AOSA, 1983). This implies that two seed lots having similar germination percentages as determined under ideal laboratory conditions may perform quite differently under field conditions due to differences in vigour potential (AOSA, 1988).

Seed viability and vigour are affected by the environment and cultural conditions under which the seed developed, matured, was harvested and stored (Roberts, 1972; Abdullah, Powel & Matthews, 1992). Reduced viability was experienced in barley seeds when the parent plant was exposed to high temperature early after awn emergence (Khan & Laude, 1969). Harris, Parker & Johnson (1965) reported that high temperatures during the last 45 days of seed maturation for the 'Hill' cultivar of soybean were associated with low seedling vigour in the progeny. Early harvesting in sweet corn resulted in seeds with high germination and low vigour whilst leaving the sweet corn crop in the field longer resulted in consistent production of relatively high seed vigour (Wilson & Trawaths,

1991). Grain sorghum seeds harvested at full maturity were of higher vigour than early harvested seed (Shepard, Naylor & Stuchbury, 1996). Gane, Biiddi, Knott & Eglea (1984) reported that it is better harvesting pea seed at around 25% seed moisture content (SMC) than when harvested at 15% SMC. Mashauri, Coolbear & Hill (1992) recommended shelling at 20 - 24% SMC rather than at lower SMC's to reduce seed damage which result in poor seed quality of maize. High temperatures during drying, or drying too quickly or excessively, can also dramatically reduce viability (Bewley & Black, 1986) and vigour (Hampton & Colbear, 1990). After harvesting, seed viability has been observed to decline as a result of ageing (Roberts, 1972; Gelmond, Luria, Woodstock & Pearl, 1978), unsound seed handling procedures (Moore, 1972) and inappropriate storage conditions (Roberts, 1972).

Numerous vigour tests have been developed and classified into the following classes: seedling growth evaluation tests, stress tests and biological tests. Procedures for many of these vigour tests have been published by AOSA (1983) and ISTA (1987). Because of the variability in field conditions, vigour tests cannot predict the percentage emergence of a seedlot, but they allow identification of seedlots which will better tolerate adverse conditions and provide the best emergence possible under prevailing conditions. Researchers have reported successful use of various seed vigour tests for sorghum, such as the NH4Cl- test (Abdulahi & Vanderlip, 1972; Vanderlip, Mockel & Jan, 1973) and the soil cold test (Baskin, Palival & Delouche, 1989). The Accelerated Ageing test was used in this study because it is rapid, easy to conduct, inexpensive and easy to interpret. It has been reported to give the best results for predicting seed storeability (Delouche & Baskin, 1973). The Accelarated Ageing test has also been shown to correlate well with stand establishment in several crops such as French bean (Roos & Manalo, 1971), cotton

(Bishnoi & Delouche,1975) soybean (Tekrony & Egli, 1977), maize (Medina & Filho, 1991), peanut (Romkaew, 1996) and chickpea (Ram, Kumari, Singh & Sardana, 1989). Although the standard germination test overestimates seed performance in the field, it can not be replaced by seed vigour tests but can be supplemented by seed vigour test results. Thus the standard germination test was included in this study because it is still an important test as its value lies in the fact that it reassures seed buyers and producers of the percentage viability. Seed vigour tests are now conducted on a routine basis in some developed countries, but the practice is not yet established in the Botswana seed industry which relies solely on the standard germination test as the indicator of seed quality. However, since sweet sorghum seeds are not produced by the Botswana seed industry, there is no information even on the germination percentage of the seed. Thus seed samples from various landraces were collected from farmers to investigate seed quality in sweet sorghum. The objective of this study was to determine the seed quality of sweet sorghum seed as typically used by farmers in Botswana.

3.3 MATERIALS AND METHODS

Seedlots

Sixty five landraces of sweet sorghum were collected from farmers in the Kgatleng, Kweneng, Ngwaketse, Central and Northeastern districts of Botswana (Fig 3.1). Accessions collected from Kgatleng, Kweneng and Ngwaketse contributed 45% of the total collection, whilst the Central district contributed 30% and the Northeast 25%. Collecting trips lasted for about 6 weeks during August and September, 1997. During the collection some information was gathered from the farmers about various aspects of sweet sorghum production.

Fig 3.1 : Location where the 65 sweet sorghum landraces were collected

Most accessions were traditional landraces. There were no introduced cultivars available or distributed by the agricultural services in the districts. Collected landraces differed with respect to genotype, production locality, time and date of harvesting and storage conditions (see Table A3.1 of the appendix). Most of the landraces collected from the Central and Northeastern districts were tall, thick stemmed and late maturing, whilst in the other districts the early maturing landraces were more common. Dried, threshed seeds were often stored in metal or plastic containers or seed bags. Some farmers stored their seeds unthreshed by hanging the heads in the shade. Threshed seeds were either untreated or treated for storage pests with wood ash or cow dung. All collected seed lots were tested for their germination capacity and those that showed germination percentages above 90% were also tested for seed vigour.

Standard germination test

The standard germination test was conducted according to the rules of the International Seed Testing Association (ISTA, 1993), in rolled paper towels. Before germination 250 seeds per seedlot, were prechilled at 5°C for 5 days. Four sheets of germination paper were saturated with 100 cm^3 distilled water, and 50 seeds were placed in 5 rows of 10 seeds per row. The paper sheets were rolled loosely and placed in polyethylene bags. Seeds were incubated at 25°C in the dark for 7 days. After 7 days germination counts of viable, normal and abnormal seedlings were done according to the criteria of the ISTA rules (ISTA, 1985).

Accelerated Ageing test

The tray method described by Hampton and Tekrony (ISTA, 1993) was used. Plastic boxes (11 x 11 x 4 cm) containing wire mesh trays (10 x 10 x 0.3 cm) were used. A total

mass of 15 g of seed was placed on the wire tray to form a single layer. Distilled water (40 cm^3) was added to each plastic box after which they were covered with the lids and placed in a Labcon germination cabinet at 43°C for 72 h. After the 72 h ageing period, the seed samples were removed from each tray and seed moisture content was determined. Four 50 seed samples were removed and subjected to the standard germination test. Germination counts were made after 7 days of incubation.

The experimental design was a randomised block with four replicates. The analyses of variance (ANOVA) was performed by the SAS programme package and statistically significant differences between means were estimated by Tukey´s test (Steel & Torrie, 1985). Results of the standard germination and the Accelerated Ageing (AA) tests were correlated.

3.4 RESULTS AND DISCUSSION

The results of the standard germination test indicated that about 66% of the sweet sorghum landraces used in this study were of commercially acceptable seed quality with a germination percentage above 85% and (Table 3.2). The mean germination percentage of the 65 landraces was 77.2 % and the range was 0 to 98.5 % (Table 3.2). There were significant differences in the germination of the landraces, with landrace X and G1 having the highest germination percentages of 98.5% and 98.0%, respectively. Landraces with the lowest germination percentage were K11 and L11 with 0% and 0.5%, respectively. In most instances poor germination was due to low viability of the seed. Landraces V, J, F and E1 had low germination percentages due to high counts of abnormal seedlings. It is apparent from the results that there were large quality differences among the 65 samples. Seed quality was

generally good as there were about 66% of landraces with a germination percentage above 85%. It has been reported that the standard germination test is an excellent predictor of field emergence under ideal field conditions (Tekrony,1993; Tekrony, Egli & Phillips,1980), but under stress conditions emergence is overestimated by standard germination and hence, seed vigour becomes an important attribute in predicting field emergence (Tekrony & Egli, 1977; Johnson & Wax, 1978). All 26 landraces used in the Accelerated Ageing (AA) test had a germination percentage around 90% in the Standard Germination test (Table 3.3).

Table 3.2 Viability (radicle emergence) and germination (normal seedlings) of the 65 Botswana sweet sorghum landraces

Sweet sorghum code	Production area	Viability %	Normal seedling %
A	Moshana	50.5	49.0
B	Tlokweng	89.5	85.0
C	Kgagodi	91.0	85.5
D	Gobojango	95.0	90.5
E	Maunatlala	99.0	95.0
F	Kgagodi	92.5	78.5
G	Sefare	95.5	90.0
I	Semolale	82.0	73.5
J	Shakwe	87.5	74.0
K	Madinare	97.5	90.5
L	Machaneng	66.5	64.0
M	Sefare	68.0	62.5
N	Machaneng	10.5	9.0
O	Maunatlala	5.0	4.5
P	Tautsure	91.0	87.5
Q	Machaneng	45.5	36.0
R	Gobojango	93.0	92.5

Sweet sorghum code	Production area	Viability %	Normal seedling %
S	Gobojango	96.5	
T	Madinare	90.5	87.0
U	Sefophe	47.5	38.5
V	Sefophe	57.0	45.0
W	Sefophe	55.5	49.5
X	Matebeleng	99.0	98.5
Y	Otse	95.5	83.0
Z	Thamaga	95.5	90.5
Al	Thamaga	98.5	97.5
B1	Malolwane	87.5	84.5
C1	Mokgomane	96.0	93.0
D1	Iyaiyane	84.0	74.5
E1	Malolwane	91.0	82.5
F1	Matebeleng	79.0	73.0
G1	Logaganeng	99.0	98.0
H1	Tutume	90.5	90.0
I1	Zwenshambe	93.5	93.0
J1	Gabane	80.5	76.0
K1	Mapoka	95.5	95.0
L1	Siviya	88.0	84.5
M1	Logaganeng	99.5	93.0
N1	Mathubulukwane	96.0	90.0
O1	Mogobane	77.5	73.5
P1	Mokgomane	97.0	92.5
Q1	Siviya	94.5	91.5
R1	Tutume	92.5	89.5
S1	Mapoka	95.0	93.0
T1	Sibina	87.5	80.0
U1	Tutume	95.5	95.5
V1	Sviya	97.0	97.0

Sweet sorghum code	Production area	Viability %	Normal seedling %
X1	Gamagangwe	92.5	88.0
Y1	Malolwane	96.0	95.5
Z1	Matubulukwane	92.3	90.5
A11	Moroka	93.5	93.0
B11	Sebina	13.5	12.5
C11	Mogobane	83.5	82.0
D11	Sebina	26.0	26.0
E11	Tutume	97.0	91.0
G11	Mogobane	96.5	95.0
H11	Mogobane	94.0	91.5
I11	Thutayaseko	91.5	91.5
J11	Mmsebele	96.5	96.0
K11	Matebeleng	0.0	0.0
L11	Oodi	0.5	0.5
M11	Moshana	30.5	26.5
N11	Zwenshambe	75.0	70.0
O11	Moroka	97.0	97.0

The mean AA germination of the 26 landraces was 76.8%, and this was 16.1 percentage points lower than the standard germination results before the AA test (Table 3.3). Percentage germination in the AA test ranged between 58.0 and 87.3% and 13 of the 26 landraces had a germination percentage above 80%. Landraces with the highest germination percentages were R1 and E with 87.5% and 86.1% respectively and the lowest was landrace G with 58.0%. Landrace X was ranked the highest in the standard germination test at 98.5% but in the AA test it ranked number 22 at only 67.4%.Landrace I11 had 91.5% germination according to the standard germination test and in the AA test it was the highest with 87.5% germination (Table 3.3).

Table 3.3 Germination percentages of twenty six sweet sorghum landraces after the Accelerated Ageing test

Landraces	Germination % before the A A test	Germination % after A A test
D	90.5	75.4 bcdef
E	95.0	82.1 abc
G	90.5	58.0 g
K	90.5	65.0 efg
R	92.5	78.9 abcd
S	94.5	76.4 abcdef
X	98.5	67.4 defg
Z	90.5	79.0 abc
A1	97.5	84.0 abc
G1	98.0	82.8 abc
H1	90.0	76.1 abcdef
K1	97.0	73.6 cdef
N1	90.0	59.0 g
P1	92.5	77.8 abcd
Q1	91.5	64.8 fg
R1	89.5	86.1 ab
S1	93.0	84.8 ab
V1	93.0	85.0 abc
Z1	90.5	76.0 abcdef
A11	93.0	81.1 abc
C11	92.0	79.8 abc
E11	91.0	86.1 ab
H11	91.5	79.3 abc
L11	91.5	87.3 a
J11	96.0	67.4 defg
O11	96.0	82.6 abc
Mean	92.9	76.8
F value	1.97	15.3
LSDt (p=0.05)	11.31 (N.S.)	10.68*
C.V. (%)	4.26	5.55

Germination percentages followed by the same letter do not differ significantly at $p \leq 0.5$ *

There was no clear relationship between the results of the standard germination test and the Accelerated Ageing test. Some seed lots with high germination percentages in the standard germination test attained low germination percentages in the AA test. The AA results give a relative indication of emergence potential under stress.

According to the AA test results the seed samples of the sweet sorghum landraces were generally of low quality. It is therefore suggested that farmers be advised on harvesting, threshing and storage of sweet sorghum to improve seed quality. The seed industry can contribute by producing sweet sorghum seed. For assessment of seed quality a combination of the standard germination test, with the Accelerated Ageing test, gives more informative results but there is still a need to correlate the results with field emergence.

Although poor seed quality may be due to several factors as already stated, early harvesting time might be the major problem in sweet sorghum because farmers harvest seed before they reach physiological maturity. Harrington (1972) suggested that developing seed achieves maximum viability and vigour at physiological maturity and after that seed begins to age with viability and vigour declining. Thus, in the following chapter, results testing Harrington's hypothesis are presented, since it is not known when sweet sorghum seeds attain maximum quality during development and maturation.

CHAPTER 4

SEED DEVELOPMENT AND MATURATION IN SWEET SORGHUM

4.1 ABSTRACT

Seed development and maturation of sweet sorghum (*Sorghum bicolor* (L) Moench.) and grain sorghum were studied in two seasons (1995/96 and 1996/97). Seeds were serially harvested for determination of dry mass accumulation, germination capacities and steep water conductivity. In 1995/96 mass maturity in grain sorghum occurred 61 days after anthesis (DAA) when seed moisture content was 38%, and in sweet sorghum it occurred 48 DAA when seed moisture content was 43%. The mass of sweet sorghum seed at mass maturity was 58% of that of grain sorghum. Maximum seed quality (minimum conductivity of steep water) was attained 11 days before mass maturity in grain sorghum and 17 days after mass maturity in sweet sorghum. In both cases this did not coincide with maximum seed germination which was observed only 90 DAA in grain sorghum and 85 DAA in sweet sorghum. This anomalous phenomenon was due to seed dormancy, hence seeds were consequently exposed to a dormancy breaking treatment during the 1996/97 season. During the 1996/97 season, mass maturity occurred earlier than in the 1995/96 season in both grain and sweet sorghum. Mass maturity occurred 38 DAA when moisture content was 36% in grain sorghum and 31 DAA when seed moisture content was 38% in the case of sweet sorghum. The mass of sweet sorghum seed at mass maturity was 55% that of grain sorghum. The shorter grain filling stage was probably due to the fact that the 1996/97 crop matured during the warm summer months as compared to the 1995/96 crop which matured during the autumn months of the season.

Maximum seed quality was attained 7 days after mass maturity in grain sorghum and 14 days after mass maturity in the case of sweet sorghum. This coincided with maximum seed germination of prechilled seeds of sweet sorghum whilst in grain sorghum, maximum seed quality occurred 10 days before maximum seed germination. Maximum seed germination was attained 17 days after mass maturity in grain sorghum. Prechilling treatment during the 1996/97 season improved germination in both grain and sweet sorghum seeds as compared to the1995/96 treatment.

4.2 INTRODUCTION

In Chapter 3 it was shown that seed of sweet sorghum landraces collected from Botswana farmers were in many cases of poor quality. This may be attributable to the fact that seed of sweet sorghum is harvested before it reaches physiological maturity. In Botswana the commercial value of sweet sorghum lies in the stalks which are sold as delicacies and therefore, the stems are harvested when they have reached an acceptable sugar content and not necessarily when the seeds are matured. This contributes towards poor germination and stand establishment of the subsequent crop. Research on carrots and on Chinese Aster seed crops has indicated that time of harvesting is a major factor affecting the quality of seed (Joyce, Steckel, Gray & Rowse, 1989; Grzesik, Gornik & Chojnowski, 1997).

A prerequisite for good stand establishment is that farmers must have access to seed of good quality. Botswana farmers obtain good quality seed of various crops from the Seed Multiplication Unit (SMU) at Sebele. Unfortunately, sweet sorghum seed is not supplied by SMU and farmers retain their own seed from one season to the next. It is suggested

that the SMU should be encouraged to produce sweet sorghum seed.

According to Harrington (1972) seeds attain maximum seed quality at the end of the seed filling period, thereafter viability and vigour decline. This stage was termed physiological maturity by Shaw & Loomis (1950). Harrington's (1972) hypothesis has been supported by other findings such as those with *Triticale* (*Triticale hexaploid* L.; Bishnoi, 1974) soybean (Glycine max.(L) Merrill; Tekrony, Egli & Phillips, 1980) and wheat (*Triticum sativum* L.; Rasyad, van Sanford & Tekrony, 1990). However, several research reports stated that maximum seed quality was only attained some time after the end of the seed filling period, thus contradicting Harrington's hypothesis. Such was the case with edible dry bean (*Phaseolus vulgaris* L.; Van de Venter, Demir & de Meillon, 1996), soybean (*Glycine max*. (L.) Zanakis, *et al*, 1994), rice (*Oryza sativa* L.; Ellis, Hong & Jackson, 1993), pepper (*Capsicum annuum*; Demir & Ellis, 1992); tomato (*Lycopersicon esculentum* Mill.; Demir and Ellis, 1992) barley (*Hordeum vulgaris* L.; Filho & Ellis, 1992a), barley and wheat (*Hordeum vulgaris* L. and *Triticum sativum* L.; Ellis & Filho, 1992b) and soybean (*Glycine max*. L. Merr.; Miles, Tekrony & Egli, 1988). The term "mass maturity" has been found to be a more appropriate term to describe the end of the seed filling period than "physiological maturity"which has been found to be potentially misleading (Ellis & Filho, 1992b).

This study was initiated because there is no information concerning the stage at which sweet sorghum seeds attain maximum quality during development and maturation. Grain sorghum was included in the study for comparison purposes.

4.3 MATERIALS AND METHODS

A Botswana sweet sorghum landrace (Gl) and grain sorghum cv. IS 257603 were planted on two plots at the Experimental Farm of the University of Pretoria. The soil type of the farm is a sandy clay loam of the Hutton form. The study was conducted during the 1995/96 and 1996/97 growing seasons. Planting dates in 1995/96 and 1996/97 were December 7 and October 18 respectively. During the 1995/96 growing season the mean maximum and minimum temperatures between planting and flowering were 26°C and 15°C respectively, and during the sequential harvesting period the maximum temperature was 21°C and the minimum

was 8°C. During the 1996/97 growing season the maximum and minimum temperatures between planting and flowering were 27°C and 15°C, respectively and during the sequential harvesting period the maximum temperature was 25°C and minimum temperature 15°C. Total rainfall in the period between planting and the end of harvesting was 797 mm during 1995/96 and 800 mm in 1996/97. Plants were irrigated during dry spells to prevent water stress.

Planting was done with a hand planter at a depth of 3 cm. Seeds were sown 0.3 m apart, with an inter- row spacing of 1.0 m. No fertilizer was applied during planting. Plants were top dressed with limestone ammonium nitrate (LAN) at the rate of 120 kg N ha^{-1} thirty days after emergence. Weeding was done by hand in the 1995/96 season and in the 1996/1997 season weeds were controlled by a pre-emergence application of atrazine at 3 kg active ingredient per hectare. Developing seeds of grain sorghum and sweet sorghum plants were serially sampled every 10 days to determine seed moisture

content, seed dry mass, germination percentage and the electric conductivity of seed steep water. Standard germination tests were conducted to measure viability. For measuring seed quality the electric conductivity of seed steep water was used as a parameter. The conductivity test provides an indication of the integrity of deteriorated membranes and cells which "leak."When deteriorated seeds are soaked in water they lose more electrolytes which increases the conductivity of the water. High conductivity of the steep water denotes low vigour and low conductivity denotes high vigour. All tests were conducted immediately after sampling.

Plants were tagged at 50% anthesis and sequential samples of the developing and maturing seeds were taken at five days intervals for determination of seed moisture content, dry mass accumulation, germination and steep water conductivity. Seeds used for these determinations were removed from the central part of three inflorescences at each sampling date. During the 1995/96 season sequential harvesting began 15 days after anthesis (DAA) and ended 105 DAA and in the 1996/97 season it started 20 DAA and ended 80 DAA.

Seed moisture content

At each sampling date, four replicates of approximately 4 g of seeds were weighed immediately to determine the fresh mass, dried at 105°C for 24 hours and reweighed to determine the dry mass.

Moisture content (MC) was expressed on a fresh-mass basis, i.e.

$$\%\,M = \frac{\text{Fresh mass - Dry mass}}{\text{Number of seeds in sample}} \times 100\%$$

Seed dry mass

At each sampling date, three replicates of 50 seeds each were weighed immediately to determine fresh mass. The dry mass of the 50 seeds was determined using the following formula: $\text{Seed mass at 0\% MC} = \frac{(100 - \text{MC}) \times \text{mass of 50 seeds}}{100}$

The dry seed mass of the sample was divided by 50 to obtain the mean dry mass of individual seeds.

Seed germination

To determine the germination capacity of the seed at each sampling date, standard germination tests were conducted according to the rules of ISTA (ISTA, 1993). During the 1995/96 growing season, four replicates of 50 freshly harvested seeds each were incubated in rolled paper towels moistened with 100 cm^3 of deionized water. The rolled paper towels were placed in a germination chamber at 25°C in the dark. Seeds of another set of four replicates were weighed and dried to a moisture content of between 10 to14% and germinated in a similar manner. Because of poor germination results, attributed to dormancy in the 1995/96 growing season, a dormancy-breaking treatment prescribed by ISTA (1993) was introduced. Seeds dried to 10 to 14 % moisture were prechilled at 5°C for 5 days during the 1996/97 season before the germination test. The control samples of unchilled seeds were also germinated. Only seeds dried to 10-14 % moisture content were used for germination tests during the 1996/97 season because the 1995/96 results showed no differences in their performance compared to fresh seeds. In all cases germination evaluations were done 10 days after the commencement

of incubation and results expressed in terms of viability (radicle emergence) number of normal and/or the number of abnormal seedlings (ISTA 1993).

Conductivity of seed steep water

The method of Hampton (1995) was used to determine the conductivity of seed steep water. At each sampling, five flasks of 300 cm^3 capacity were filled with 250 cm^3 deionized water, covered with aluminium foil put under temperature equilibrated at 20°C for 24 hrs. At each sampling date, samples of 50 dried seeds with moisture contents between 10 and 14%, were weighed and added to the four flasks (four replicates), while the fifth remained as a control to ascertain the conductivity of the water without seeds. The flasks were gently swirled and returned to the growth chamber for another 24 hours. Conductivity was determined by a Metrohm conductometer and conductivity of the steep water was expressed as $\mu S\ cm^{-1}\ g\ seed^{-1}$ (Hampton, 1995).

4.4 RESULTS AND DISCUSSION

(a) 1995/1996 season

To estimate the date of mass maturity an iterative regression analysis procedure was used (Filho & Ellis, 1991) by fitting a positive relation from 15 to 61 days after anthesis DAA in the case of grain sorghum and from 15 to 48 DAA for sweet sorghum. The estimated time of mass maturity (mm) was 61 DAA with a moisture content of 38% in grain sorghum and 48 DAA with a moisture content of 43% in the case of sweet sorghum (Fig.4.1). The mass of sweet sorghum at mass maturity was 58% of that of grain sorghum and harvest maturity was reached 90 DAA in grain sorghum and 85 DAA in sweet sorghum. At this stage the moisture content was below 14% in both crops.

The moisture content declined steadily from 83.4% in grain sorghum and from 81.9% in sweet sorghum from 20 DAA until 55 DAA (approximately mass maturity), where after it decreased rapidly until 105 DAA when the moisture content was below 12% and the experiment was terminated (Fig. 4.1). Harvest maturity occurred 95 DAA in both crops when moisture content was below 12 % (Fig 4.1).

Minimum conductivity of steep water for the grain sorghum seed was observed at 50 DAA indicating maximum seed quality 11 days before mass maturity (Fig 4. 2). In sweet sorghum, minimum conductivity of steep water occurred 65 DAA indicating maximum seed quality 17 days after mass maturity (Fig 4.3). In both cases this did not coincide with maximum seed germination.

Maximum seed germination of dried grain sorghum seed was observed 90 DAA which was 40 days after minimum conductivity (Fig 4.2). In sweet sorghum maximum seed germination was observed 85 DAA, 20 days after minimum conductivity (Fig 4.3). Germination of fresh seed showed a similar pattern to dried seed and maximum germination occurred at approximately the same time (Fig.4.2 & 4.3). However, for the grain and the sweet sorghums, maximum germination was observed well after maximum seed quality. This anomalous phenomenon was postulated to be due to seed dormancy and it was decided that seeds should be exposed to a dormancy breaking treatment during the following season (1996/97).

b) 1996/97 season

The positive relation was fitted to estimate time of mass maturity from 20 DAA to 38 DAA in the case of grain sorghum and from 20 DAA to 31 DAA in sweet sorghum, using

an iterative regression analysis procedure (Filho & Ellis, 1991). Estimated time of mass maturity was 38 DAA when seed moisture content was 36% in grain sorghum and 31 DAA when seed moisture content was 38% in the case of sweet sorghum (Fig 4.4). The mass of sweet sorghum at mass maturity was 55% of that of grain sorghum.

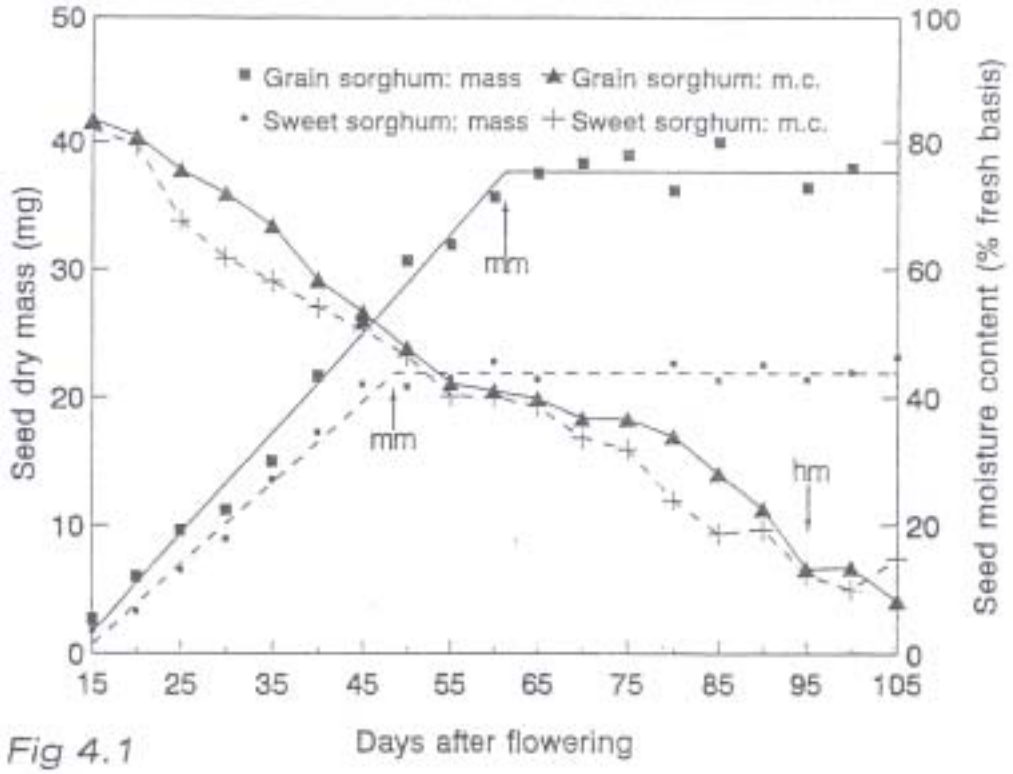

Fig 4.1

Dry mass and moisture content (% fresh – mass basis) of seeds harvested serially from field grown and sweet sorghum plants during the 1995/96 season (mm = mass maturity; hm = harvest maturity)

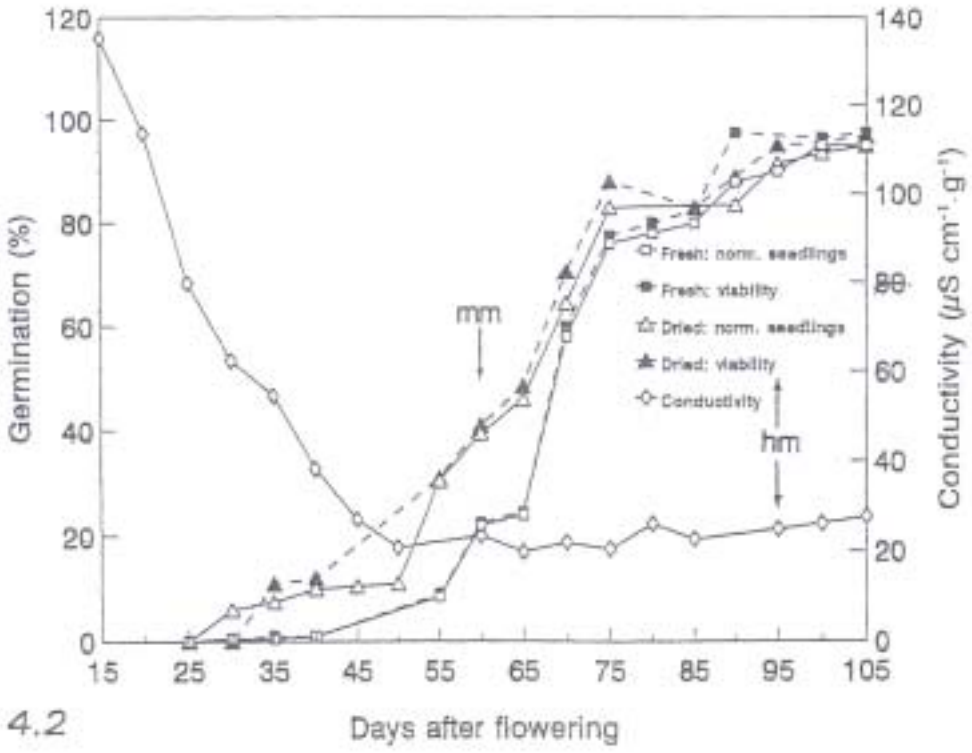

Fig 4.2

Electric conductivity of seed steep water, and viability and normal germination of fresh and rapidly dried seeds of samples harvested serially from field grown plants of grain sorghum during the 1995/96 season (mm = mass maturity; hm = harvest maturity)

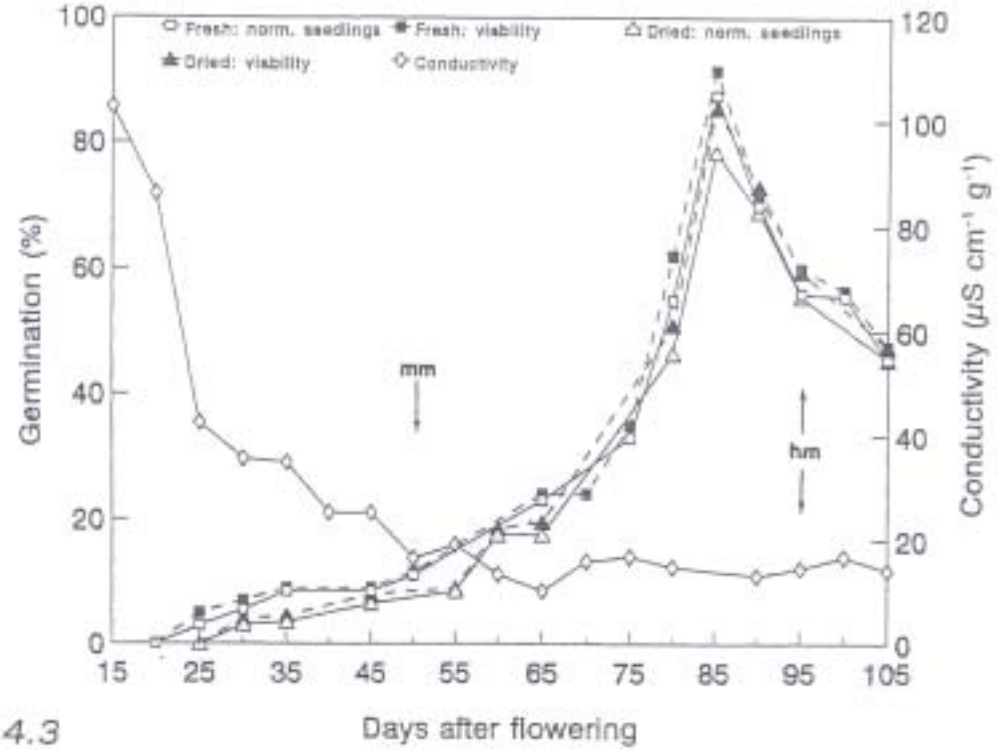

Fig 4.3

Electric conductivity of seed steep water, and viability and normal termination of fresh and rapidly dried seeds of samples harvested serially from field grown plants of sweet sorghum during the 1995/96 season (mm = mass maturity; hm = harvest maturity)

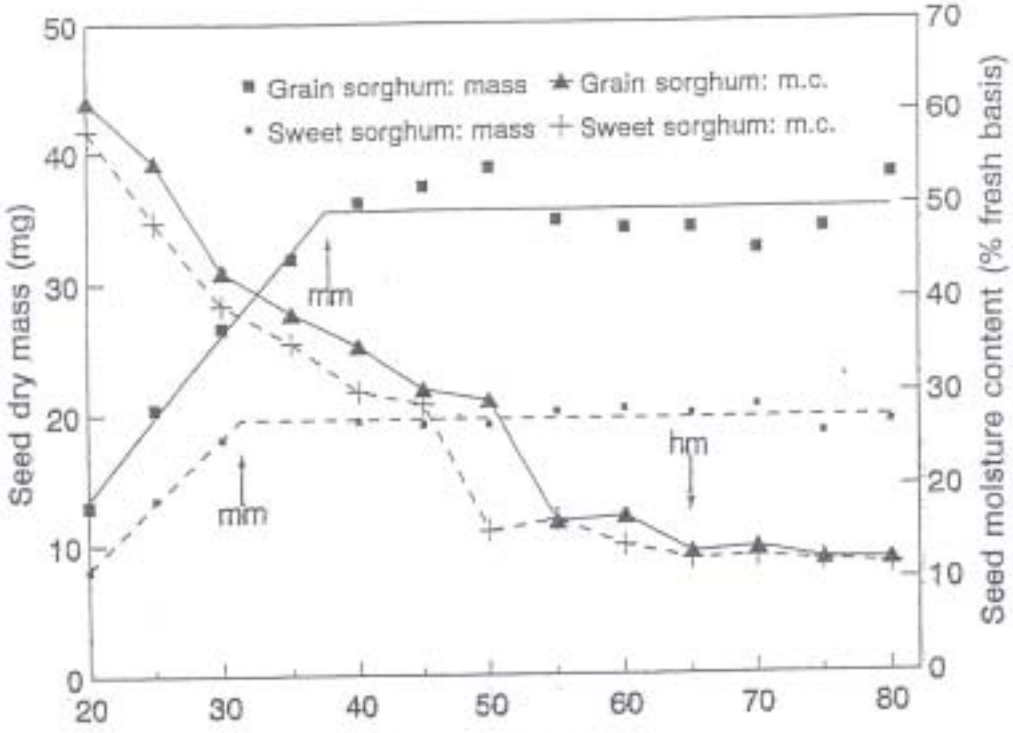

Fig 4.4

Dry mass and moisture content (% fresh – mass basis) of seeds harvested serially from field grown grain and sweet sorghum plants during the 1996/97 season (mm = mass maturity; hm = harvest maturity

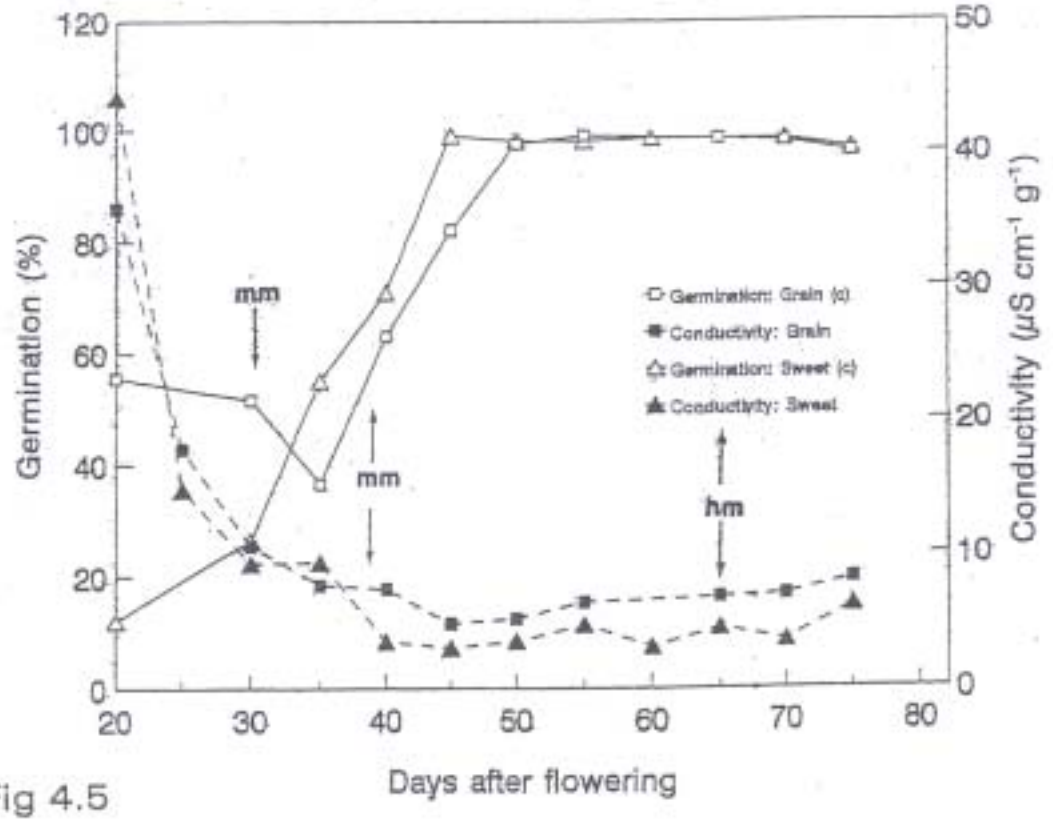

Fig 4.5

Electric conductivity of seed steep water, and viability and normal germination of prechilled dry seeds of samples harvested serially from field grown plants of grain and sweet sorghum during the 1996/97 season (mm =mass maturity; hm =harvest maturity)

Harvest maturity was reached 65 DAA in both crops, 25 days earlier than the previous season in grain sorghum and 20 days earlier in sweet sorghum. At this stage the seed moisture content was below 14% (Fig 4.4) The shorter grain filling period was probably due to the fact that the 1996/97 crop matured during the warm summer months, compared to the 1995/ 96 crop which matured during the cool autumn months. The moisture content similarly declined faster than the previous season.

Minimum conductivity of steep water for seed of both crops was observed much earlier in the 1996/97 season than in the previous season. It occurred 45 DAA for both crops (Fig 4.5), indicating that maximum seed quality was reached 7 days after mass maturity in grain sorghum and 14 days after mass maturity in the case of sweet sorghum. This coincided with maximum seed germination of prechilled seeds for sweet sorghum which was observed at 45 DAA. In grain sorghum maximum seed germination of dried, prechilled seed was observed only 55 DAA (Fig 4.5).

Germination percentage of prechilled seeds was superior to that of untreated seeds (see Table A4.1 of the Appendix). At 55 DAA treated seeds of both grain and sweet sorghum had germinated 99% and 98% respectively, compared to the untreated seeds of both crops which had attained only 26% and 57.5% respectively (Table 4.1). This suggests that poor germination in the experiments of 1995/96 season was due to seed dormancy.

During 1995/96 minimum conductivity, (maximum seed quality) of the steep water of grain and sweet sorghum did not coincide with maximum seed germination (maximum seed viability). It was postulated that seed dormancy prevented full germination of mature seed.

The rate of germination began to increase only after mass maturity (maximum seed mass) was reached. This increase in germination was due to a decrease in dormancy of mature seeds. However, in 1996/97 the minimum conductivity of the steep water of grain and sweet sorghum occurred at the same time, and this coincided with maximum seed germination in sweet sorghum, whilst in grain sorghum it lagged by only 5 days. This shows that maximum seed quality was attained approximately 45 to 55 DAA in both sweet and grain sorghum. These results indicate that mass maturity in sweet sorghum and grain sorghum preceded the minimum conductivity of steep water, an indication of maximum seed quality (physiological maturity). Similar observations were made in other crops such as *Atriplex codobensis* L., (Aiazzi, Arguello & Dirienzo, 1998), *Phaseolus vulgaris* L., (Van de Venter *et.al.* 1996), *Lucopersicon esculentum* Mill., (Demir & Ellis, 1992), *Hordeum vulgare (*Ellis & Filho,1992b*), Pennisetum glucum*, (Kameswara, Rao, Mengesha & Ellis, 1991), *Vicia faba* L. and *Lens culinaris* Medik., (Ellis, Hong & Roberts, 1987). The results indicated that physiological maturity in sweet and grain sorghum follow the model proposed by Ellis & Filho (1992b), where maximum dry weight (mass maturity) precedes maximum viability (physiological maturity) which is in contrast to the hypothesis of Harrington (1972).

Seed development in the case of sweet sorghum was more rapid than that of grain sorghum in both seasons. This may be due to the fact that sweet sorghum seeds are smaller in size genotypically. However, when comparing sweet sorghum and grain sorghum performance in the two seasons, seed development of both cultivars during 1996/97 was much faster. Grain and sweet sorghum seeds reached mass maturity 23 and 17 days earlier than in 1995/96, respectively. This was due to higher temperatures

during seed development in 1996/97 which accelerated maturity. This phenomenon has been observed in other crops such as in leek (Gray, Steckel & Hands, 1992) and rice (Ellis, Hong & Jackson, 1993).

The differences between 1995/96 and 1996/97 seed germination patterns were probably due to the effect of the dormancy breaking treatment. Results of the 1996/97 season showed high levels of germination at early developmental stages after the dormancy breaking treatment. Comparing seed performance of treated and untreated seeds at 30 DAA it is noted that prechilled seeds had reached 51.5% germination in the grain sorghum and 26.5% germination in sweet sorghum, whilst untreated seeds had only reached 17% and 13% respectively. This confirms the conclusion of Stanway (1958) that freshly harvested sorghum seeds need to be prechilled prior to conducting germination tests.

Moisture content in the seeds of grain and sweet sorghum declined steadily until after mass maturity, where after it decreased rapidly until harvest maturity. This was due to environmental conditions because after mass maturity the seed was no longer connected to the plant's vascular system. Mass maturity for sweet and grain sorghum, in both seasons, coincided with the time when moisture content was between 36% and 34%, which is similar to the observations of Ellis *et al*, (1993) for rice.

There was no difference in the germination capacity of fresh and dried seed in sweet and grain sorghum. This contrasted with the results obtained with wheat (Rasyad *et al*,1990) and in castor bean (Kermode & Bewley, 1985) where it was observed that drying treatment of seeds enhanced the germination capacity of immature seeds to its

maximum value.

It is clear from the results that a standard germination test conducted without pretreatment for dormancy is not an adequate method of determining maximum seed quality in freshly harvested seed of both sweet and grain sorghum. Fresh seed of both sweet and grain sorghum did not respond to drying before germination. Seed development and maturation in both crops were accelerated by high temperatures. Maximum seed quality (as determined by maximum germination and minimum conductivity of seed steep water) in sweet sorghum was attained between 14 to 17 days after mass maturity and in grain sorghum the results were inconclusive because of the differences in the 1995/96 and 1996/97 results. Investigations to determine the time when the stem juice attains maximum sweetness are required to be able to make recommendations to farmers as to the best time of harvesting seed of high quality.

CHAPTER 5

CHARACTERISATION AND EVALUATION OF TEN SWEET SORGHUM LANDRACES

5.1 ABSTRACT

Ten Botswana sweet sorghum landraces were grown at the experimental farm of the University of Pretoria for characterisation of morphological and agronomic characters. The objective was to characterise and describe differences observed in the ten landraces and thus establish the potential of local germplasm as source of material for future crop improvement. The results revealed the presence of late and early maturing types. Late maturing landraces had taller and thicker main stems with more internodes compared to the early maturing landraces. Consequently, the late maturing landraces had higher stem fresh mass, stem dry mass and leaf dry mass. There was a wide variation in the tillering ability of landraces. At harvesting the least tillering landrace produced 2.3 tillers per plant and the most tillering landrace produced 5.3 tillers per plant. Landraces differed in proness to lodging with the most sensitive landrace showing 100% lodging and the least prone showing 5% lodging. Great variation was demonstrated in head exsertion, inflorescences, shape and compactness, length of panicle, glume colour, grain size, grain colour and grain numbers per panicle. Glume cover of the grain varied between 25% and 75%. Heads with high grain cover percentages had a tendency of low shattering. However, there were no differences in grain plumpness and grain form among the landraces. All landraces were awnless except for landraces 2 and 5 which were awned. Landraces differed in juice characteristics except in purity. Early maturing landraces had low stalk fibre percentages and low sucrose and brix percentages as

compared to the late maturing landraces. Landraces 9 and 10 were superior in juice purity and sucrose content and they were the most preferred landraces by an informal testing panel. From these results it was evident that there is a range of genetic diversity in Botswana sweet sorghum landraces which can be used in future for crop improvement.

5.2 INTRODUCTION

Sweet sorghum is rated a minor crop in Botswana and little or no documented information is available. No local research has been undertaken to improve sweet sorghum production nor to develop new varieties. As a result local farmers use traditional landraces selected over generations. In most cases these landraces differ from one district to another and major differences were found in the stems, inflorescences, maturity period, seed size and seed colour characteristics.

Collection and characterisation of germplasm are important first steps in building a gene pool for an under researched crop, to enable scientists to evaluate and improve the crop. Collection and evaluation of sweet sorghum cultivars have been carried out elsewhere. In the USA Coleman & Stokes (1958) Johnson *et al*, (1961) and Cowley & Smith (1972) evaluated sweet sorghum varieties for their potential use in the manufacture of crystallized sugar and fermentable carbohydrates, disease resistance and juice quality potential. In Australia, Ferraris (1981a; 1981b; 1988; Ferraris & Charles-Edwards,1986a; 1986b & conducted studies comparing the response of sweet sorghum varieties to environment, in terms of photosynthetic efficiency, yield and fermentable carbohydrate content. In India, Maheshwari, Prasad, Singh & Sharma (1974) and Shih, Gascho & Rahi (1981) investigated factors influencing biomass,

fermentable sugars and disease resistance. Inman-Bamber (1980) evaluated sweet sorghum varieties for potential as a sugar producing crop in the Republic of South Africa .

Large collections of grain sorghum germplasm are available in Botswana in the Department of Agricultural Research of the Ministry of Agriculture, which has a Plant Genetic Resources Unit. The Department of Agricultural Research liaises with SADCC/ICRISAT Sorghum and Pearl Millet Improvement Program in all matters relating to germplasm collection. A lot of work has been done on the characterisation and evaluation of grain sorghum accessions, but very little or none has been done on sweet sorghum in Botswana. About 146 grain sorghum germplasm accessions collected from various parts of Botswana were characterized for agronomic characteristics including days to flowering, plant height, head types and grain colour (Anoymous, 1987). Sweet sorghum landraces were collected during the 1996/97 growing season for characterisation and evaluation in this study. The collection area represented the principal sweet sorghum growing areas of Botswana, as shown in Fig 3.1. The objective of this study was to characterise and describe differences in the 10 selected sweet sorghum landraces and thus establish the potential of local germplasm as a source of material for future crop improvement.

5.3 MATERIALS AND METHODS

Due to difficulties in characterisation of many accessions at a time, of the 65 accessions collected (Chapter 3) 10 landraces were characterised for a number of readily identified traits which included maturity period, leaf and stems yield, juice quality, inflorescence and seed characteristics. The landraces were characterised according to the Sorghum

Descriptors (IBPGR & ICRISAT, 1993). Characterisation of the 10 sweet sorghum landraces was conducted during the 1997/98 growing season on the Experimental Farm of the University of Pretoria. Soil characteristics at the Experimental Farm is described in Table A5.1in the Appendix. Rainfall and temperature data for 1996/97 to 1998/99 growing seasons in the Experimental Farm are presented in Table A5.2 in the Appendix.

Before planting, two plots of 18 m long and 10 m wide, were disced and harrowed. The plots were established in a 'Wagon wheel' pattern. Each landrace occupied a single row of 8 m representing a spoke of the wheel. Planting was done with a hand planter at an intra row spacing of 25 cm in a well prepared seedbed. No fertilizers were added during planting. Thinning to one plant per hill was done after approximately 20 days when the plants were well established. After 60 days, plants were topdressed with limestone ammonium nitrate (LAN) at the rate of 120 kg N ha^{-1}. Plots were kept weed free and supplementary irrigation was applied during periods of low rainfall. Aphid infestation was fairly severe and the crop was sprayed with an aphicide on several occasions.

For data collection the rows were divided into three segments, i.e. inner, central and outer segments, to ascertain plant population effects. Intervals between phenological events were recorded. After heading a combination of high winds and heavy rains resulted in some lodging, allowing an opportunity to rate the landraces for proness to lodging. During final harvesting twenty stalks were harvested from each row segment, stripped, packed in polyethylene bags, sealed (see Fig.5.1) and sent to the South African Sugar Association (SASA) Mount Edgecombe, Kwazulu-Natal for juice analysis. The juice was tested for brix value (soluble solid content), pol percentage (sucrose content as measured by a polarimeter), juice purity (percentage ratio of pol to brix) and fibre

content (non-solubles bagasse after washing with water for one hour according to standard sugar cane technology methods. Five typical plants from each row segment were harvested to determine final stem height, stem thickness, number of internodes, number of leaves and tillers per plant, fresh stem weight and dry mass of stem and leaves. Number of leaves included those of the main stem and its tillers.

The inflorescences and seed were also characterised according to the Sorghum Descriptors (IBPGR & ICRISAT,1993). The analysis of variance (ANOVA) was performed by the SAS programme package and statistical significant differences between means were estimated by Tukey's Test (Steel &Torrie, 1985).

Fig 5.1 Preparation of sweet sorghum samples sent to South African Sugar Association (SASA) for juice analysis. Sweet sorghum stems are stripped, packing in polyethylene bags and taken to the cool room.

5.4 RESULTS AND DISCUSSION

Phenology

Phenological data of the ten sweet sorghum landraces are shown in Table 5.1. The early

emerging landraces were L1, L2, L4, L5 and L8 which attained 50% emergence 4 days after sowing (DAS), while L3, L6, L7 and L9 attained 50% emergence 5 DAS and the latest landrace to emerge was L10 at 6 DAS. The general trend indicated that the five early maturing landraces reached boot, flowering, milk and soft dough stages at the same time and they were all harvested 109 days after emergence (DAE), during the hard dough stage. While Landraces L3, L6 and L7 were harvested 17 days later than the first lot and landraces L9 and L10 reached the dough stage at 131 and 139 DAE, respectively. These results identified early maturing and late maturing types. The classification was consistent to Cowley & Smith (1972) and Ferraris & Stewart, (1979) who classified landraces that matured within 100 to 120 days after emergence as early maturing, and those that reached maturity after 120 days as late maturing. Differences in days to harvesting are beneficial in that it expands the sweet sorghum season.

Stem characteristics

There were significant differences in main stem height, thickness and number of internodes (Table 5.2). In the late maturing types, landrace L6 had the longest stem (354 cm) and landraces L10 and L3 the shortest (330 and 331 cm, respectively). In the early maturing types landrace L4 had the longest stem (324 cm) and landrace L2 had the shortest (288 cm). These results indicated longer stems in late maturing landraces compared to the early maturing types. This was due to the fact that stems of the late maturing types contained more internodes than the early maturing ones (Stoskopf, 1985). The same trend was observed in stem thickness. Late maturing landraces had thicker stems than the early maturing types (Table 5.2). The stem thickness for the late maturing landraces ranged from 2.6 to 2.8 cm. While in the early maturing types, the stem thickness ranged from 2.1 to 2.7 cm. Thick stalks are desirable because small

diameter stalks have a great tendency to lodge in the field and consumers tend to prefer thick stems for reasons of juiciness. The number of internodes in the main stems ranged from 10 to 14.

Table 5.1 Phenological data and days to harvest of the ten sweet sorghum landraces

Landraces	Days to 50% emergence	Days to 50% boot stage	Days to 50% flowering	Days to 50% milk stage	Days to 50% soft dough	Days to final harvesting
L1 (B)	4	79	88	95	105	109
L2 (G1)	4	79	88	95	105	109
L3(Z)	5	84	93	105	113	126
L4 (X1)	4	79	88	95	105	109
L5 (C1)	4	79	88	95	105	109
L6 (J)	5	94	105	112	117	126
L7 (E)	5	89	105	112	117	126
L8 (D)	4	79	88	95	105	109
L9 (R1)	5	94	109	119	124	131
L10 (A11)	6	105	117	126	131	139

* B, G1, Z, X1, C1, J, E, D, R1, and A11 refer to original codes in Table A3.1in the Appendix

The late maturing landraces had more internodes than the early maturing types. These results are in agreement with Coleman's, observation that late maturing sweet sorghum cultivars usually have long, thick stems, with harder rinds and more internodes (Coleman, 1970).

Most of the landraces showed a tendency to lodge during a wet and windy period. Landraces L3, L4, L7, L5, L1 and L6 were severely affected by lodging (Table 5.2).

However, it is not possible to draw definite conclusions from these results because the wind direction could have affected some landraces more than others due to the varying row orientation. Landrace 10 lodged the least and this was attributed to better root development and thick stems. The 5% lodging observed in L10 was due to stem breakages, while for most of the other landraces lodging was due to root lodging with stalks remaining intact.

Table 5.2 Length, diameter and number of internodes of the main stem and lodging % of the ten sweet sorghum landraces

Landraces	Stem height (cm)	Stem thickness (cm)	Number of internodes	Lodging %
L1	293	2.7	10	75
L2	288	2.1	10	50
L3	331	2.8	12	100
L4	342	2.4	11	100
L5	310	2.4	10	80
L6	354	2.6	14	75
L7	320	2.7	13	90
L8	299	2.5	12	45
L9	344	2.7	13	50
L10	330	2.7	14	5
LSDt (p=0.05)	55.95	0.5	-	-
C.V. (%)	6.07	6.59	-	-

Leaf and stem characteristics

Data for leaf area, leaf dry mass, stem fresh and dry mass and moisture contents are shown in Table 5.3. There were significant differences between landraces in leaf area. The leaf area per plant ranged from 4584 cm^2 (landrace 8) to 16399 cm^2 (landraces 10). There was a tendency towards late maturing landraces (L10, L3, L9 and L6) having

larger leaf areas than the early maturing landraces (L8, L1, and L5). It was observed that early maturing landraces had fewer and narrower leaves compared to late maturing landraces with numerous and broader leaves. Leaf dry mass directly correlated with leaf area. The differences in leaf area represented the cumulative effects of differences in morphology of the landraces. There were significant differences among landraces in fresh stem mass but not in a stem dry mass (Table 5.3).

Table 5.3 Leaf area, leaf dry mass, stems fresh mass, stem dry mass, number of tillers and moisture content per plant of the ten landraces

Landraces	Leaf area per plant (cm)	Leaf dry mass per plant (g)	Stems fresh mass per plant (g)	stem dry mass per plant (g)	Number of tillers per plant	stem moisture content (%)
L1	6373	67.3	2329	530	4.0	77.3
L2	7526	71.2	2487	502	4.7	78.6
L3	13237	121.8	3906	896	5.3	77.0
L4	9965	100.6	3049	593	4.0	80.9
L5	6953	69.1	2296	527	2.3	77.0
L6	9452	105.5	2418	524	3.3	78.1
L7	7982	83.7	2418	480	3.3	80.1
L8	4584	74.0	2080	490	2.3	76.5
L9	10848	101.7	2655	723	3.7	72.8
L10	16399	139.0	2927	787	4.7	73.1
LSDt (p=0.05)	9113	57.1	1152.8	458.8	N/S	-
C.V. (%)	33.3	20.9	14.8	25.9	42.84	-

In the late maturing landraces, total stem fresh mass per plant ranged from 2418g to 3906g while in the early maturing types total stem fresh mass ranged from 2080g to 3049g. Stem dry mass followed the same trend as the stem fresh mass. The results showed a tendency of late maturing types attaining higher stem weights than the early maturing types. Ferraris & Charles-Edwards (1986a) also observed that late maturing

cultivars of sweet sorghum achieved a greater biomass compared to early maturing cultivars.

There were no significant differences between landraces in the number of tillers per plant at maturity, mainly due to the fact that from 60 days after emergence landraces lost tillers due to factors such as increased shading in the canopies (data not presented). However, there was a clear tendency for landraces L5 and L8 of having fewer tillers (2.3) compared to landrace L3 (5.3) and landrace L2 and L10 (4.7). Most tillers in landraces L3 and L10 were of marketable value (data not presented). This is an important characteristic affecting crop productivity and the inclusion of L10 in future breeding programmes is recommended.

Generally, there was no difference between landraces in stem moisture content (Table 5.3). Landrace 4 (80.9%) and L7 (80.1%) had the highest moisture content and this juiciness was confirmed when tasting matured stems. Landraces with more moisture in the stem would be more desirable, provided levels of sugar are high.

Panicle and grain yield characteristics

Data of the mean width and length of the panicle, mean peduncle length, 100-seed weight and the grain number per panicle of the landraces are presented in Table 5.4. The size of the inflorescence (width x length of a panicle) varied. Landraces L7 and L8 had the smallest and landraces L10, L3, L6, and L4 had the largest panicles. Early maturing landraces typically had smaller panicles than the late maturing types. Significant differences in the length of peduncles were observed among the landraces, and the peduncles of L2, L4, L5 and L1 and L9 were the longest and those of the L6, L10, and L8 were the shortest. The results show longer peduncles in the early maturing

landraces than in the late maturing landraces. Short peduncles are a disadvantage in terms of pest and disease sensitivity because insects and fungi tend to develop around the sheath of the flag leaf and extend to the panicle attacking the seeds (Doggett, 1970).

Table 5. 4 Mean panicle length, width, peduncle length, numbers of seed per panicle and 100-weight of ten sweet sorghum landraces

Landraces	Length of panicle (cm)	Width of Panicle (cm)	Length peduncle (cm)	Number of seed per panicle	100-seed weight (g)
L1	31.3	8.3	50.0	2708	1.86
L2	27.8	8.0	59.3	2875	2.44
L3	36.0	8.7	49.3	3893	2.14
L4	36.2	8.5	59.3	1585	2.48
L5	27.3	9.7	57.0	1933	2.23
L6	29.0	9.3	40.3	3839	2.69
L7	23.5	6.7	48.0	1193	1.45
L8	23.5	7.3	44.7	1500	1.91
L9	27.7	6.8	50.0	3769	2.51
L10	32.7	10.0	41.3	3199	2.60
LSDt (p=0.05)	2.67	1.02	15.87	-	0.32
C. V. (%)	3.09	4.52	10.85	-	4.91

Wide variation was observed in the number of seed per panicle (Table 5.4). Landraces L7, L8, L4 and L5 had less than 2000 seeds per panicle whilst landraces L3, L6, L9 and L10 had more than 3000 seeds per panicle. The results indicated that some of the late maturing landraces have the potential for seed production and they compare well to grain sorghum with 800 to 3000 seeds per panicle (Stoskopf, 1985). Although landrace

L3 had the highest grain number per panicle amongst the late maturing landraces, its 100-seed weight was the lowest of the four. The number of seeds per panicle and the weight of seed are important in determining grain yield. Although seed yield is not a priority in sweet sorghum, during drought years sweet sorghum could alternatively be utilized for grain production (Farraris, 1981b). However, under normal conditions it is not recommended to encourage grain production in sweet sorghum grown for stem sales because tall plants with heavy panicles lodge easily due to the leverage forces on the stem brought about by the weight of grain at the apex (Ferraris, 1981b). Seed sizes varied greatly within and between landraces as seen in Table 5.4. This indicates that farmers have not been selecting for seed size whilst selecting for stem characteristics.

Juice quality

There were significant differences among landraces in all characters of juice quality except, in purity (Table 5.5). The fibre content in stems of the late maturing types typically ranged from 10 to 12%, and for the early maturing types between 7 and 9%, but only L10 (12.4%) and L4 (7.6%) differed significantly. These results suggests that early maturing landraces had lower stalk fibre percentages as compared to late maturing types. According to the classification of Bryan, Moroe & Bascho (1985) the fibre content of all ten landraces can be classified as low in fibre content. According to this classification, fibre contents between 15 and 18% is considered high in fibre. They also reported that a high fibre content results in more juice being retained in the stalk bagasse.

A wide variation in brix percentage (soluble solids in the juice) was observed as shown in Table 5.5. Late maturing landraces especially (L10, L9, L3) had higher brix percentages compared to the early maturing landraces (L1, L2, L4, L8). Though not

statistically significant there was a clear trend for the purity percentage to be higher than 37% for some late maturity landraces, and lower than 30% for most of the early landraces (L1, L2, L4, L5). In sweet sorghum where stems are chewed, a high soluble solid content of the juice will be preferable therefore, brix is an important characteristic in identifying landraces with quality juice.

Table 5.5 Fibre, brix, purity, and pol percentages of the ten sweet sorghum landraces (Analysed by SASA)

Landraces	Fibre %	Brix %	Purity %	Pol %
L1	8.9	8.7	27.1	2.36
L2	8.6	8.2	23.0	2.63
L3	10.7	11.4	32.2	2.65
L4	7.6	9.3	16.6	1.55
L5	8.6	8.3	22.4	1.86
L6	11.3	10.4	33.7	3.56
L7	11.4	10.0	38.8	4.00
L8	10.4	8.2	28.2	2.46
L9	10.1	12.0	37.8	4.57
L10	12.4	15.1	38.8	5.82
LSDt (p=0.05)	3.14	2.40	N/S	2.96
C.V. (%)	10.71	8.04	26.48	32.1

Fibre = non-solubles after washing with water for one hour (bagasse); Brix = soluble solid content; Purity = percentage ratio of pol to brix; Pol = sucrose as measured by a polarimeter; Sucrose= estimated pure disaccharide

Pol values give an indication of the sucrose content and some of the late maturing landraces were significantly higher than those of the early maturing types (Table 5.5). Landraces L10 and L9 had the highest pol percentages of 5.82% and 4.57% with L5 being the lowest (1.86%). The lowest in both pol and sucrose were L4 and L5 with pol being1.55% and 1.86%, in sucrose, 6.13g and 5.74g, respectively. It is therefore evident

from these results that late maturing landraces had better juice quality compared to the early maturing landraces. However, these landraces were lower in sucrose content compared to the varieties grown in the Natal Midlands by Inman-Bamber, (1980). This is in line with the observation of Ferraris, (1981a) who reported that high yields of sugar (sucrose) and solubles (brix%) are associated with a long growing period and tall thick stems. The results suggest that there are sweet and juicy landraces like L10 and L9 in Botswana which can be included in breeding programmes for juice quality.

Inflorescence characteristics

Inflorescence characteristics are summarized in Table 5.6 and illustrated in Figs 5.2(a-b). There was a wide variation in head exsertion among the landraces, with inflorescences that were well exserted, exserted and those which were slightly exserted. Head exsertion is related to the length of the peduncle, with short peduncles bearing slightly exserted inflorescences.

Sweet sorghum landraces demonstrated great variation in the shape and compactness of inflorescence as shown in Table 5.5 and Fig 5.2(a - b). Landraces L1, L3, L6 and L10 had compact elliptic inflorescences, whilst landraces L4 and L5 had typical broomcorn morphology. The inflorescence of L9 was loose erect and the rest were semi-loose erect.

Table 5.6 Inflorescence and grain characteristics of the ten sweet sorghum landraces

Landraces	Head exsertion	Compactness of panicle	Awn	Grain form	Grain plumpness	Glume colour	Grain colour	Grain cover (%)	Shattering
L1	well exserted	compact elliptic	0	S	P	grey	yellow	75	very low
L2	well exserted	semi-loose dropping	+	S	P	purple	orange	50	high
L3	exserted	compact elliptic	0	S	P	grey	yellow	75	inter-mediate
L4	well	broom-corn	0	S	P	black	red	50	high

Landraces	Head exsertion	Compactness of panicle	Awn	Grain form	Grain plumpness	Glume colour	Grain colour	Grain cover (%)	Shattering
	exserted								
L5	slightly exserted	half broomcorn	+	S	P	grey	red	25	high
L6	exserted	compact elliptic	0	S	P	red	red	75	very low
L7	exserted	semi-loose erect	0	S	P	white	yellow	50	inter-mediate
L8	slightly exserted	semi-loose erect	0	S	P	red	red	50	low
L9	slightly exserted	loose erect	0	S	P	red	yellow	25	high
L10	slightly exserted	compact elliptic	0	S	P	black	white	50	high

*Characterisation according to Sorghum Descriptors (IBGR & ICRISAT, 1993)

Differences in the shape of inflorescences are so clear that they can be used for selection purposes. All landraces were awnless except for landraces 2 and 5 and grains of all the landraces were smooth and plump.

The landraces had varying glume and grain colour (Table 5.6 & Fig 5.2(a - b). The prevailing glume colours were grey, red, black and white and these were not correlated to the colour of the seed in any way. Seed colours were yellow, orange, red and white. There was no variation of seed colour within a landrace. This suggests that during breeding programmes seed colour could be used as a marker for selection.

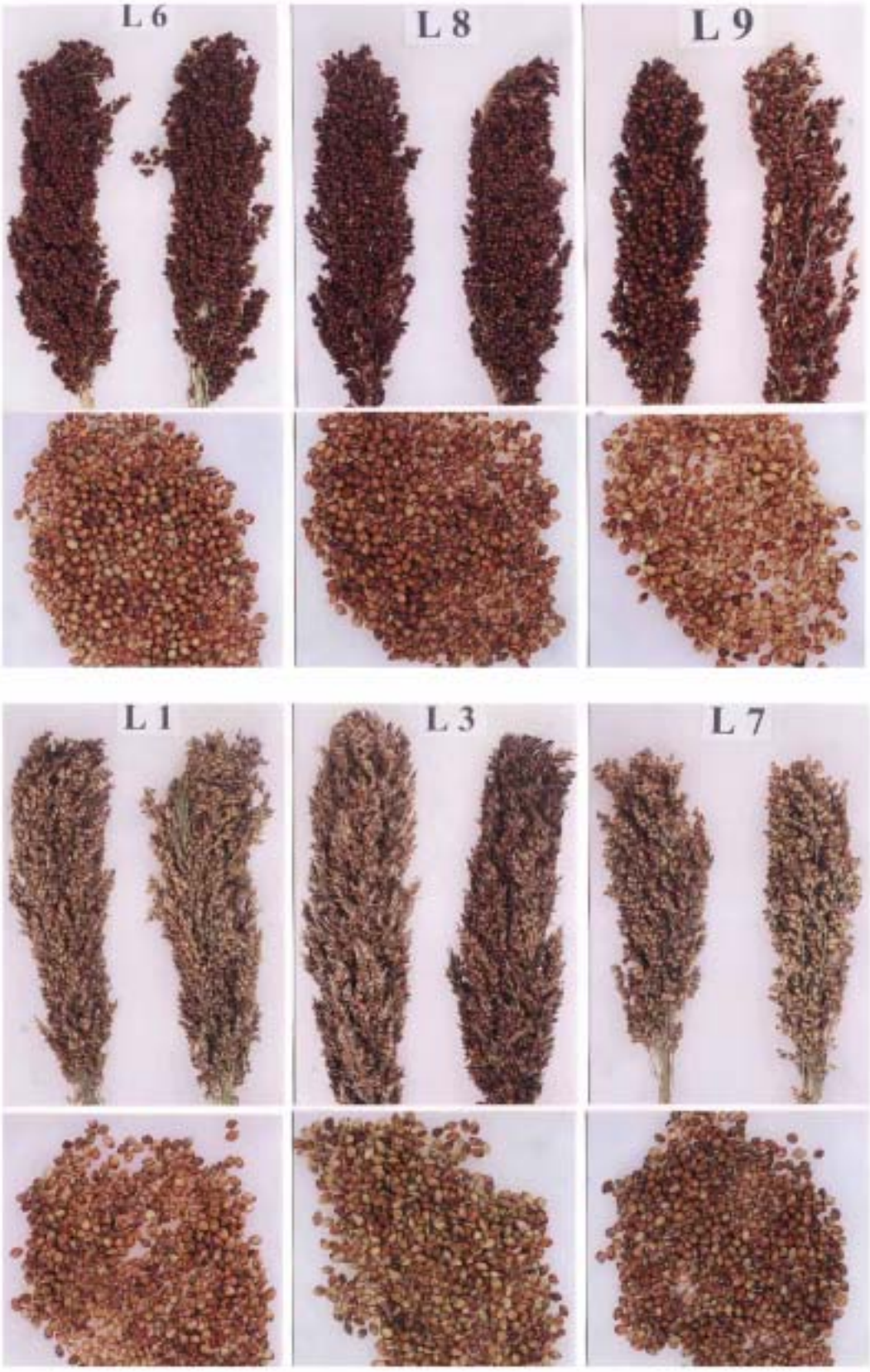

Fig 5.2 (a)

Fig 5.2 (a:b) Photographs illustrating differences in unflorescence development and seed charactaristics of the ten sweet sorghum landraces

Fig 5.2 (b)

There was a wide variation in grain cover and the range was between 5 and 75 percent (Table 5.6). Landraces with 25% and 50% grain cover were more prone to grain shattering compared to those with grain cover of 75%.

This study showed that Botswana landraces have a range of genetic diversity which can be used for crop improvement as well as adaptation in different regions. With data obtained from this chapter it has been possible to characterize individual landraces for phenology, date of maturity, morphology, yield per plant, juice characteristics and inflorescence characteristics. The most promising early (L2 and L4) and late (L9 and L10) landraces are characterised in Table 5.7.

In future the remaining 55 landraces ought to be characterized and there is need for inclusion of landraces from neighbouring countries for comparison purposes. However, the observations in the characterization exercise of the 10 landraces forms the bases for characterization of the genepool of sweet sorghum.

Table 5.7 Characters of the promising early and late maturing sweet sorghum landraces

Characteristics	Best early maturing landraces		Best late maturing landraces	
	Landrace 2	Landrace 4	Landrace 9	landrace 10
Days to 50% hard dough	109	109	131	139
Stem height (cm)	288	342	344	330
Stem thickness (cm)	2.1	2.4	2.7	2.7
Number of internodes	10	11	13	14
Number of tillers per plant	4.7	4.0	3.7	4.7
Stem fresh mass (g) per plant	2487	3049	2655	2927
Stem dry mass (g) per plant	502	593	722	786
Stem moisture content (%)	78.6	80.9	72.1	73.1
Stem fresh mass per stalk (g)	307.0	394.7	441.7	443.0
Fibre %	8.6	7.6	10.1	12.4
Brix %	8.2	9.3	12.0	15.1
Purity %	32.0	16.6	37.8	38.8
Pol %	2.63	1.55	4.57	5.82
Length of peduncle (cm)	59.3	59.3	50.0	41.3
Length of panicle (cm)	27.8	36.2	27.7	32.7
Width of panicle (cm)	8.0	8.5	6.8	10.0
head exsertion	well exserted	well exserted	slightly exserted	slightly exserted
compactness	semi-loose dropping	broom-corn	loose-erect	compact elliptic
awn	+	0	0	0
glume colour	purple	black	red	black
grain cover	50%	50%	25%	50%
grain colour	orange	red	yellow	white
number of seed per panicle	2875	1585	3769	3199
100-seed weight	2.44	2.48	2.51	2.60
shattering %	high	high	high	high
lodging %	50%	100%	50%	5%

CHAPTER 6

MANIPULATION OF TILLERS AND INFLORESCENCE TO INCREASE SUCROSE CONCENTRATION IN SWEET SORGHUM STEMS

6.1 ABSTRACT

Two field experiments were conducted at the experimental farm of the University of Pretoria during the 1996/97 growing season, to investigate the effect of deheading and removal of tillers on stem mass and juice quality of sweet sorghum. Five treatments were applied: a control, panicle removal at boot stage, at 100% flowering stage, at milk stage and removal of 50% florets at 100% flowering. In the investigation on removal of tillers, four treatments were applied: a control with no tillers removed, all tillers removed, one tiller retained per plant and two tillers retained per plant. Reduction in the number of developing seeds in the inflorescence improved juice quality. Deheaded plants were significantly higher in brix, purity, pol and sucrose than the control plants. Deheading at boot stage or at flowering increased the brix value and sucrose content in the stems more than in plants deheaded at milk stage or in plants with 50% florets removed at 100% flowering. However, the scars and branching resulting from panicle removal may render the stems unacceptable to consumers. Hence manipulation of florets might be a better option for improving juice quality. Removal of tillers did not cause any significant difference in the juice quality and in the stem mass of the four treatments. However, there was a tendency of the main stem without tillers to have higher stem mass, brix, purity, pol and sucrose content than the control. These results suggest that little competition between main stems and tillers for assimilates and need further investigations.

6.2 INTRODUCTION

The economic value of sweet sorghum is in the stem and not in the grain as in grain sorghum. In the characterisation exercise in Chapter 5 it was observed that seed production of some of the late maturing landraces of sweet sorghum compared well to grain sorghum, with up to 3893 seeds per panicle. If photosynthates used in grain formation and development could be diverted into the stems, stem yield and juice quality may be improved. In sugarcane it has been reported that inhibition of flowering with some chemicals resulted in considerable increases in cane and sugar yields (Humbert, Zamora & Frazer, 1967). However, in the Republic of South Africa, Donaldson & Van Staden (1989) did not observe any notable benefits after applying ethephon to two sugarcane varieties (N17 & N23) to prevent flowering.

Sweet sorghum stores starch as the principle nonstructural carbohydrate in grain, but primarily stores sucrose in stems. Differences in stem nonstructural carbohydrates between sweet sorghum and grain sorghum before physiological maturity, have been associated with larger grain yields in grain sorghum cultivars (Miller & Creelman, 1980) It is speculated that the smaller grain yield in sweet sorghum may be due to competition between elongating stems and preanthesis head development (Goldsworthy, 1970; Eastin, 1972; Willey & Basiime 1973). During sweet sorghum development and grain filling, photosynthates are available for dry matter production and after anthesis photosynthates are available for grain requirements and the excess accumulates as sugars or starch in the stem (Ferraris 1981b, Ferraris & Charles-Edwards 1986b).

In sweet sorghum the sugar, mainly sucrose, is accumulated in large amounts in the stem during the development of the inflorescence, when the panicle has formed and is emerging from the boot (Ventre, 1948; Wall, Sieglinger & Davies, 1948; McBee & Miller, 1982). During this period there is no competition between grain development and sugar accumulation (Lingle, 1987). Sucrose in the stem may increase or remain constant between the soft dough and the ripe stage of the grain, depending on variety or ripening conditions (Broadhead, 1972). Under most field conditions sucrose content in sweet sorghum stems is at its maximum during the dough stage (Coleman, 1970). However, distribution of sugars, starch and acid is not uniform throughout the sweet sorghum stalks (Ventre *et al*,1939). The four top internodes representing about 18 % of the stalk weight, are higher in starch, titratable acidity and sucrose than the remainder of the stalk. Internodes near the ground level are high in invertable sugars (Coleman & Stokes, 1964).

Broadhead (1973) and Ferraris (1981b) observed that deheading sweet sorghum increased brix, sucrose and starch, but stems contained less juice than normal plants. In addition, Ferraris (1981b) also observed that leaves of deheaded plants remained green for longer and the stems were less prone to lodging. Coleman (1970) observed that the growth of stalks were not greatly influenced by limited seed production but the stalks produced a number of side branches. According to Stokes, (1958) limited seed production in sweet sorghum results in reduced lodging and hastened maturity.

Tillering in sweet sorghum could be profitable if all the tillers produced by crown buds developed to maturity. This would mean an increase in the number of stems and

prolonged harvesting period since the main shoot matures earlier than tillers. Tillering is also useful in that the roots that develop from the basal nodes lend physical support to the plant and reduce root lodging. However, not all tillers develop up to marketable size. At high population densities some tillers grow tall and thin and others die due to competition, constituting a loss in economic yield (Ferraris, 1988).

This chapter describes experiments on the effects of deheading, removal of florets and reduction of tillers on the juice quality of sweet sorghum stems.

6.3 MATERIALS AND METHODS

Experiments were conducted on the Experimental Farm of the University of Pretoria during the 1996/97 growing season. Sweet sorghum plants were grown on a sandy clay loam soil of the Hutton form. The soil was cultivated and disced to a fine tilth. Plot size was 4.0 m by 3.5 m, with four rows at 0.90 m spacing. Planting was done with a hand planter at a depth of 3 cm. Seeds were sown 0.3 m apart, with an inter-row spacing of 1.0 m. To eliminate the border effect only the two inside rows were harvested. After four weeks the plants were thinned to one plant per planting position, and then top dressed with LAN at the rate of 120 kg N ha^{-1}. Weeds were controlled using pre-emergence application of atrazine at the rate of 3 kg active ingredient per hectare.

Experiment 1

The purpose of this experiment was to quantify the effect of deheading on yield and quality of sweet sorghum stems. Deheading and removal of florets were done between the boot stage and milk stage. The design was completely randomized with five treatments replicated four times.

Treatments consisted of the following:

(1) C= control

(2) Pb=panicle removed at boot stage

(3) Pf=panicle removed at 100% flowering

(4) Pm=panicle removed at milk stage

(5) Fr = removal of 50% of florets at 100% flowering

At boot stage the panicles were pulled off while at the full flowering (100% flowering) and milk stages, the panicles were severed with a knife. Florets were removed with a pair of scissors. At maturity a sample of 20 stalks randomly selected from each plot was harvested. The leaf sheaths and panicles were removed and the stalks were packed in polyethylene bags, sealed and sent to South African Sugar Association for standard juice analyses. Stalk samples awaiting transportation to the laboratories were kept in a cold room at 5°C. In most cases samples were transported over night when it was cool and analysed on arrival at the laboratories.

Experiment 2

This experiment was also planted in a completely randomised design with four treatments replicated three times. Sweet sorghum plants were left to grow up to the boot stage when the following four treatments were applied.

(1) C= control

(2) T0= all tillers removed and only the main stem left

(3) T1= one tiller retained per plant

(4) T2= two tillers retained per plant

All late developing tillers were removed until harvesting. At maturity a sample of 20

stalks was randomly selected, prepared and sent to the laboratories of SASA for juice analyses. Data of both experiments were analysed by the conventional analyses of variance and the significant differences between means were determine by Tukey's multiple range test (Steel & Torrie, 1985).

6.4 RESULTS AND DISCUSSION

Experiment 1

The effect of deheading and removal of florets on the juice quality of sweet sorghum is summarized in Table 6.1.

TABLE 6.1 Effect of deheading and floret removal on sweet sorghum stalks and juice quality (SASA)

Treatment	Stalk components			juice components			estimated
	Stalk fresh mass (g)	Stem dry matter (g)	Stalk fibre %	Brix %	Juice purity %	Pol %	Sucrose / stalk (g)
C	331	23 b	11.1	11.6 b	56.0 b	6.5 b	21.8 b
Pb	360	26 a	11.5	14.6 a	64.6 a	9.5 a	33.9 a
Pf	352	26 a	11.5	14.6 a	68.3 a	10.0 a	35.1 a
Pm	289	25 a	12.2	14.3 a	68.6 a	9.8 a	28.3 a
Pr	299	26 a	11.8	14.2 a	67.8 a	9.7 a	28.8 a
LSDt (p=0.05)	N/S	3.09	N/S	2.09	8.51	2	10.97
C.V. (%)	12.17	5.38	6.39	6.7	5.8	12	16.47

+Means followed by different letters are significantly different at the 5% level by Tukey's Multiple Range Test.
C=control; Pb=panicle removal at boot stage; Pf=panicle removal at 100% flowering; Pm=panicle removal at milk stage; Pr=removal of 50% of florets at 100% flowering.
Fibre= non-solubles after washing with water for one hour (bagasse); brix = soluble solids; purity = a percentage ratio of pol to brix; pol = sucrose as measured by a polarimeter; sucrose = estimated pure disaccharide

There were no significant differences in stalks fresh mass among the treatments (Table 6.1). However, the stem dry mass of the control was significantly lower than stem dry

masses of the other treatments. According to the results, removal of the seed sink allowed for an additional 3g of dry matter to be stored in the stems. Although there were no significant differences between the treatments in stalk fibre content, stalk fibre in plants deheaded at milk stage was higher (12.2%) than in the other treatments.

The quality of juice improved with deheading. Deheaded plants produced much higher brix values and pol percentages (Table 6.1). Similarly the juice purity and estimated sucrose content followed the same pattern as brix and pol values. These results are consistent with those of Broadhead (1973) and Ferraris (1981b) who reported higher brix values, sucrose and starch content from deheaded plants than in the control plants. Broadhead (1973) attributed the increase in brix value and sucrose content in deheaded plants to decreased juiciness in deheaded plants.

Although the juice quality did not differ significantly between deheading treatments, plants deheaded at boot stage and at 100% flowering stage produced somewhat higher brix values compared to plants deheaded at milk stage and those which had 50% florets removed. The pol percentage was slightly higher in plants deheaded at 100% flowering stage. These results are consistent to those of Broadhead (1973) who reported an increase of sucrose content in plants deheaded at boot stage compared to plants deheaded at later stages. Generally, results show that reduction in the number of developing seed in the inflorescence improves juice quality.

From these results it was observed that juice quality was generally better in plants deheaded at early stages compared to plants deheaded at the late developmental stages. Better juice quality in plants deheaded at early stages may be due to the fact that accumulation of sugar in sweet sorghum stems begins during the development of

inflorescence as indicated by McBee & Miller 1982. Therefore, plants deheaded at later seed developmental stages are expected to have less sugars in the stem because some assimilates would have been used in supporting the developing seeds.

Plants that were deheaded developed side branches as illustrated in Fig 6.1 (a-b) and those with 50% florets removed did not produce side branches Fig 6.2 (a-b). It was also observed that deheaded plants lodged less than normal plants Fig 6.3b and fully developed panicles caused extreme lodging Fig. 6.3c. Coleman (1970) and Broadhead (1973) also reported side branching and less lodging in deheaded plants. Deheaded plants also remained greener for a longer time than the control plants as observed by Ferraris (1981b). Henzell & Gillieron (1973) attributed the delay in senescence to removal of hormonal control. Thus removal of florets was included to improve the stalk quality by preventing development of branches in the stem, and minimize stem damage caused by deheading.

Deheading may improve juice quality but the scars and side branches reduce the value of the stalk. A 50% removal of the florets might be a better option as it improved juice quality (Table 6.1) without affecting stem quality. Inducing barrenness by chemicals may be an answer rather than mechanical practice which is time consuming and tedious.

(a) (b)

Fig 6.1 (a – b) Profuse branching due to deheading.

(a) (b)

Fig 6.2 (a – b) No branching in stems of plants with 50% florets removed.

Fig 6.3 (a)

Fig 6.3 (b)

Fig 6.3 (c)

Fig 6.3 (a – c) Differential lodging due to tiller removal and panicle pruning NOTE extreme lodging of main stems with tillers (a), less lodging (b) due to pruning of florets (inner row) and absence of lodging in deheaded plants (outer row). Extreme lodging due to fully developed panicle (c).

Removal of tillers did not cause any significant difference in the juice quality of the main stems (Table 6.2). However, the stem fresh mass and juice quality tended to be somewhat higher in the main stems where all tillers were removed. These results indicate that there might be some competition for assimilates between tillers and main stem, but additional investigations will be required.

TABLE 6.2 The effect of tiller removal on juice quality of the main stem of sweet sorghum (SASA)

Treatment	Stalk components			Juice components			estimated
	Stalk fresh matter (g)	Stem dry matter (g)	stalk Fibre %	Brix %	Juice Purity %	Pol %	Sucrose / stalk (g)
C	381	23	11.1	12.1	52.6	6.4	24.3
T0	434	24	10.3	13.7	55.4	7.6	33.0
T1	419	23	10.1	13.2	51.1	6.8	27.9
T2	367	24	10.9	13.3	54.7	7.3	26.6
C.V.	12.65	3.24	5.39	7.14	7.67	12.67	16.38
	N/S	N/S	N/S	N/S	N/S	N/S	N/S

C=control; T0= all tillers removed and only the main stem left; T1=one tiller retained per plant; T2=two tillers retained per plant.
Fibre= non-solubles after washing with water for one hour (bagasse); brix = soluble solids; purity=a percentage ratio of pol to brix; pol=sucrose as measured by a polarimeter; sucrose = estimated pure disaccharide

Main stems with less or no tillers became prone to lodging Fig 6.3a. Removal of tillers results in decreased number of stalks per hectare, resulting in the reduction of the economic yield. Thus from the producers point of view the disadvantages of manipulating a sweet sorghum crop by removal of panicles or tillers outweigh the possible advantages. However, this does not exclude the possibility that breeding and selection for small panicles and reduced tillering may benefit stem size and quality. It may also justify research by plant breeders to determine whether male sterile varieties may be sweeter and juicier than male fertile varieties.

CHAPTER 7

EFFECT OF PLANTING DATE AND SPACING ON STEM YIELD AND SUCROSE CONCENTRATION OF SWEET SORGHUM

7.1 ABSTRACT

The effects of planting date and spacing were studied at the Experimental Farm of the University of Pretoria during the 1996/97 growing season. Sweet sorghum seed were sown on 18 October, 18 November and 17 December at 60 cm, 40 cm and 20 cm intra-row spacings. Main stem height and thickness, stem fresh and dry mass, brix value, pol percentage and juice purity were determined. The October planting resulted in higher stem yields, more tillers and taller main stems than the November and December plantings. Brix value was not affected by planting date. The December planting had the highest pol percentage and juice purity. The 60 cm intra row spacing produced the highest stem yield per plant but stem yield per unit area was higher at 20 cm intra row spacing. Spacing did not affect main stem height, but the 20 cm intra row spacing produced thinner main stems. Similarly, spacing did not have any effect on pol percentage, juice purity, brix value and stalk fibre content. These results indicate that early planting increases stem yields but reduces juice quality. Spacing did not affect juice quality. Wider intra row spacing increased stem yield per plant but reduced stem yield per unit land area.

7.2 INTRODUCTION

In Botswana early planting is recommended because most farmers use late maturing varieties. However, planting as early as October or November is not always possible due to late rains or lack of ploughing facilities. This results in short growing seasons with sweet sorghum being harvested beginning of March up to the mid of May.

For a rainfed crop to be successful it is necessary that its growth cycle should be of such a duration that it is comfortably contained within the available growing period. Failure to match the existing conditions may result in the reduction of yield and quality. Son (1971), through manipulation of planting date, was able to attain the highest sugar yields by planting late cultivars of sugarcane early and early cultivars later. Thus in sweet sorghum it is important to understand the best planting dates to enable farmers to manipulate planting dates to have longer periods of sweet sorghum sales and utilize higher prices early and late in the season.

Physiological mechanisms in plants are capable of sensing differences in day length. Under most field conditions late planting is associated with a reduction in number of days to panicle initiation and flowering, which may be the effect of temperature and photoperiod (Pauli, Stickler & Lawless, 1964; Heskerth, Chase & Nanda 1969; Caddel & Weibel, 1971). Stickler, Pauli, Laude, Wilkins & Mingis (1961) showed that early planting in grain sorghum increased grain yields through increased tillering and number of heads per unit area in Kansas.

Many studies in sweet sorghum have shown that yields declined as planting date was delayed but results on brix value, sucrose content and purity levels are inconclusive.

According to Hipp, Cowley, Gerard & Smith (1969) and Broadhead (1972b), in Mississippi, yields of sweet sorghum stalks increased with early planting, but brix value, sucrose content and juice purity were not affected by planting date. Similarly Cowley & Smith (1972), in Texas, reported a decline in yields of stalk with late planting but did not find any correlation between planting dates, sucrose content, purity levels and brix value. In India Maheshwari *et al*, (1974) also reported a decline in yield of sweet sorghum stalks but juice quality like sucrose content, juice purity and brix value were improved with delay in planting date. In South Africa Inman-Bamber (1980) reported a rapid decline in the stalk and sucrose yield of sweet sorghum with delayed planting dates. A delay of 10 weeks resulted in a two and a half week's reduction in the time to maturity and this caused a drop in sucrose yields of about 40% (Inman-Bamber, 1980).

Similarly, Ferraris & Charles-Edward (1986b) in Australia, Petrini, Belletti & Salamini (1993) and Almodares, Sepali & Karve (1994) in Iran, reported higher yields of stalks, brix value, sucrose content and purity with early planting compared to late planting.

Information on the effect of plant density on yield and quality of sweet sorghum is limited. In grain crops plant density affects grain yield, total dry matter production, stem height, diameter and tiller production (Downey, 1971). Increase in yield with increase in plant density up to a point where yields per unit area approaches an upper limit due to competition, have been reported (Adams, Arkin & Burnett, 1976). As plant density increases the number of tillers and their contribution to grain yield tend to decline (Myers & Faole, 1980). In forage sorghum, Eilrich, Long, Stickler & Pauli (1964) reported that plant population or row width did not show any significant effect on

soluble carbohydrate, but that soluble carbohydrate was higher in row system than in a drill system.

Broadhead *et al*,(1963) in Mississippi, indicated that populations ranging from 46,000 to 65000 ha-' were optimum for stem yield and juice quality of sweet sorghum. Broadhead *et al*, (1963) also reported a decrease in sweet sorghum yields of stalk and syrup per hectare once plants were spaced wider than 15 to 20 cm apart. In addition it was reported that closer spacings than 15 to 20 cm resulted in thin stems which lodged readily and matured unevenly. Flemming & Wood (1967) found similar results in maize and reported increased height as plant density increased.

In sweet sorghum Martin & Kelleher (1984) in Australia, reported increased dry matter and water-soluble carbohydrate yields with denser spacing. They also reported less internodes and thicker stems in wider spacings than closer spacings, whilst in closer spacings thinner stems with slightly more tillers were reported. McBee & Miller (1982) reported a significant increase in starch at anthesis in plants grown at 10 cm spacing compared to wider spacings, while Cowley (1969) reported that sucrose content and purity levels were not affected by spacing. Hence there is a need to determine optimum plant densities in sweet sorghum.

The objective of this study was to evaluate the effect of planting date and spacing on the stem yield and juice quality in sweet sorghum.

7.3 MATERIALS AND METHODS

Experiments were conducted on the Experimental Farm of the University of Pretoria,

during the 1996/97 growing season. Sweet sorghum landrace (G1) was planted on a sandy clay loam soil of the Hutton form. The soil was cultivated and disced to fine tilth. The experimental design was a split-plot design with three replications. Planting date treatments were randomly allocated to the main plots and spacing treatments to subplots. The main plot size was 34.2 m long by 8 m wide and the subplots were 3.8 m by 8m each. In each subplot there were four rows and to eliminate border effects the two middle rows were harvested. At each planting date the seedbed was ploughed and disced to a fine tilth and the seed was planted with a hand planter at a distance of 0.9 m between rows. Thirty days after emergence plants were thinned to the required intrarow spacings. No base fertilizer was applied at planting, but at forty days after emergence plants were top dressed with LAN at the rate of 120 kg N ha^{-1}. Plots were irrigated whenever there were dry spells to maintain growth. Weeds were controlled by a pre-emergence application of atrazine at a rate of 3kg active ingredient per hectare and hand weeding was done as necessary. There were no serious diseases, but aphids were a problem and they were sprayed with an aphicide.

There were three planting date treatments:

(i) October 18

(ii) November 18

(iii) December 17

The intrarow spacing treatments were:

(i) 20 cm

(ii) 40 cm

(iii) 60 cm

During the growth period two sample harvests were taken from each subplot, one at panicle initiation and the second at boot stage. Three representative plants were sampled from each subplot to estimate plant height, stem diameter, number of leaves per plant, leaf area per plant and number of tillers. Dry mass of leaves and stems were determined after oven drying at 70°C to a constant mass. Duration to panicle initiation and boot stage were recorded as the number of days from emergence until 50% of the plants were at the specific stage of development.

During the final harvest at the hard dough stage a sample of 20 stalks per subplot was harvested. Stalks were stripped, wrapped in large polythene bags, weighed and sent to the South African Sugar Association (SASA) for standard juice analysis. Samples waiting to be transported to SASA were stored in a cold room at a temperature of 5°C.

Data were analysed by the conventional analyses of variance and the significant differences between the means were determined by Tukey's Multiple Range Test (Steel & Torrie, 1985).

7.4 RESULTS AND DISCUSSION

Data collected at the panicle initiation stage and the boot stage is summarized in the Appendix Table A7.1 and A7.2**.** The growing periods to panicle initiation, boot stage and hard dough stage are shown in Table 7.1. The planting date x spacing interaction was not significant therefore, main effects are discussed. The main effects of planting date and spacing on the stem fresh and dry mass, moisture content, number of tillers, main stem height and thickness and juice quality are presented in Tables 7.2 and 7.3.

Planting date

Days to panicle initiation and boot stage decreased with later planting dates (Table 7.1). This may be the result of lower temperature and shorter day length experienced by plants in the later plantings (Caddel & Weibel, 1971). Days from boot stage to hard dough stage increased with late planting probably due to the lower temperatures during seed filling of later planted crops. This was also observed in Chapter 4 where seeds reached maximum maturity faster under warmer conditions.

Table 7.1 Effect of planting date on sweet sorghum phenology

Planting date	Days from emergence to Panicle initiation stage	Days from panicle initiation to boot stage	Days from boot stage to hard dough stage	Days from emergence to hard dough stage
18-10-96	56	31	21	108
18-11-96	50	26	30	106
17-12-96	48	23	41	112

The highest stem yields were observed in the October planting (Table 7.2). There was no significant difference in stem yield between the November and December plantings. The high stem yields in the October planting is associated with an increase in the growing period from emergence to panicle initiation and boot stage; and increases in tiller numbers and stem height.

These results are consistent with the findings of Inman-Bamber (1980), Ferraris (1988) and Almodares, Sepali & Karve (1994) who reported increased stem dry mass with early planting as compared to late plantings. They attributed the decrease in dry mass with delayed planting to a reduction of the growth period in sweet sorghum (Inman-Bamber, 1980).

TABLE 7.2 The main effect of planting date and spacing on the stem fresh and dry mass, stem moisture content, number of tillers, plant height and main stem girth at hard dough stage (harvesting time)

Treatment	Stem fresh mass per plant (g)	Stem dry mass per plant (g)	Stem moisture content %	Number of tillers per plant	Main stem height (cm)	Main stem girth (cm)
Planting Date						
Oct.	1779a	508a	73.4b	4.1a	278.0a	8.1a
Nov.	952b	203b	76.4a	2.0b	213.0b	8.1a
Dec.	1019b	297b	70.6c	1.8b	227.0b	7.4a
LSDt (p=0.05)	619	108	2.3	1.5	22	NS
C.V. (%)	41	27	2.5	45.3	7.4	11.0
Spacing						
20 cm	867b	247b	73.2a	1.9a	249.0a	7.1b
40 cm	1236a	363a	74.0a	3.3a	240.0a	8.1ab
60 cm	1646a	398a	73.1a	2.7a	229.0a	8.3a
LSDt (p= 0. 05)	619	108	NS	NS	NS	1.16
C.V. (%)	41	27	2.5	45.3	7.4	11.0

+ Means followed by different letters are significantly different at the 5% level by Tukey's Multiple Range Test.

Hipp, *et al*,(1969) related differences in stem yield from different planting dates to differences in solar radiation received by the plants. In southern Africa solar radiation is high throughout the summer months indicating that it may not be a limiting factor in sweet sorghum growth and yields. In the trial on the Experimental Farm of the University of Pretoria the October planting reached seed formation stages in January during the time when solar radiation was at 29M Jm^2/day, the November planting in February when solar radiation was 27 M Jm^2/day and the December plantings in March when solar radiation was 26 M Jm^2/day (Schulze, 1997). This indicates that there was little variation in solar radiation between the three months and it is highly unlikely that

the differences in stem yield were due to solar radiation.

Stems from the November planting were significantly higher in moisture content than those from the October and December plantings (Table 7.2). The lowest moisture content was recorded in the December planting. This difference in stem moisture content might explain the poor juice quality observed in the October and November plantings (Table 7.3). High moisture content in the stem may tend to dilute concentration of sucrose content, lowering pol percentage, brix value and juice purity.

The October planting produced 4.1 tillers per plant and the two later planting dates 2.0 and 1.8 tillers per plant. These results are in agreement with those of Stickler *et al*, (1961) who reported more tillers with early planting. The high number of tillers in the October planting contributed to the high stem yields. Highest main stem height was recorded in the early planting, (Table 7.2). However, planting date did not affect the main stem thickness.

These results indicate that early planting improves main stem size through increasing main stem heights. Sucrose percentage (pol %) increased with delay in planting (Table 7.3). The highest sucrose content of 8.0% was recorded with the December planting date and the lowest of 4.0% with the October planting date. Similarly the juice purity of the three planting date treatments followed the same pattern as the sucrose percentage (Table 7.3). These results are consistent with the results of Maheswari *et al*, (1974) who reported increased sucrose content and juice purity with late planting. On the contrary Almodares *et al*, *(*1994) reported higher pol, brix and purity in early plantings. There were no significant differences between the planting date treatments regarding the brix

value (Table 7.3). This is in agreement with the observation of Broadhead (1972) who reported that brix was not affected by planting date. The December planting resulted in a somewhat higher stem fibre content than the October and November planting dates.

TABLE 7.3 The main effect of planting date and spacing on the juice quality of sweet sorghum

Treatment	Pol %	Purity %	Brix %	Stalk Fibre %
Planting Date				
Oct.	4.0c	32.6c	12.1a	10.2b
Nov.	6.8b	53.5b	12.6a	10.1b
Dec.	8.0a	61.3a	13.1a	11.4a
LSDt (p=0.05)	1.2	5.7	NS	1.0
C.V. (%)	15.1	9.5	8.2	7.7
Spacing				
20 cm	6.3a	49.7a	12.6a	10.9a
40 cm	5.9a	47.4a	12.4a	10.3a
60 cm	6.5a	50.2a	12.8a	10.5a
LSDt (p=0.05)	NS	NS	NS	NS
C.V.(%)	15.1	9.5	8.2	7.7

+ Means followed by different letters are significantly different at the 5% level by Tukey's Multiple Range Test. T1=October planting, T2=November planting, T3=December planting, S1=20 cm, S2=40 cm, S3 = 60 cm

Generally, these results indicate that early planting in sweet sorghum increased stalk yields through increased number of tillers and main stem heights, but reduced juice quality. Although the acceptability of sweet sorghum to the consumer is mainly determined by size and appearance of the stems, there is need to improve juice quality. This negative relationship between stem yield and juice quality requires more research in order to optimise yield and quality. Observations in this Chapter are based on the

reaction of only one landrace. It would therefore, be necessary to screen other promising landraces in order to ascertain whether there are genotypes that partition assimilates towards sucrose accumulation rather than vegetative or reproductive growth when planted early.

Spacing

Higher stem yields per plant were observed in the 60cm and 40 cm spacing treatments (Table 7.2). Increased stalk yields per plant with increased spacing results from less interplant competition for radiation, water and /or nutrients. Although the number of tillers per plant did not differ between the spacing treatments the tendency was that the 40 cm and 60cm spacings produced more tillers than the 20 cm spacing (Table 7.2). This could account for higher stem yields per plant in the widely spaced plants. On a unit area basis the 20 cm spacing produced 4.8 kg m^{-2} of fresh stems, compared to 2.8 kg m^{-2} in the case of the 60 cm treatment (Table 7.4). These results are consistent with the findings of Martin & Kelleher (1984) who reported increased dry mass yields at higher plant densities.

Table 7.4 Effect of row spacing on population and fresh stem yield per unit area

Intra row spacing (cm)	population per square metre	Stem yield per square metre (kg m^{-2})
20	5.5	4.8
40	2,7	3.3
60	1,7	2.8

Spacing did not influence stem moisture content and main stem height (Table 7.2). The spacing treatments did not differ in the number of tillers per plant and this is contrary to the results of Kelleher (1984) who reported slightly more tillers in wider spacings.

Similarly, there were no significant differences in main stem heights between the treatments, however, the main stems of the 20 cm spacing were thinner than those of the 40 cm and 60cm spacings. These results are consistent with the findings of Broadhead *et al,* (1963) who reported thinner stems with higher densities.

Spacing did not have any significant effect on juice quality (Table 7.3). However, there was a tendency for stems from the 60 cm spacing to be higher in sucrose content (pol %), juice purity and brix compared to the other spacing treatments (Table 7.3). These results support those of Cowley (1969) who reported that sucrose and purity values were not affected by spacing.

The results obtained from the experiment at the University of Pretoria indicated that juice quality was not affected by spacing per se. Although wider spacing resulted in somewhat shorter and thicker stems on a unit area base the higher plant population (20 cm spacing) produced the highest yields. Based on these results the 20 cm spacing can be recommended for sweet sorghum production in pure stands. Since these results can not be extrapolated to Botswana conditions where sweet sorghum is broadcasted with other crops, there is a need for more experiments on cultural practices including planting date and spacing under local conditions.

CHAPTER 8

EFFECT OF NITROGEN AND SPACING ON STEM YIELD AND JUICE QUALITY OF TWO SWEET SORGHUM LANDRACES

8.1 ABSTRACT

Main effects of nitrogen, landrace and spacing were studied at the Experimental Farm of the University of Pretoria during the 1998/99 growing season. The nitrogen rates adopted were 0 kg N ha-¹, 60 kg N ha-¹ (applied early in the growing season), 60 kg N ha-¹ (applied at boot stage) and 120 kg N ha-¹ (applied early in the growing season). Intra-row spacings were 15 cm and 30 cm for both the early maturing (D) and late maturing (A11) landraces. Stem yields of the three nitrogen treatments were significantly higher than the yields of the unfertilized control. Similarly, sucrose content of the three nitrogen treatments were much higher than that of the zero nitrogen treatment. The wider intra-row spacing (30 cm) resulted in a significant increase in stem yield and sucrose content, compared to the closer intra-row spacing (15 cm). The late maturing landrace produced higher stem yields and sucrose content than the early maturing landrace. The best treatment combination (nitrogen x landrace x spacing interactions) for high stem yields per hectare with the late maturing landrace was 15 cm intra-row spacing with 120 kg N ha_¹; for the early maturing landrace it was at 15 cm intra-row spacing with 60 kg N ha_¹. It is concluded that nitrogen increases stem yields and sucrose content in sweet sorghum. Wider intra-row spacing (30 cm) increased both stem yields and sucrose content.

8.2 INTRODUCTION

No applicable information is available regarding the fertilization and spacing requirements of sweet sorghum as a cash crop for small scale farmers. In Botswana sweet sorghum is typically grown in mixtures with other crops and it's rarely planted in rows. This results in areas of high and low populations in the same field and thinning is rarely done in the densely populated areas. Most farmers do not fertilize their crops due to environmental unpredictability, traditional preferences and financial constraints. Specifically, farmers in Botswana do not fertilize the sweet sorghum crops because they believe that kraal manure and fertilizers reduce the sweetness of the juice.

Generally sweet sorghum responds well to fertilizers, especially nitrogen. However, it is critical that the amount of nitrogen applied does not lower the quality of the juice, as reported with sugarcane (Ojha, Singh & Ahmad, 1973). Results obtained from studies conducted to evaluate the effect of nitrogen fertilizer on the stem, syrup and juice yield in sweet sorghum are inconclusive as to how much N will give the highest yields. According to Broadhead, Freeman, Coleman & Zummo (1974) stalk and syrup yields increased with up to 90 kg N ha_¹ fertilizer in Mississippi. Jordan-Karim (1979) also in Mississippi, reported significant dry matter and sugar yield responses with N fertilization up to 112 to 168 kg N ha_¹. Similarly, Jackson & Arthur (1980) reported yield responses with up to 112 kg N ha_¹ in soils of Ohio. Ferraris (1988) reported that total yield of stem sugars increased with nitrogen to moderately high levels. Bennett (1982) compared the effectiveness of a legume cover crop and N fertilizer on several sweet sorghum cultivars. The results indicated that above ground biomass and juice sugar yield in a syrup cultivar of sweet sorghum were significantly higher with 168 kg N ha_¹ fertilizer than with 84 kg N ha_¹ fertilizer. A two year Alabama study on the effect of lime and fertilizer showed a significant increase in biomass, sugar content and juice extracted from stalks due to

liming. In non limed soils, biomass and sugar yields decreased with high N where the P and K content of soils were low, but not with high P and K levels in the soil (Soileau & Bradford, 1985). Galani, Lomte & Choundhary (1991) reported an increase in juice yield and no response in juice brix in an experiment with increasing N rates (0, 40, 80 and 120 kg N ha_¹). Cowley & Smith (1972) did not find any correlation between nitrogen levels and sucrose content and purity. Detrimental effects on juice quality regarding timing of nitrogen application has been reported. For syrup production (and probably sugar production) late application of fertilizer, especially nitrogen, should be avoided as this interferes with juice quality (Freeman, Broadhead & Zummo, 1973). Recently, Utzurum, Fukai & Foale (1998) reported a longer growing period and increased biomass accumulation in grain sorghum as a result of late nitrogen application. This effect also might be applicable to sweet sorghum as a dryland crop of the semi-arid tropics.

The results obtained from the experiment at the University of Pretoria on plant density showed that high plant density (20 cm spacing) produced the best yields on a unit area basis (see Chapter 7). These results suggested that 20 cm intra row spacing may be recommended for sweet sorghum. In Botswana the spacing recommended for maize and grain sorghum is 30 cm between plants and 90 cm between rows. For quick adoption of spacing recommendations in sweet sorghum, recommending the same spacing as for the other crops would be advisable. Hence farmers could use the same planting equipment. The objective of this trial was to investigate the effect of nitrogen, and intra-row spacing (plant population) on the yield and juice quality of two sweet sorghum landraces.

8.3 MATERIALS AND METHODS

The experiment was conducted on the Experimental Farm of the University of Pretoria, during the 1998 / 1999 growing season. Sweet sorghum seeds were planted on sandy clay

loam soil of the Hutton form. The soil was cultivated and disced to fine tilth before planting. The experimental design was a split-plot with four nitrogen levels randomly allocated to the main plots, two landraces allocated to subplots and two spacing treatments to sub-sub-plots. There were four replications. The main plot size was 25.6 m long by 8 m wide and the subplot size was 6.4 m by 4 m and sub-subplots were 3.2 m by 4 m each. Seeds were planted in rows of 90 cm and no base fertilizer was applied. Plants were thinned thirty days after emergence to the required intra row spacing. Plots were irrigated to maintain growth whenever there were dry spells. Weeds were controlled by a pre-emergence application of atrazine at a rate of 3 kg active ingredient per hectare and hand weeding was done as necessary. There were no serious disease problems but aphids were a problem and were sprayed with an aphicide.

Nitrogen treatments:

N0 = control (0 N kg N ha_¹)

N1 = 60 kg N ha_¹ (early)

N2 = 120 kg N ha_¹ (early)

N3 = 60 kg N ha_¹ (late)

In treatments N1 and N2 nitrogen was applied 40 days after emergence and in treatment N3 it was applied at boot stage.

Spacing treatments :

S1 = 15 cm intra-row spacing

S2 = 30 cm intra-row spacing

Landraces :

L1 = early maturing landrace (D according to Chapter 3 codes)

L2 = late maturing landrace (A11 according to Chapter 3 codes)

Plants were serially harvested at two week intervals, from 40 to 96 days after emergence.

At each harvest three plants were cut at the base and combined into one sample. The plants were measured for height, number of leaves, leaf area and number of tillers. To determine dry mass the leaves and stems were oven dried at 70°C to a constant mass. During the final harvest at 96 days after emergence an additional sample of 20 stalks was harvested per plot and sent to the South African Sugar Association (SASA) for standard juice analysis. The juice was tested for soluble solids content (brix), sucrose content (pol), juice purity and fibre according to standard sugar cane technology methods. Samples awaiting transport were stored in a cool room at a temperature of 5°C to minimize conversion of sucrose to glucose.

Data was analysed by the conventional analyses of variance and the significant differences between the means were determined by Tukey's Multiple Range Test (Steel & Torrie, 1985).

8.4 RESULTS AND DISCUSSION

The main effects of nitrogen, spacing and landrace on the stem yield and juice quality of sweet sorghum are presented in Table 8.1 and the significant nitrogen x landrace x spacing interactions in Table 8.2. Significant first order interactions are summarised in Tables A8.2 - A8.6 in the appendix, but not discussed. In the presentation of the results the emphasis is on stem yield and juice quality. Data on the number of leaves, leaf area, leaf dry mass and main stem height are presented in Table A8.1 in the appendix and are not discussed in the text.

Stem yields

The N1 treatment (60 kg N ha^{-1} applied early resulted in higher stem yields than the unfertilized control (N0), with no differences between the other three nitrogen

treatments (Table 8.1). These results are consistent with the findings of Broadhead *et al*, 1963; Jordan-Karim (1979) and Jackson & Arthur (1980) who reported increased stem dry mass with increasing nitrogen. In this trial it was observed that plants that received nitrogen at boot stage remained greener and maintained their leaves for a longer period than plants that received nitrogen earlier. Urtzurrum *et al*, (1998) reported similar observations of later senenscense in grain sorghum plants fertilized at flag leaf stage than those which received nitrogen early. In the production of sweet sorghum for stem sales, this effect of late nitrogen application may be valuable because there is better demand for tall green stems in the market. Stem fibre percentage followed the same trend as stem yields in reaction to the nitrogen treatments, with higher fibre content associated with higher stem yields.

The intra-row spacing significantly affected yields per plant, with much higher dry stem yields (481g per plant) obtained from the 30 cm intra-row spacing than with the 15 cm intra-row spacing (289 g per plant). The higher yield in the wider spacing is the result of more tillers (2.9 tillers per plant) than in the closer intra-row spacing which had only 1.6 tillers per plant. Under conditions of 37,000 (S2) and 74,000 (S1) plants per hectare, respectively, this is equivalent to yields of 17.8 and 21.3 t ha^{-1} dry stems (74 and 88 t ha^{-1} fresh stems). These results indicate that the higher yield per plant at the wider spacing did not compensate enough for the fewer number of plants.

TABLE 8.1 The effect of nitrogen, spacing and landrace on stem fresh mass, stem dry mass, number of tillers, stalk fibre, pol percent, brix value and juice purity

Treatments	Stem fresh mass per plant (g)	Stem dry mass per plant (g)	Number of tillers per plant	Stem fibre (%)	Pol (%)	Brix (%)	Purity (%)
Nitrogen							
N0	1435.7 b	345.1 b	2.1a	9.2 b	5.2 c	13.8 a	37.8 b
N1	1752.8 a	429.1 a	2.5a	10.4 a	6.8 a	14.4 a	47.2 a
N2	1611.3 ab	371.5 ab	2.1a	9.8 ab	6.1 b	14.0 a	42.0 b
N3	1533.8 ab	395.8 ab	2.4 a	10.4 a	6.8 a	14.0 a	47.6 a
LSDt (p=0.05)	305.9	69.0	NS	0.8	0.7	NS	5.2
Spacing							
S1	1168.3 b	289.5 b	1.6 b	9.7 a	5.8 b	13.8 b	40.2 b
S2	1998.5 a	481.3 a	2.9 a	10.6 a	6.7 a	14.4 a	47.2 a
LSDt (p=0.05)	163.3	36.95	0.31	0.5	0.35	0.38	2.79
Landraces							
L1	1323.1 b	334.5 b	2.3 a	9.2 b	5.6 b	14.5 a	38.0 b
L2	1843.7 a	423.3 a	2.3 a	10.6 a	6.9 a	13.6 b	49.3 a
LSDt (p=0.05)	163.3	36.9	NS	0.83	0.7	0.7	5.2
C.V. (%)	20.5	19.0	26.9	8.9	11.3	5.3	12.7

+ Means followed by different letters are significantly different at the 5% level by Tukey's Multiple Range Test. Pol % = sucrose as measured by a polarimeter ; Brix = soluble solids ; Purity = a percentage ratio of pol and brix; fibre = non solubles after washing with water for one hour as % of stem. Treatments; N0 = 0 kg N ha_^{1}) N1 = 60 kg N ha_^{1} (early application), N2 =120 kg N ha_^{1} (early application), N3 = 60 kg N ha_^{1} (late application), S1 = 15 cm intra-row spacing, S2 = 30 cm intra -row spacing L1=early maturing landrace,
L2 = late maturing landrace

There were no significant differences between intra-row spacing in stem fibre content, but the wider intra-row spacing had a tendency of producing higher stalk fibre (10.6%) than the closer intra-row spacing (9.2%).

The late maturing landrace (L2) yielded significantly more than the early landrace (L1) despite the fact that they both produced an average of 2.3 tillers (Table 8.1). Stems of the late landrace were taller than those of the early landrace. Ferraris (1981a) reported that late maturing cultivars of sweet sorghum tend to have tall and thick stems compared to early maturing types. The large stem yields in the late maturing landrace is attributed to a longer growing period which resulted in plants producing more vegetative material than the early maturing landrace.

The nitrogen fertilizer x landrace x spacing interaction was significant for stem yield as shown in Table 8.2. The late maturing landrace (L2) at 30 cm intra-row spacing (S2) consistently produced the highest stem yields per plant at the different nitrogen treatments. The highest yield of (672 g per plant) was obtained with 60 kg N ha_¹ applied early in the growing season (N1L2S2). On a unit area basis the late maturing landrace produced the highest stem yield per hectare (27 t ha_¹) at 15 cm intra-row spacing with 120 kg N ha_¹ (N2L2S1). The lowest stem yield (257 g per plant and 19.0 t ha_¹) was observed with the unfertilized control at 15 cm intra-row spacing (N0L2S1).

In the early maturing landrace (L1) the highest stem yield per plant (455 g) was obtained at 30 cm intra-row spacing with 60 kg N ha_¹ applied early in the growing season (N1L1S2) and the highest stem yield per hectare (19.8 t ha_¹) was obtained at 15 cm intra -row spacing with 60 kg N ha_¹ applied early (N1L1S1). The lowest stem yield per plant (216 g) was observed at 15 cm intra-row spacing with 120 kg N ha_¹ (N2L1S1) and lowest stem yield per hectare of (13.1 t ha_¹) was observed at 30 cm intra-row spacing with unfertilized control (N0L1S2).

TABLE 8.2 Interaction between nitrogen x landrace × spacing on stem fresh and dry mass, yield per unit area and pol%

Treatments			Attributes			
Nitrogen	Landraces	Spacing	Stem fresh mass per plant (g)	Stem dry mass per plant (g)	Stem dry mass tons per ha-	Pol %
N0	L1	S1	955	256	18.9	4.24
N0	L1	S2	1397	354	13.1	6.50
N1	L1	S1	1049	268	19.8	5.73
N1	L1	S2	1701	455	16.8	7.02
N1	L2	S1	1309	323	23.9	6.69
N1	L2	S2	2953	672	24.9	7.77
N2	L1	S1	800	216	16.0	5.77
N2	L1	S2	1900	449	16.6	6.10
N2	L2	S1	1600	373	27.6	7.02
N2	L2	S2	2147	546	20.2	8.25
N3	L1	S1	1005	265	19.6	4.20
N3	L1	S2	1778	414	15.3	5.16
N3	L2	S1	1548	359	26.6	6.90
N3	L2	S2	1804	448	16.6	8.08
			**	**	**	**

** significant at P = 0.01

Pol % = sucrose as measured by a polarimeter; Treatments: N0 =0 kg ha_N, N1 = 60 kg ha_N (early application), N2 =120 kg ha_N (early application), N3 = 60 kg ha_N (late application), S1 = 15 cm intra-row spacing, S2 = 30 cm intra -row spacing; L1 = early maturing landrace, L2 = late maturing landrace

Juice Quality

The juice characteristics (pol, brix and purity percentages) are presented in Table 8.1 for the main effect treatments and in Table 8.2 for the individual treatment combinations. The three nitrogen fertilizer treatments (N1, N2 and N3) resulted in higher pol percentages than the unfertilized treatment. The brix value is an indication of the percentage soluble solutes in the juice. No differences in the brix value occurred as a

result of the nitrogen treatments. The effect of the nitrogen treatments on juice purity followed the same pattern as in pol percentage. These results indicate that sucrose content and juice purity were increased by nitrogen fertilizer and with the best effect obtained with the 60 kg N ha_¹ applied early in the growing season. This is consistent with the findings of Galani *et al*, (1991) who reported an increase in juice yield but no response in juice brix value with increase in nitrogen fertilisation. The effects of late nitrogen application (60 kg N ha_¹) on juice quality was similar to that of the 60 kg N ha_¹ applied early in the growing season, with the juice quality better than that of the unfertilized treatment. This contradicts the findings of Freeman, *et al, (*1973) who reported that late application of fertilizers, especially nitrogen, has a negative effect on juice quality. These results suggest that it may be possible for sweet sorghum growers to increase the sucrose content by applying nitrogen even at late development stages rather than not at all.

Wider intra-row spacing (30 cm intra-row spacing) produced much higher pol, brix and juice purity values than the closer intra-row spacing. These results contradict the findings of Broadhead *et al*, (1963) who reported that spacing did not affect sucrose, brix and juice purity values. However, the results are in agreement with McBee & Miller (1982) and Ferraris & Charles-Edwards (1986b) who reported some increase of the concentrated soluble sugars with lower populations. However, in Chapter 7 spacing did not have any significant effect on juice quality but there was a tendency for stems from the 60 cm spacing to be higher in sucrose content, purity and brix value compared to the other spacing treatments. From the results of the two experiments, it can be inferred that wider intra-row spacing may contribute towards better juice quality. The late maturing landrace(L2) had better juice quality characteristics than the early maturing landrace (L1) as shown in Table 8.1. Ferraris (1981a) reported similar results of high solubles and sugar

yields for late maturing, tall and thick-stemmed cultivars compared to early maturing cultivars. The early maturing landrace had the highest percentage of soluble solutes (brix).

The nitrogen fertilization x landrace x spacing interactions were only significant for pol percentage (Table 8.2). Both early and late maturing landraces produced the highest pol percentage at 30 cm intra-row spacing in all the nitrogen treatments. For the late maturing landrace the highest pol percentage of 8.25was observed at 30 cm intra-row spacing with the 120 kg N ha_¹ treatment (N2L2S2), while the highest pol percentage of 7.02 in the early maturing landrace was observed at 30 cm intra-row spacing with 60 kg N ha_¹ (N1L1S2).

Generally the results obtained from this experiment suggest that the 60 kg N ha_¹, whether applied early or late, increased stem yields per plant, juice purity and pol percentage (sucrose) more than the 120 kg N ha_¹ treatment. Based on these results the rate of 60 kg N ha_¹ can be recommended for sweet sorghum production in pure stands. However, for small scale farmers in Botswana fertilization with readily available organic manures (kraal, poultry) may be preferred and therefore needs investigation.

The late maturing landrace (L2) had higher stem yields and better juice quality characteristics than the early maturing landrace (L1), but the early maturing landrace was higher in brix value. Both early and late maturing landraces produced the highest pol % at wider spacing in all nitrogen treatments.

CHAPTER 9

GENERAL DISCUSSION

Sweet sorghum is not a new crop in Botswana, it has long been grown for its sweet stems. Recently the crop has attracted interest as a potential cash crop. Growers of sweet sorghum are faced with problems of poor crop establishment, lack of uniformity in stem size and low concentrations of sucrose in the juice.

Difficulties in establishing good crop stands under local conditions are probably associated with poor seed quality, unsuitable planting depths and sub-optimal soil moisture levels during germination and emergence. It is a prerequisite that farmers must use seed of high quality. In this study it was observed that sweet sorghum seedlots of a number of landraces collected from small scale farmers in Botswana were of low quality. Causes of poor quality in these seedlots were not established. However, according to Powel & Matthews, (1992) seed quality (seed viability and vigour) is affected by the environmental and cultural conditions under which the seed developed and matured, as well as by harvesting and storage practices. Growers of sweet sorghum need advice in the handling of seed to improve seed quality. The formal seed industry can contribute by either producing seed of high quality for farmers or by testing the quality of farmers' seedlots. In the testing of seed quality the seed industry should not only rely on the standard germination test but must include the Accelerated Ageing test because it approximates emergence under sub-optimal conditions and correlates well with stand establishment (Medina & Filho,1991; Romkaew, 1996). For instance in this study the germination test indicated that 61% of the of the sixty-five landraces had germination

capacities above 85%, whilst the AA test revealed that only 20% had germination capacities above 80%.

Harvesting sweet sorghum before mass maturity (physiological maturity) results in poor seed quality (Joyce *et al,* 1989). Observations on seed development and maturation of sweet sorghum in this study indicated that the highest seed germination occurred 14 to17 days after mass maturity. These results confirm that harvesting before mass maturity results in seed of low quality. Similar results were reported by Van de Venter *et al,* (1996); and Zanakis *et al,* (1994). Therefore, farmers should be advised to allow parent plants to mature for seed purposes.

A range of genetic diversity in Botswana sweet sorghum landraces was identified during the characterization exercise. This was indicated by differences in the morphology of vegetative and reproductive structures, as well as differences in phenology ranging from early to late maturing landraces. The late maturing landraces have tall, thick stems with more internodes as observed by Coleman (1970) and Ferraris & Charles-Edwards (1986a). Such stem characteristics are desirable in the marketing of sweet sorghum and realise high prices. The hard rind and high fibre content in the late maturing landraces cause concern because such stems become difficult to peel off and chew with more juice being retained in the fibre (Bryan *et al,*1985).

The late maturing landraces have better juice quality than the early maturing landraces, confirming observations of Ferraris (1981a). These observations suggest that improvement of juice quality in sweet sorghum may be possible through selection and breeding programmes.

Although seed yield is not a priority in sweet sorghum, the late maturing landraces, and some of the early maturing landraces, displayed high potential for seed production and compared well with grain sorghum. This means that during drought years, sweet sorghum seed can alternatively be utilized as grain (Ferraris & Stewart, 1979). Unfortunately sweet sorghum seeds are often bitter and not very palatable.

Panicle and floret removal in this study improved juice quality as was also observed by Broadhead (1973). However, this strategy proved not to be viable in improving juice quality where stems are the economic yield. Deheaded plants remained with scars and side branches which left stems unattractive, confirming reports of Coleman (1970) and Broadhead (1973). Breeding and selection of genotypes with smaller panicles and reduced tillering to benefit stem size and juice quality may be possible. Similarly, determining whether male sterile varieties may be sweeter and juicier than male fertile varieties is recommended. Chemically induced barrenness may be an alternative.

In Botswana the most common method of planting amongst small scale farmers is broadcasting. This results in areas of high and low crop density and farmers are usually reluctant to thin highly populated areas. Farmers grow a variety of crops in mixtures and this causes complex competition between crops. Inter-cropping practices impede the introduction of improved management practices to increase yields. Improved crop management strategies are a prerequisite to allow crop yield potential to be expressed. Studies of planting date, spacing and nitrogen have demonstrated that sweet sorghum yield and quality can be improved by raising levels of management. Early planting (October) resulted in higher stem yields, more tillers and taller main stems than late

planting (November, December). Similar results were reported by Inman-Bamber (1980), Ferraris (1988) and Almodares *et al,(*1994). Planting as early as October in Botswana is often not possible due to late rains and lack of ploughing and planting facilities. Establishing suitable planting dates for early and late maturing landraces in Botswana still needs attention.

Unfortunately planting early did not improve juice quality, contrary to observations by Ferraris & Charles-Edwards (1986b), Petrini *et al,* (1993) and Almodares *et al,* (1994). This negative relationship between stem yield and juice quality requires more research in order to optimise yield and quality.

Application of nitrogen resulted in higher stem yields and sucrose content than the unfertilized control. Similar results were reported by several researchers (Jordan-Karim, 1979; Jackson & Arthur, 1980; Ferraris, 1988 and Bennett,1982). In the results of this study the rate of 60kg N ha^{-1} was identified as a suitable rate for sweet sorghum production in pure stands under the experimental conditions. In the past several fertilizer trials in Botswana have failed to convince farmers to adopt the use of fertilizers. Small scale farmers would accept use of organic manures (kraal, poultry) and application rates still need to be calibrated in on-farm demonstration trials.

A 30 cm intra-row spacing in sweet sorghum resulted in high stem yield per plant and sucrose content and it was recommended for sweet sorghum production in pure stands. For farmers who have already adopted row planting, this recommendation should be readily acceptable because maize and grain sorghum are planted at the same spacing. Uniform spacing is an important strategy for improving stem yields because it directly

affects stem size.

On the bases of the results obtained from this study, farmers can improve yield and quality of sweet sorghum by adopting some of the strategies investigated. For example a plot of one hectare planted immediately after the first rains in rows of 90 cm by 30 cm intra-row spacing and topdressed with 60 kg N ha^{-1} can result in a yield of 37 000 plants. In the case where a late maturing landrace is used, 37 000 tall and thick main stems could be harvested and sold at an estimated price of P2.00 (Botswana currency P1.00 equivalent to R1.25) per stem. This compares favourably with practically all other cropping alternatives available to small scale farmers in rural areas. Sweet sorghum is an agronomic viable cash crop for small scale farmers. However, a detailed economic analyses taking into consideration the variation in stalk quality is required before specific recommendations can be made to growers. Price elasticity in the supply-demand functions will determine the economic viability of this crop.

This investigation into practices to improve yield and quality of sweet sorghum produced a number of interesting results which should contribute towards establishing sweet sorghum as a cash crop for small scale farmers:

- Identification of the fact that harvesting of seed before mass maturity resulted in poor quality.
- Promising landraces have been collected and characterised.
- juice analyses provided new information on quality characteristics of sweet sorghum landraces presently grown.
- Progress has been made to quantify the effect of planting date, spacing and nitrogen nutrition.

However, a number of aspects deserve further attention:

1. The study was conducted using landraces collected from farmers, and these landraces are genetically heterogenous. Selection and multiplication of genetically uniform landraces will reduce experimental variation. It would also provide improved genotypes to farmers.
2. It was observed that the seed quality of seedlots collected from farmers was generally poor. Investigations into factors causing poor seed quality can alleviate the situation. Cultivar selection and seed multiplication by the Department of Agriculture (Seed Multiplication Unit) can contribute greatly towards improved seed planting material.
3. Only ten of the landraces in the collection were botanically characterised, and of these only a few were represented in the field trials. A large source of unexplored genotypes awaits evaluation.
4. It has been observed that physical removal of panicles and florets is not feasible although yield and juice quality were improved. The effect of male sterility and selection of genotypes with small panicles in improving stem yield and juice quality of sweet sorghum deserves attention.
5. Technology transfer in order to change attitudes of small scale farmers regarding production practices of this traditionally neglected crop, needs attention.

SUMMARY

Sweet sorghum (*Sorghum bicolor* (L.) Moench) belongs to the same species as grain sorghum and is characterised by tall stems with sweet juice. In Botswana, sweet sorghum is grown mainly for its sweet stems which are chewed as a snack. It is commonly grown by small scale farmers in mixtures of crops. Recently the crop has attracted interest as a potential cash crop and growers are faced with problems of poor crop establishment, poor stem quality and low concentrations of sucrose in the juice. The aim of this study was to investigate factors that can be utilized to improve crop yields and sucrose content. This was achieved through the following:

1. Collection of seed from small scale farmers to determine germination capacity
2. Study the effect of harvesting sweet sorghum seed before physiological maturation
3. Characterisation of collected germplasm
4. Investigation of deheading and tiller removal on juice quality
5. Study the effect of planting date, nitrogen and spacing on the stem yield and juice quality

Sixty five landraces of sweet sorghum were collected and the seed quality determined by using the standard germination and the Accelerated Ageing (AA) test. The standard germination test results showed that 61% of the accessions had a germination percentage in excess of 85%, while the AA test showed that only 20% of the accessions had a germination percentage of above 80%. These results showed that seed quality of sweet sorghum seed in Botswana was generally of a low standard. Low seed quality may be the result of harvesting seed before physiological maturity, drying and threshing seed under unfavourable ambient temperatures and poor storage facilities.

Effects of harvesting seed before physiological maturity on seed development and maturation in sweet sorghum were studied. Seed attained mass maturity 31 days after anthesis (DAA) and 38 DAA in the case of grain sorghum. Maximum seed quality occurred 14 days after mass maturity in sweet sorghum whilst in grain sorghum it occurred 7 days after mass maturity. This coincided with maximum seed germination in sweet sorghum. These results indicate that harvesting before physiological maturity may lower seed quality.

Ten out of the sixty-five landraces, ranging from early to late maturing landraces were characterised. Differences in the morphology of vegetative and reproductive structures, as well as differences in phenology were documented. The late maturing landraces had better juice quality than the early types, with high brix values and high sucrose content. From these results it was evident that there was a range of genetic diversity in Botswana sweet sorghum landraces which can be utilised in future for improvement of yields and quality through breeding and selection programmes.

The effects of panicle, floret and tiller removal on the juice quality of sweet sorghum were investigated. Reduction in the number of developing seeds in the inflorescence improved juice quality. Deheaded plants were significantly higher in brix value, juice purity and sucrose (pol percentage). Early deheading (boot stage) produced higher brix and sucrose (pol percentage) that late deheading (flowering and milk stages). Removal of tillers did not result in significant differences in juice quality and stem mass of the main stems. Establishing whether male sterile varieties may be sweeter and juicier than male fertile varieties is justified. Another alternative would be to breed and select for plants with small panicles and

reduced tillering to benefit stem size and quality. This does not exclude possibilities of investigating chemically induced barenness.

Early planting in October resulted in higher stem yields, more tillers and taller plants than late planting in November and December. These results suggest that increase in stem yield per plant in sweet sorghum may be expected when the planting date is advanced as close as possible to the onset of the rains because this gives a longer growing season. Late planting resulted in the highest pol percentage, juice purity and stalk fibre. Brix value was not affected by planting date. Although stem appearance is more important in sales of stems, the negative relationship between stem yield and juice quality requires more research in order to optimise yield and quality.

Nitrogen increased stem yields and improved juice quality. However, for small scale farmers in Botswana fertilisation with readily available organic manures (kraal, poultry) may be preferred and this needs to be assessed in on-farm demonstration trials. Sweet sorghum is an agronomically viable cash crop for small scale farmers in Botswana. However, price elasticity in the supply demand functions will determine the economic viability of this crop.

LITERATURE CITED

ABDULAHI, A. & VANDERLIP, R. L., 1972. Relationship of vigour tests and seed source and size to sorghum seedling establishment. *Agron. J.* **64** : 143 - 4.

ABDULLAH, D. R., POWEL, A. A. & MATTHEWS, S., 1992. Prediction of the storage potential of long bean (*Vigna sesquipedalis L. Fruhw*) seed in the humid tropics. *Seed Sci. & Technol.,* **20** : 141 - 147.

ACKERSON, R. C., KRIEG, D. R. & SUNG, J. M., 1980. Leaf conductance and osmoregulation of field-grown sorghum genotypes. *Crop Sci.* **20** : 10 -14

ADAMS, J. E., ARKIN, G. F. & BURNETT, E., 1976. Narrow rows increase dryland grain sorghum yields. *Tex. Agric. Exp. Stn. Misc. Publ. p.* 1248. Cited in Myers & Foale (1980).

AIAZZI, M. T., ARGUELLO, J. A. & DIRIENZO, J. A., 1998. Physiological maturity in seeds of *Atriplex cordobensis* (Gandogeret Stuckert) correlation with visual indicators. *Seed Sci. & Technol*, **26** : 405 -411.

ALMODARES, A., SEPALI, A., DALILOTOJJARY, H. & GHVAMI, R., 1994. Effect of phenological stages on biomass and carbohydrate contents of sweet sorghum cultivars. *Ann. of plant physiol.,* **8** : 42- 48.

ALMODARES, A., SEPALI, A. & KARVE, A.D., 1994. Effect of planting date on yield and sugar production of sweet sorghum. *Ann. of plant physiol.* **8** : 49 -54.

ANONYMOUS, 1987. Department of Agricultural research Botswana. Annul Report.

ANONYMOUS, 1996. Lost crops of Africa. Vol. 1. Grains. Development national Research Council. National Academy Press. Washington, D. C.

ASSOCIATION OF OFFICIAL SEED ANALYSTS., 1983. Seed Vigour Testing Handbook. Contribution No 32 to the Handbook on Seed Testing, Association of Official Seed Analysts, N.E. USA, 88 p.

ASSOCIATION OF OFFICIAL SEED ANALYSTS., 1988. Rules for testing seeds. *J. Seed Technol.* **12** : 1 -117.

AYYANGAR, G. N. R. & RAO, V. P., 1931. Studies in sorghum. I. Anthesis and pollination. *Indian J. Agric. Sci*. **1** : 445 - 454.

BASKIN, C. C., PALIWAL, S. & DELOUCHE, J. C., 1989. Estimating field emergence of sorghum. 2nd International Seed Testing Congress Seed Symposium, *Abstracts of papers* No **61:** ISTA, Zurich.

BENNETT, W. G., 1982. Alcohol production potential of four sorghums (Sorghum bicolor L. (Moench.) cultivars utilizing commercial and legume nitrogen. Masters Thesis. Dept. of Agron. Mississippi State Univ. P. 63. (In Soilean et. Al. 1985).

BEWLEY, J. D. & BLACK, M., 1986. Seed physiology of development and germination. Plenum Press, London, UK 367 p.

BISHNOI, U. R., 1974. Physiological maturity of seeds in *Triticale hexaploid* L. *Crop Sci.*. **14** : 819 821.

BISHNOI, U. R. & DELOUCHE, J. C., 1975. Cottonseed quality and its relation to performance in laboratory and field tests. *Agron. Abst.* 90 p.

BOVEY, R. W. & McCARTHY, M. K., 1965. Effect of preharvest desiccation on grain sorghum. *Crop Sci.* **5** : 523-526.

BROADHEAD, D. M., 1969. Sugar production from sweet sorghum as affected by planting dates, after ripe harvesting and storage. *Agron. J.* **61** : 811-812.

BROADHEAD, D. M., 1972(a). Effect of stalk chopping on leaf removal and juice, quality of Rio sweet sorghum. *Agron. J.* **64** : 306 -308.

BROADHEAD, D. M., 1972(b) . Effect of planting date and maturity of Rio sweet sorghum. Agron. J. **64** : 389 -390.

BROADHEAD, D. M., 1973. Effect of deheading on stalk yield and juice quality of Rio sweet sorghum. Crop. Sci. **13** : 395 - 396.

BROADHEAD, D. M., FREEMAN, K. C., COLEMAN, O. H. & ZUMMO, N., 1974. New variety - this sweet sorghum looks good. Mississippi Farm Research **37 (5)**: 4,7.

BROADHEAD, D.M., STOKES, I.E. & FREEMAN, K.C., 1963. Sorgo spacing experiments in Mississippi. Agron. J.55 : 164 – 166.

BRYAN, W. L., MOROE, R. L.& BASCHO, G. J., 1985. Evaluation of sweet sorghum for fuel alcohol. ASAE Paper No 81-3571, ASAE St. Joseph, MI 49085.

BYRD, H. W. & DELOUCHE, J. C., 1971. Deterioration of soybean seed in storage. Proceedings of the Association of Official Seed Analysts. **61** : 41 -57.

CADDEL, J. L. & WEIBEL, D. E., 1971. Effect of photoperiod and temperature on the development of sorghum. Agron. J. **63** : 799 - 803.

CLARK, R. B., 1982. Mineral nutritional factors reducing sorghum yields: micro-nutrients and acidity. The Proceedings: ICRISAT.

COLEMAN, O. H., 1970. Syrup and sugar from sweet sorghum. In Wall, J.S. & Ross, W.M. (Ed). Sorghum production and utilization. P. 416 - 440. AVI Publ. West port C.T.

COLEMAN, O. H., 1983. Syrup and sugar from sweet sorghum. Cover Title:Sugarcanes Pamphlets USDA. Avi Publishing Company, Westport.

COLEMAN, R. E., 1970. Sweet sorghum for sugar production. *Proc. Am. Soc.of S. Cane. Technol.* **17:** 1 - 9.

COLEMAN, R. E., 1972. Sweet sorghum for sugar production. Proc. Am. Soc. Sug. Cane technol. **17** : 1 - 9.

COLEMAN, O. H. & DEAN, J. L., 1964. Inheritance of resistance to methyl parathion in sorgo. *Crop Sci.* **4** : 371-373.

COLEMAN, O. H. & STOKES I. E., 1958. The inheritance of weak stalk in sorgo. *Agron.J.* **50** : 119 - 120.

COLEMAN, O. H. & STOKES. I. E., 1964. Storage studies of sorgo. U.S. Dept. Agric. Bull 1307.

COWLEY, W. R., 1969. Sweet sorghum in South Texas : Yield potential and cultural practices. *J. Rio Grand Hort. Soc.* **23** : 157-162.

COWLEY, W. R. & LIME, B., 1976. In : "Fuels from sugar crops". Conf. Poc. (cited in Ferraris & Stewart, 1979).

COWLEY, W. R. & SMITH, B. A., 1972. Sweet sorghum as a potential sugar crop in south Texas. Proc. Int. Soc. Sug. Cane Technol. **14** : 628 - 633.

DELOUCHE, J. C. & BASKIN, C. C., 1973.Accelerated Ageing techniques for predicting the relative storeability of seed *lots. Seed Sci.& Technol.* **1** : 117 -118.

DEMIR, I. & ELLIS, R. H., 1992(a). Changes in seed quality during seed development and maturation in tomato. *Seed Sci. Res.* **2** : 81-87.

DEMIR, I. & ELLIS, R. H., 1992(b). Development of pepper (*Capsicum annum*) seed quality. *Ann. Appl. Biol.* **121** : 385-399.

DOGGETT, H., 1970. Sorghum, 1st ed. Longmans, Green and Co. Ltd: London, Harlow.

DOGGETT, H., 1988. Sorghum, 2nd ed. Longmans, Green and Co. Ltd: London, Harlow.

DONALDSON, R. A. & VAN STADEN, J.,1989. A view of chemicals used ad ripeners of sugarcanw in S.A. Int. Soc.Sugarcane Technol. Proc. **20 : 2** : 647 & 2 94655.

DOWNEY, L. A., 1971. Plant density yield relations in maize. J.Aust. Instit. Agric. Sci. **31** : 138 – 146.

EASTIN, J. D., 1972. Photosynthesis and translocation in relation to plant development. In N.G. P. Rao and L.R. House (ed) . Sorghum in the seventies. Oxford and IBH Publishing Co. New Delhi. 214 - 246.

EASTIN, J. D., HULTQUIST, J. H. & SULLIVAN, C. Y., 1973. Physiological maturity in grain sorghum. Crop Sci. **13** :175 - 178.

EILRICH, G. L., LONG, R. C., STICKLER, F. C. & PAULI, A. W., 1964. Stage of maturity, plant population and row width as factors affecting yield and chemical composition of atlas forage sorghum composition of atlas forage sorghum. Kansa Agric. Exp. Stn. Tech. Bull. 138.

ELLIS, R. H. & FILHO, P. A, C., 1992(a). The development of seed quality in spring and winter cultivars of barley and wheat. *Seed Sci. Res.***2** : 9-15.

ELLIS, R. H. & FILHO, P. C., 1992(b).Seed development and cereal seed longevity. *Seed Sci. Res.* **2** :15-19.

ELLIS, R. H., HONG, T. D. & JACKSON, M. T., 1993. Seed production environment, time of harvest, and the potential longevity of seeds of three cultivars of rice (*O. sativa* L.). *Ann. of Bot.* **72** : 583 -590.

ELLIS, R. H., HONG, T. D. & ROBERTS, E. H., 1987. The development of desiccation toleration and maximum seed quality during seed maturation in six grain legumes. *Ann. of Bot.* **59** : 23-29.

FERRARIS, R., 1981(a). Early assessment of sweet sorghum as an agro-industrial crop. 1. Varietal evaluation. *Aust. J. Exp. Agric. Anim. Husb.* **21** : 75 - 82.

FERRARIS, R., 1981(b). Early assessment of sweet sorghum as an agro-industrial crop. 2. Maturity factors. *Aust. J. Exp. Agric. Anim. Husb.* **21** : 83-90.

FERRARIS, R., 1988. Sweet sorghum: Agronomic evaluation and potential application for Australian Agro-Industry. CSIRO Division of Tropical Crops and Pastures Report No.5

FERRARIS, R. & CHARLES-EDWARDS, D. A., 1986(a). A comparative analysis of the growth of sweet and forage sorghum crops. I. Dry matter production, phenology and morphology. *Aust. J. Agric. Res.* **37** : 495 - 512.

FERRARIS, R. & CHARLES-EDWARDS, D. A., 1986 (b). A comparative analysis of the growth of Sweet and Forage Sorghum crops. II Accumulation of soluble carbohydrate and nitrogen. *Aust. J. Agric. Res.,* **37** : 513 - 522.

FERRARIS, R. & STEWART, G. A., 1979. New options for sweet sorghum. *J. Aust. Inst. Agric. Sci.* **45** : 156-164.

FILHO, P. C. & ELLIS, R. H., 1991(a). The development of seed quality in spring barley in four environments. I. Germination and longevity. *Seed Sci. Res.* **1** : 163-177.

FILHO, P. C. & ELLIS, R. H., 1991(b). The development of seed quality in spring barley in four environments. II. Field emergence and seedling size. *Seed Sci.Res.***1:** 179-185.

FLEMMING, A. A. & WOOD, E. H., 1967. Effect of soil moisture and plant population on corn hybrids at high fertility level. Agron. Abst. Div. C -3 : 35 - 36 (in Downey**,** L.A.,1971)**.**

FREEMAN, K. C., BROADHEAD, D. M. & ZUMMO, N., 1973. Culture of sweet sorghum for syrup production. Agric. Res. Serv. Agric. Handbk. No. 441. U.S. Dep. Agric. : Washington, D.C.

GALANI, N. N., LOMTE, M. H. & CHOUDHARI, S. D., 1991. Juice yield and brix as affected by genotype, plant density and nitrogen levels in high energy sorghum. Bharatuya Sugar. **16** : 23 -24. In Field crop abstracts 1992 vol. 45 N6. p.371.

GANE, A. J. C., BIIDDI, A. J. C., KNOTT, C. M. & EGLEA, D. J., 1984. The PGRO Pea Growing Handbook. Processors and Growers Research Organisation, Peterborugh, England. 242 p.

GELMOND, H., LURIA, I. WOODSTOCK, L. W. & PEARL, M., 1978. The effect of Accelerated Ageing of sorghum seeds or seedling vigour. *J. Exp. Bot.* **29** : 489 - 495.

GOLDSWORTHY, P. R., 1970. The growth and yield of tall and short sorghums in Nigeria. J. Agric. Sci. **75** : 109 -122.

GRAY, D., STECKEL, J. R. A. & HANDS, L. T., 1992. Leek (*Allium parrum* L.) seed development and germination. *Seed Sci. Res.* **2** : 89-95.

GRZESIK, M., GORNIK, K. & CHOJNOWSKI, M., 1997. Martenal effect on *Callistephus chinensis* seed yield and quality. In : Basic and Applied Aspects of Seed Biology. (Eds. R.H. Ellis, M. Black, A.J. Murdoch, T.D. Hong), Khuwer Academic Publisher. Dordrecht / Boston / London. 129 -135.

HALMER, P. & BEWLEY, J. D., 1984. A physiological perspective on seed vigour testing. *Seed Sci. Technol.* **12** : 516 -575.

HAMPTON, J. G. & COLBEAR, P., 1990. Potential versus actual seed performance - can vigour testing provide an answer? *Seed Sci. Technol.* **18** : 215 -228.

HAMPTON, J. G., 1995. Conductivity test. In van de Venter, H. A. (ed.). Seed vigour testing. International Seed Testing Association, Zürich, Switzerland.

HANSEN, R. W. & FERRARIS, R., 1985. Post-harvest changes in fermentables sugars in sweet sorghum (Sorghum bicolor cv. Wray) *J. Sci. Food Agric.* **36** : 557 -560.

HARLAN, J. R. & de WET, J. M. J., 1972. A simplified classification of cultivated sorghum. *Crop Sci.* **12** : 172 - 176.

HARRINGTON, J. F., 1972. Seed storage longevity. In Kozlowski, T.T. (ed.). Seed biology, Volume III. Academic Press, New York. p. 142-245.

HARRIS, D., FRY, G. J., MILLER, S. T. & PAIN, A., 1992. Seedbed and crop establishment. In 'Proceedings of the second annual scientific conference of the SADCC/ODA. Land and water management programme. SACCAR, Botswana.

HARRIS, H. B., PARKER, M. B. & JOHNSON, B. J., 1965. Influence of molybdenum content of soybean seed and other factors associated with seed source on progeny response to applied molybdenum. *Agron. J.* **57 :** 397 - 399.

HENZELL, R. G. & GILLIERON, W., 1973. Effect of partial and complete panicle removal on the rate of death on some *Sorghum bicolor* genotypes under moisture stress. Queensland J. Agric. & Anim. Sci. **30** : 291 - 299.

HESKER, P., 1966. General botany. In: "Sorghum". Handbook. Publ. No.2 pp 2.1 - 2.3.Old. Dep. Primary Ind. Brisbane. (Cited in Ferraris, R. & Stewart, G.A., 1979.)

HESKETH, J. K., CHASE, S. S. & NANDA, D. K., 1969. Environmental and genetic modification of leaf number in maize, sorghum and Hungarian millet. *Crop Sci.***9** : 460-463.

HIPP, B. W., COWLEY, W. R., GERARD, C. J. & SMITH, A. B.,1969. Influence of solar radiation and date of planting on yield of sweet sorghum. *Crop Science* **10** : 91-92.

HUMBERT, R., MARIO, P., ZAMORA, M. & FRASER, T. B., 1967. Ripening and maturity control progress at Ingenio Los Mochis; Mexico. Proc. 12 th Congr. ISSCT, Elsevier, Amsterdam pp. 446 - 452.

HUME, D. J. & KEBEDE, Y., 1981. Response to planting date and population density by early maturing sorghum hybrids in Ontario. Canadian J. Plant Science **61** : 265 - 273

IBPGR / ICRISAT. 1993. Descriptors for sorghum (*Sorghum bicolor (L.) Moench).* International Board for Plant Genetic Research Institute for the Semi - Arid Tropics, Patancheru, India.

INMAN-BAMBER, N. G., 1980. An evaluation of sweet sorghum as a sugar crop in the Midlands Mistbelt. S. A. Sugar J. **64** : 419.

INTERNATIONAL SEED TESTING ASSOCIATION. 1985. International rules for seed testing. Rules 1985. *Seed Sci. Technol.* **13** : 299 -520.

INTERNATIONAL SEED TESTING ASSOCIATION.1987. Handbook of Vigour Test Methods. Int. *Seed Test. Assoc.* Zurich, Switzerland.

INTERNATIONAL SEED TESTING ASSOCIATION. 1993. International rules for seed testing. Supplement to *Seed Sci. Technol.* **21** : 1 - 287.

ISBELL, V. R. & MORGAN, P. W., 1982. Manipulation of apical dominance in sorghum with growth regulators. *Crop Sci.* **22** : 30 - 35.

JACKSON, D. R. & ARTHUR, M. F., 1980. Alcohol crop for the U.S. Gasohol USA. **2** : 26 -33. (In Soileau et.al., 1985)

JANSSEN, G. McCLELLAND, C. K. & METZGER, W. H., 1930. Sap extraction of sorghum and the localization of juice and sugars in internodes of the plant. *J. Am. Agron*. **22** : 627 - 639.

JONSON, M. W., SPEROW, C. B. & McLAREN, G. A., 1961. Factors influencing the yield and quality of sorgo syrup production in West Virginia. W. VA Univ. Agric. Exp. Stn. Bull No. 450 (cited in Doggett, 1970).

JONSON, R.R. & WAX, L.M., 1978. Relationship of soybean germination and vigor tests to field performance. Agron. J **70** : 273 – 278.

JORDAN-KARIM, F., 1979. Effects of row spacing and nitrogen fertilizer on yield and yield components of seven sorghum cultivars. Masters Thesis, Dept. Of Agon. Mississippi State Univ. P 45.

JOYCE, R., STECKEL, A., GRAY, D. & ROWSE, H. R., 1989. Relationships between indices of seed maturity and carrot seed quality. *Ann. of Appl. Biol.*, **114** : 177-183.

KAMESWARA R. N., APPA RAO, S., MENGESHA, M. H. & ELLIS, R. H., 1991. Longevity of pearl millet seeds harvested at different stages of maturity. *Ann.of Appl. Biol.*, **119** : 97-103.

KANEMASU, E. T., BARK, D. L. & CHINCHOY, E., 1975. Effect of soil temperature in sorghum emergence. *Plant & Soil* **43** : 411-417.

KARVE, A. D., GHANEKAR, A. R. & KSHIRSAGAR, S. N., 1975. (Cited in Ferraris R.& Steward, A.D., 1979)

KASSAM, A. H. & ANDREWS, D. J., 1975**.** Effects of sowing date on growth, development and yield of photosensitive sorghum at Samaru, Northern Nigeria. Samaru Research Bul. No 245. p18

KERMODE, A. R. & BEWLEY,J. D., 1985. The role of maturation drying in the transition form seed development to germination. I. Acquisition of desiccation-tolerance and germinability during development of *Ricinus communis* L.seeds. *J.of Exp. Bot.*, **36** :1916 -1927

KHAN, R. A. & LAUDE, H. M., 1969. Influence of heat stress during seed maturation on germinability of barley seed at harvest. Crop Sci. **9** : 55 -58.

LINGLE, S. E., 1987. Sucrose metabolism in the primary culm of sweet sorghum during development. *Crop Sci.* **27** : 1214 - 1219.

MAHESHWARI, B. K., PRASAD, J., SINGH,G. B. & SHARMA, R. K., 1974. Studies of sweet sorghum in India - II. Effect of date of sowing and stage of harvest on yield and quality of sweet sorghum. 40th Proceedings of the S.T.A. of Indian.

MARTIN, J. H., LEONARD, W. H. & STAMP, D. L., 1975. Principles of field crop production. 3rd Ed. Collier Macmillan International Edition London.

MARTIN, P. M. & KELLEHER, F. M., 1984. Effects of row spacing and plant population on sweet sorghum yield. *Aust. J.Exp. Anim. Husb.* **24** : 386-390.

MASHAURI, I. M., COLBEAR, P. & HILL, M. J., 1992. Interactions between seed moisture, processing damage and storage on the subsequent germination performance of maize. Proceedings of the 4th Australian Seed Research Conference. 211 - 216.

MASSACCI, A., BATTISTELLI, A. & LORETO , F., 1996. Effect of drought stress on photosynthetic characteristics, growth and sugar accumulation of field grown sweet sorghum. *Aust. J. Plant Physiol.* **23** : 331 - 340.

MAUNDER, A. B. & SHARP, G. I., 1963. Localization of outcrosses within the panicle of fertile sorghum. *Crop Sci.* **3** : 449-450.

McBEE, G. G. & MILLER, F. R. , 1982. Carbohydrates in sorghum culms as influenced by cultivars, spacing and maturity over a diurnal period. Crop Sci. **22** : 381 - 385.

McLAREN, N. W., & SMIT, E., 1996. Sorghum diseases in South Africa. ARC-Grain crops Institute. LNR-Instituut vir Graangewasse / Potchefstroon.

MEDINA, P. F. & FILHO, M. J., 1991. Evaluation of physiological quality of maize (*Zea mays L.)* Seeds. *Seed Abst.* **14** : *451.*

MILES, D. F., TEKRONY, D. M. & EGLI, D. B., 1988. Changes in viabilit y germination and respiration of freshly harvested soybean during development. Seed *Sci. Res.* **28** : 700-704.

MILLER, F. R. & CREELMAN, R. A., 1980. Sorghum. A new fuel. P. 219 -232. In Vietor, D.M. & Miller F. R., 1990. Assimilation, partitioning and nonstructural carbohydrates in sweet compared with grain sorghum. Crop Sci. **30** : 1109 - 1115.

MILLER, F. R., QUINBY, J. R. & CRUZADO, H. J., 1968. Expression of known maturity genes of sorghum in temperate and tropical environments. *Crop Sci* **8** : 675 - 677.

MOORE. R. P. , 1972. Mechanisms of water damage in mature soybean seed. *Proc. Assoc. Offic. Seed Anal.* **61:** 112 - 118.

MYERS, R. J. K. & FOALE, M. A., 1980. Row spacing and population in Australian Grain Sorghum Production. J. Aust. Inst. Agric. Sc. 214-220.

OJHA, S. S., SINGH J. P. & AHMAD, N., 1973. Factors affecting juice quality of sugarcane. A review. Indian Sugar. Government sugarcane Research Station, U.P. 861- 866.

PAULI, A. W., STICKLER, F. C. & LAWLESS, J. R., 1964. Developmental phases of grain sorghum (Sorghum vulgare Pers.) as influenced by variety, location and planting date. Crop Sci. **4** : 10 - 13.

PEACOCK, J. M., 1982. Response and tolerance of sorghum to temperature stress. These Proceeding : ICRISAT.

PENDLETON, B. B., TEETES, G. L., & PETERSON G. C., 1994. Phenology of sorghum flowering. *Crop Sci.* **34** : 1263 -1266.

PERRY, D. A., 1983. Commentary on ISTA vigour test committee collaborative trials. *Seed Sci. Technol.* **12;** 301 -308.

PETRINI, C., BELLETTI, A. & SALAMIN, F., 1993. Accumulation and distribution of dry matter and soluble carbohydrates in two sweet sorghum cultivars; influence of sowing date and harvesting time. *Eur. J. of Agron.* **2** : 185 - 192. In Field Crop Abst. 1994 47 No. 8

PREMACHANDRA, G. S. HAHN, D. T. & JOLY, R. J., 1994. Leaf water relations and gas exchange in two grain sorghum genotypes differing in their pre - post flowering drought tolerance. J. Plant Physiol. **75** : 617 - 622.

QUINBY, J. R., HESKETH, J. D. & VOIGHT, R. L., 1973. Influence of temperature and photoperiod on floral initiation and leaf number in sorghum. *Crop Sci.* **13** : 243 - 246.

RAM, C., KUMARI, P., SINGH, O. & SARDANA, J.,1989. Relationship between seed vigour tests and field emergence in chickpea seed. *Seed Sci. Technol.,* **17**: 169 -173.

RASYAD, D. A., VAN SANFORD, D. A. & TEKRONY, D. M., 1990. Changes in seed viability and vigour during wheat seed maturation. *Seed Sci. Technol.* **18** : 259-267.

ROBERTS, E. H., 1972. Loss of viability and crop yield. In: E. H. Roberts, ed. Viability of seeds, 307 - 320 p. London Chapman and Hall.

ROMKAEW, J., 1996. Influence of seed vigour on field emergence, growth, yield and storeability of large - seeded peanut seed. Master of Science Thesis, Kasetsart University Bangkok. In: Santi

Pracha, Q.Santpracha and Wongvarodom V.,1997. Hybrid corn sees quality and accelerated aging. *Seed Sci. Technology.* **25** : 203 - 208.

ROOS, E. E. & MANALO, J. N., 1971. Testing vigour of beans following favourable storage conditions. *Hort. Science,* **6** : 347 - 348.

SANTO, R. N. & NALAMWAR, R. W., 1991. Effect of herbicides and weeding on RGR, NAR and yield of sorghum. Annals of Plant Physiology. 5(1) 135 - 138 Department of Agronomy, Punjabrao Krishi Vidyapeeth, Akola 444104, Maharashtra, India.

SCHULZE, R. E., 1997. South African Atlas of Agrohydrology and Climatology. Water Research Commission, Pretoria. Report T.T.82/96.

SHAW, R. H. & LOOMIS, W. E., 1950. Bases for the prediction of corn yields. *Plant Physiol.* **25** : 225-244.

SHEPARD, H.L., NAYLOR, R.E.L. & STUCHBURY, T., 1996. The influence of seed maturity at harvest and drying method on the embryo, %-amylase activity and seed vigour in sorghum (*Sorghum bicolor* (L) Moench). Seed Sci. Technol. **24** : 245 -259.

SHIH, S. F., GASCHO, G. J. & RAHI G. S., 1981. " Modelling biomass production of sweet sorghum."*Agron. J.* **73** : 1027 -1032.

SMITH, B. A., SMITH, R. C., ROMO, R. V., de la CRUZ, R.A. & GRIFFITHS, T. P., 1970. Removal of starch from sweet sorghum juice. *Sugar J.,* **32** : 25 - 30.

SOILEAU, J. M. & BRANDFORD, B. N., 1985. Biomass and sugar yield response of sweet sorghum to lime and fertilizer. *Agron. J.* **77** : 471 - 476.

SON, S.H., 1971. Studies on ecological variation in the inheritance of agronomic characters of sweet sorghum (Sorghum vulgare Pers.). Cultivars in Korea. Res rep office rur. Dev., Suwon 14 : 77 - 113. (Fld crop abstr. 1973 No 184).

STANWAY, V., 1958. Prechilled vs non-prechilled germination of *sorghum vulgare* Pers. Assoc. Off. *Seed Anal. Proc*., **48** : 93-95.

STEEL, R. G. D. & TORRIE, J. H., 1985. Principles and procedures of statistics. McGraw-Hill. Inc., New York.

STICKLER, F. C., PAULI, A. W., LANDE, H. H., WILKINS, H. D. & MINGiS, J. L., 1961. Row width, plant population studies with grain sorghum at Manhattan, Kansas. *Crop. Sci.* **1** : 297-300.

STOKES, I. E. , 1958. Brawley, a new variety of sweet sorghum for southern Califonia. Sorghum Newsletter. **1** : 34.

STOKES, I. E., COLEMAN, O. H. & DEAN, J. L., 1957. Culture of sorgo for syrup production. U.S. Dept. Agr. Farmers : Bull 2100. (Cited in Coleman,1970).

STOSKOPF, N.C., 1985. Cereal grain crops. A Prentice-Hall Co. Reston, Virginia. USA**.**

TEKRONY, D. M. & EGLI, D. B., 1977. Relationship between laboratory indices of soybean seed vigour and field emergence. *Crop Sci.* **17**: 573 - 577.

TEKRONY, D. M., EGLI, D. B. & PHILLIPS, A. D., 1980. Effect of field weathering on the viability and vigour of soybean seed. *Agron. J.* **72** : 749-753.

TEKRONY, D. M., 1993. Accelerated Ageing Test. *J. of Seed Technol.* **17** : 110 -120.

UTZURRUM, J. R., FUKAI, S. & FOALE, M. A., 1998. Effect of late nitrogen application on growth and nitrogen balance of two cultivars of water-stressed grain sorghum. *Aust.J. Agric. Res.,* **49** : 687 - 694.

VAN DEN BERG, J. & DRINKWATER, T. W., 1997. Field guide to identification of sorghum pests in Southern Africa. ARC-Grain crops Institute. LNR-Instituut vir Graangewasse / Potchefstroon.

VAN DE VENTER, H. A., DEMIR, I. & DE MEILLON, 1996. Seed development and maturation in edible dry bean (*Phaseolus vulgaris* L.) cv Teebus. *S. A. Tydskr. Plant Grond*. **13** : 47 -50.

VANDERLIP, R. L., MOCKEL, F. F. & JAN, H., 1973. Evaluation of vigour tests for sorghum seed. *Agron.J.* **65** : 486 - 488.

VENTRE, E. K., 1948. Sucrose, dextrose and levulose content of some domestic varieties of sorgo at different stages of maturity. *J. Agric. Res.* **76** : 145 - 151.

VENTRE, E. K., BYALL, S. & WALTON, C. F. Jr., 1939. Jellying and crystallization of sirups made from different parts of the sorgo stalk at different stages of maturity. *J. Agric. Res.* **59** : 139 - 150.

WALL, J. B., SIEGLINGER, R. & DAVIES, F., 1948. Chemical composition of sorghum plants at various stages of growth, and relation of composition to chinch bug injury. *Okla. Agr. Exp. Stn. Tech. Bull*. T-3. (Cited in Lingle S.E., 1987).

WEBSTER, J. E., BENEFIEL, D. & DAVIES, F., 1953. Yield of sorghum juice in relation to time of harvest. *Agron. J.* 157-160.

WEIBEL, D.E., 1982. Relationships of black layer to sorghum kernel moisture content and maximum kernel weight in the tropics. *Crop Sci.* **22** : 219 – 233.

WILLEY, R. W., & BASIIME, D. R., 1973. Studies on the physiological determinants of grain yield in 5 varieties of sorghum. *J. Agric. Sci*. **81** : 537 548.

WILSON, G. L. & EASTIN, J. D., 1982. The sorghum plant and its environment. These *Proceedings* : ICRISAT.

WILSON, D. O. Jr. & TRAWATHS, S. E., 1991. Physiological maturity and vigour in production of "Florida Staysweet" shrunken 2 sweet corn seed. *Crop Sci.,* **31** : 1640 -1647.

YEKLICH, R. W. & KULIK, M. M., 1979. Evaluation of vigor tests on soybean seeds. Relationship of the standard germination test, seedling vigor classification, seedling length and tetrazolium staining to field performance. Crop Sci. **19** : 247 - 253.

ZANAKIS, G. N., ELLIS, R. H. & SUMMERFIELD, R. J., 1994. Seed quality in relation to seed development and maturation in three genotypes of soyabean (*Glycine max.*). *Exp.Agric.,* **30 :** 139 -156.

ZARTMAN, R. E. & WOYEWODZIC, R. T.,1979. Root distribution patterns of two hybrid grain sorghum under field conditions. *Agron. J.* **71** : 319 – 325.

APPENDIX

TABLE A 2.1 : Sweet sorghum syrup production and composition as affected by the stage of maturity at harvesting (Stokes et al. 1957).

Stage of maturity	Percent Extraction	Percent Sucrose	Percent Purity	Litres of syrup / ton of stalk
Early flowering	57.3	4.70	41.9	50.8
Flowering	57.8	5.64	46.7	62.1
Late Flowering	58.0	6.92	52.7	67.5
Grain early milk	58.5	8.86	60.1	76.5
Late milk	57.5	9.57	63.0	77.9
Dough	57.9	10.28	65.2	80.1
Hard dough	56.8	10.94	67.0	82.4
Ripe	56.2	11.29	68.3	82.8
Post ripe 1 week	55.7	10.64	67.4	78.3
Post ripe 2 weeks	56.1	10.11	66.6	75.6
Post ripe 3 weeks	54.4	9.32	63.6	71.1

TABLE A 2.2 : The effect of stage of maturity of sweet sorghum cane and of delay of milling on the sugar composition of sweet sorghum juice (Jonson et al., 1961)

		% of sugar on a dry matter basis			
Variety	Stage of maturity cane when cut	Time of extraction	Reducing sugars	Sucrose	Total sugars
Brawley	Soft dough	Immediately after cutting	25.5	57.4	82.9
Tracy	"	"	57.9	19.3	77.2
Sart	"	"	25.7	57.9	83.6
Williams	"	"	47.3	41.1	88.4
Honey	"	"	48.2	37.9	86.1
Sugar	"	"	26.9	57.9	84.8
Brawley	soft + 10 days	"	13.2	68.8	81.9
Tracy	"	"	51.0	30.7	81.7
Sart	"	"	45.7	30.5	76.2
Williams	"	"	37.5	35.7	73.2
Honey	"	"	36.9	35.8	72.7
Sugar	"	"	26.3	51.7	78.0
Brawley	soft dough	10 days after cut.	33.9	44.2	78.1

TABLE A2.3 Performance of three Texan varieties and a local variety in a trail at Dalton (Inman-Bamber,1980).

Variety name	**Roma**	**Ramada**	**Rio**	**PNR989**
Yield Components				
Age (months)	5.0	4.6	4.6	4.6
Fibre % stalk	14.2	14.9	15.9	18.6
Dry matter % stalk	27.3	25.5	27.8	21.1
Sucrose % stalk	9.3	6.0	9.0	0.4
ERS % stalk	6.7	2.8	6.7	-
Juice Purity %	71.2	55.6	75.3	16.3
Stalk population ('000/h)	88.0	92.0	80.0	-
Stalk length (m)	2.38	1.74	1.42	2.05
stalk yield (t/ha)	37.0	20.0	14.0	25.0
DM yield (t/ha)	10.0	5.1	3.9	5.3
Sucrose yield (t/ha)	3.4	1.2	1.3	-

Table A3.1 Details of the seedlots of the sixty six different sweet sorghum landraces collected from Botswana.

Code	Production area	Harvesting date	Harvesting Stage	Seed treatment	Seed Storage
A	Mushana	Feb., 1997	Milk	ash	plastic bags
B	Tlokweng	April, 1997	Milk	ash	plastic bags
C	Kgagodi	April, 1996	Dough	ash	plastic bags
D	Gobojango	April, 1997	Milk	ash	plastic bags
E	Maunatlal	March, 1997	Milk	ash	tin
F	Kgagodi	April, 1996	Dough	ash	sack
G	Sefare	April, 1997	Milk	ash	plastic bags
H	Mokgomane	April, 1997	Milk	none	plastic bags
I	Semolale	May, 1997	Milk	ash	sack
J	Shakawe	April, 1996	Milk	none	plastic bag
K	Madinare	March, 1997	Milk	none	plastic bag
L	Machaneng	April, 1997	Milk	none	tree shade
M	Sefare	May, 1997	Dough	none	tree shade
N	Machaneng	May, 1997	Milk	none	floor drying
O	Maunatlala	May,1997	Dough	none	plastic bag
P	Tautsure	April, 1997	Milk	ash	plastic bag
Q	Machaneng	May, 1997	Milk	none	tree shade
R	Gobojango	April, 1997	Milk	ash	seed bag
S	Gobojango	May, 1997	Milk	none	tree shade
T	Madinare	April, 1997	Milk	ash	plastic bag
U	Sefophe	April, 1996	Milk	none	tree shade
V	Sefophe	April, 1996	Milk	ash	seed bag
W	Sefophe	April, 1997	Milk	none	plastic bag
X	Matebeleng	April, 1997	Milk	none	tree shade
Y	Otse	April, 1996	Milk	ash	plastic cont.
Z	Thamaga	May, 1997	Milk	ash	plastic bag
A1	Thamaga	April, 1997	Milk	none	tree shade
B1	Malolwane	April, 1996	Milk	ash	tin
C1	Malolwane	April, 1996	Milk	ash	tin
D1	Iyaiyane	May, 1997	Milk	none	tree shade
E1	Malolwane	April,1996	Milk	ash	plastic bag
F1	Matebeleng	April, 1997	Milk	none	roof drying

Code	Production area	Harvesting date	Harvesting Stage	Seed treatment	Seed Storage
G1	Logaganeng	May, 1997	Milk	none	roof drying
H1	Tutume	May, 1997	Milk	none	roof drying
I1	Zwenshambe	May, 1997	Milk	none	roof drying
J1	Gabane	April, 1996	Milk	ash	plastic bag
K1	Mapoka	May, 1997	Milk	none	roof drying
L1	Siviya	April, 1997	Milk	none	roof drying
M1	Logaganeng	April, 1997	Milk	none	roof drying
N1	Mathubulukwane	May, 1997	Milk	ash	tin
O1	Mmogobane	March, 1997	Milk	none	plastic bag
P1	Mokgomane	April, 1997	Milk	none	plastic bag
Q1	Siviya	April, 1997	Milk	none	roof drying
R1	Tutume	April, 1997	Milk	none	roof drying
S1	Mapoka	May, 1997	Milk	none	roof drying
T1	Sebina	April, 1997	Milk	ash	plastic cont.
U1	Tutume	April, 1997	Milk	none	floor drying
V1	Siviya	April, 1997	Milk	ash	plastic bagg
W1	Siviya	April, 1997	Milk	none	roof drying
X1	Gamagangwa	April, 1997	Milk	ash	plastic bag
Y1	Malolwane	March, 1996	Milk	ash	tin
Z1	Mathubulukwane	April, 1997	Milk	none	tree drying
A11	Moroka	May, 1997	Milk	none	roof drying
B11	Sebina	May, 1997	Milk	none	tree drying
C11	Mokgomane	April, 1997	Milk	none	tree drying
D11	Sebina	May, 1997	Milk	none	tree drying
E11	Tutume	May, 1997	Milk	none	roof drying
F11	Mogomane	April, 1997	Milk	none	tree drying
G11	Mogomane	April, 1997	Milk	ash	sack
H11	Mogomane	April, 1997	Milk	ash	sack
I11	Thutayaseko	April, 1997	Milk	ash	sack
J11	Mmsebele	April, 1997	Milk	none	floor drying
K11	Matebeleng	May, 1997	Milk	none	floor drying
L11	Oodi	April, 1997	Milk	none	floor drying
M11	Moshana	May, 1997	Milk	none	drum drying
N11	Zwenshambe	May, 1997	Milk	none	tree drying
O11	Moroka	April, 1997	Milk	none	floor drying

Code	Production area	Harvesting date	Harvesting Stage	Seed treatment	Seed Storage
P11	Sebina	April, 1996	Milk	none	tree drying.

Table A4.1: Standard germination test for dried untreated seeds and dried prechilled seeds

Grain sorghum			Sweet sorghum	
DAA	Untreated seeds germination (%)	Treated seeds germination (%)	Untreated seeds germination %)	Treated seeds germination (%)
20	12.5	55.5	12.5	12.0
25	13.0	69.5	26.5	48.5
30	17.0	51.5	15.0	26.5
35	29.5	36.5	5.0	55.0
40	21.5	63.5	12.0	71.0
45	21.5	82.0	35.5	99.0
50	25.0	97.5	31.0	98.0
55	26.5	99.0	57.5	98.0
60	69.5	90.0	21.0	98.5
65	37.5	98.5	54.0	93.5
70	61.5	98.0	54.0	98.5
75	80.0	96.0	65.5	80.0
80	76.5	98.0	49.0	84.0

Table A 5.1 Soil Characteristics of the experimental site

South African classification	Suurbekom family ; Hutton form
USDA Soil Taxonomy System	Loamy, mixed, thermic Rhodic Kandiudalf
Clay content	Ap=23%: B21=39%; B22=44%
Silt	14 %
Water holding capacity in the 1.2 m of soil	134 mm
pH in the top 0.2 m soil	6.0
Chemical analysis : P	21 mg kg^{-1}
: K	480 mg kg^{-1}
: Ca	126 mg kg^{-1}
: Mg	255 mg kg^{-1}

Source: Nel *et al*, 1996. Trends in maize grain yields in a long-term fertilizer trial. Field Crops Research. **47** : 53-64.

Table A5.2 Meteorological data for 1996/97 to 1998/99 growing seasons in the Experimental Farm.

RAINFALL (mm)						TEMPERATURE (°C)							
Months	**1996**	**1997**	**1998**	**1999**	**Long Term**	**1996**		**1997**		**1998**		**1999**	
						Min	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Jan		115.4	135.2	269.6	**121.6**			17.0	27.1	16.7	27.4	16.5	27.6
Feb		34.8	120.5	213.8	**92.6**			16.6	28.9	16.7	28.5	16.3	29.3
Mar		327.0	69.4	154.2	**86.1**			15.2	23.5	16.1	28.3	15.8	28.1
Apr		49.7	1.5	72.2	**51.2**			10.1	21.9	12.5	26.8	12.1	25.5
May		103.6	0.0	16.2	**21.7**			6.6	19.2	5.8	21.6	8.5	21.3
June		0.0	0.0	9.7	**8.9**			3.5	19.8	3.5	21.4	4.6	19.9
July	2.3	0.0	0.0		**8.4**	3.4	17.2	4.8	18.7	5.1	20.1		
Aug	3.8	0.0	0.0		**5.9**	6.7	20.3	7.4	22.7	6.6	21.9		
Sep	0.1	41.1	40.7		**20.9**	10.4	25.6	11.8	24.0	11.3	25.3		
Oct	72.8	23.4	50.0		**63.4**	14.3	27.5	12.7	25.4	13.1	24.6		
Nov	60.5	126.6	45.2		**109.3**	14.7	25.8	14.5	26.9	14.8	26.3		
Dec	139.6	98.7	148.4		**116.9**	15.8	26.7	16.0	27.8	15.4	25.5		

Table A6.1 Summary of ANOVA table for effect of deheading and floret removal of sweet sorghum inflorescence on the juice quality (SASA)

Source										
	Stalk Fibre %		Brix %		Purity %		Pol %		Suc %	
	df	F-prob.	df	F-prob.	df	F-prob.	df	F-prob.	df	F-prob.
Treatment	4	0.330	4	0.0030	4	0.0023	4	0.0029	4	0.0159
Rep	3	0.150	3	0.1262	3	0.0451	3	0.0451	3	0.3399
Error	12		12		12		12		12	
Total	19		19		19		19		19	
C.V.(%)		6.393		6.670		5.801		11.568		16.472

Table A7. 1 Summary of ANOVA table for the main effect of planting date and spacing on the juice quality of sweet sorghum (SASA)

Source										
	Stalk Fibre %		Brix %		Purity %		Pol %		Suc %	
	df	F-prob.	df	F-prob.	df	F-prob.	df	F-prob.	df	F-prob.
Treatment										
Spacing	2	0.3489	2	0.7057	2	0.4005	2	0.4560	2	0.2654
Planting date	2	0.0075	2	0.1584	2	0.0001	2	0.0001	2	0.0001
Spa. X Date	4	0.3580	4	0.9760	4	0.7784	4	0.9586	4	0.5846
Rep	2	0.8396	2	0.8332	2	0.0431	2	0.2826	2	0.3105
Error	16		16		16		16		16	
Total	26		26		26		26		26	
C.V.(%)	7.68		8.21		9.49		15.08		20.47	

Table A7.2 Summary of ANOVA table for effect of planting date and spacing on the stem and leaf components of sweet sorghum

Source										
	Stem fresh mass		stem dry mass		moisture content		Stem thickness		No of Tillers	
	df	F-prob.	df	F-prob.	df	F-prob.	df	F-prob.	df	F-prob.
Treatment										
Spacing	2	0.0056	2	0.0001	2	0.0001	2	0.1488	2	0.0015
Planting date	2	0.0174	2	0.0063	2	0.6073	2	0.0240	2	0.0680
Spa. X Date	4	0.6456	4	0.5209	4	0.5255	4	0.6958	4	0.1351
Rep	2	0.6839	2	0.0615	2	0.1906	2	0.8288	2	0.9635
Error	16		16		16		16		16	
Total	26		26		26		26		26	
C.V.(%)	40.762		26.531		2.539		11.042		45.31	

Table A7.3 The main effect of planting date on the stem fresh & dry mass, stem moisture content, number of tillers, plant height and mainstem thickness at boot stage

Treatment	Stem fresh mass per plant (g)	Stem dry mass per plant (g)	Leaf fresh mass per plant (g)	Leaf dry mass per plant (g)	Leaf area per plant (cm)	Mainstem height (cm)	Stem thickness (cm)	Number of tillers per plant
Planting date								
T1	1151.8a	236.0a	290.4a	106.1a	7338.7a	2.9a	3.1a	8.6a
T2	1058.6a	171.0b	186.3b	66.3b	5765.8a	2.3b	2.2b	7.8b
T3	865.1a	139.7b	180.0b	63.7b	5558.1a	2.1b	1.8b	7.8b
Spacing								
S1	1277.7a	233.7a	287.3a	98.6a	7054.3a	2.4a	3.1a	8.4a
S2	980.9a	166.8b	206.1b	76.1ab	5985.6a	2.4a	2.5a	8.2a
S3	816.9a	146.1b	163.3b	61.4b	5122.6a	2.5a	1.5b	7.6b
Mean	1025.2	182.2	218.9	78.7	6054.2	2.4	2.4	8.1
C.V.%	39.2	25.0	23.5	27.3	33.0	7.3	24.6	5.1
LSD	488.3	55.4	62.5	26.1	2433.0	0.2	0.71	0.5

TABLE A7.4 The effect of planting date on the stem fresh and dry mass, leaf fresh and dry mass and leaf area, plant height, stem thickness and number of tillers at panicle initiation stage

Treatment	Stem fresh mass per plant (g)	Stem dry mass per plant (g)	Leaffresh mass per plant (g)	Leaf dry mass per plant (g)	Leaf area per plant (cm)	Mainstem height (cm)	Stem thickness (cm)	Number of tillers per plant
Planting date								
T1	93.9b	6.6b	51.2b	7.8b	1844.7b	1.0b	3.3a	5.6b
T2	98.5b	9.5b	56.4b	10.1b	1507.3b	1.1ab	1.9b	6.6a
T3	212.8a	27.2a	107.3a	21.9a	3586.1a	1.2a	4.4a	6.8a
Spacing								
S1	144.8a	15.8a	65.2a	12.0 a	2032.6 a	1.2a	6.4a	2.0b
S2	130.6a	13.1a	66.4a	11.8 a	2344.8 a	1.1ab	6.2a	3.5a
S3	130.6a	14.3a	83.3a	16.0 a	2560.7 a	1.0ab	6.4a	4.0a
Mean	135.1	14.4	71.6	13.3	2312.7	1.1	6.3	3.2
C.V. %	23.7	24.3	30.7	30.5	29.3	12.3	10.5	35.1
LSD	38.9	4.3	26.8	4.9	824.6	0.2	0.8	1.4

TABLE A8.1 The effects of nitrogen, spacing and landrace treatments on number of leaves, leaf area, leaf dry mass, and mainstem height

Treatment	Number of leaves per plant	Leaf area per plant (cm ²)	Leaf dry mass per plant (g)	Mainstem height (cm)
Nitrogen				
N0	25.8c	5576b	56.0c	317a
N1	30.1ab	7605a	74.0a	307a
N2	26.6bc	6376ab	58.3bc	301a
N3	31.6a	7482a	66.6bc	318a
L.S.D.	4. 3	1515.4	8.95	25.3
Spacing				
S1	23.0b	4791b	45.4b	316a
S2	34.1a	8728a	82.0a	315a
L.S.D	2.3	809.0	4.78	0.11
Landraces				
L1	24.9b	5615b	53.2b	304b
L2	32.2a	7905a	74.2a 4.8	327a
L.S.D	2. 3 15.97	809	14.9	0.11
C.V.%		23.8		6.8

+ Means followed by different letters are significantly different at the 5% level by Tukey's Multiple Range Test.

Treatments: N0 = Control (zero nitrogen), N1 = 60kgN/ha (early application), N2 =120kgN/ha (early application), N3 = 60 kg N/ha (late application), S1 = 15 cm, S2 = 30 cm, L1= early maturing landrace, L2 = late maturing landrace

TABLE A8. 2 Interaction between nitrogen H spacing on stem fresh mass, stem dry mass and pol%

Attributes	Stem fresh mass per plant (g)		Stemdry mass per plant (g)		Pol %		Leaf area per plant cm²		Leaf dry mass per plant (g)	
Spacing	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
Nitrogen										
N0	1018.2	1853.2	256.5	433.8	4.3	6.2	4256	6896	40.5	71.6
N1	1178.8	2326.8	295.2	563.1	6.8	6.9	4739	10470	46.7	101.1
N2	1276.9	1790.7	312.0	430.9	5.6	6.6	5303	7449	48.4	68.2
N3	1199.2	2023.4	294.5	497.2	6.6	7.0	4867	10097	46.0	87.2
	**	**	**	**	**	**	**	**	**	**

**** significant at 0.01%**

TABLE A8. 3 Interaction between nitrogen H landrace on pol % and juice purity %

Attributes	Pol %		Purity %	
Landraces	L1	L2	L1	L2
Nitrogen				
N0	5.1	5.4	39.3	36.4
N1	6.4	7.6	55.1	42.7
N2	4.7	7.3	51.7	33.0
N3	5.9	7.5	51.1	40.0
	**	**	**	**

**** significant at 0.01%**

TABLE A 8. 4 Interaction between landrace H Spacing on leaf area, leaf dry mass and number of leaves

Treatment	leaf area per plant (cm ²)		leaf dry mass per plant (g)		number of leaves per plant	
Spacing	S1	S2	S1	S2	S1	S2
Landraces						
L1	4129.58	7099.87	37.71	68.66	20.88	29.00
L2	5452.79	10356.34	53.05	95.39	25.19	39.13
	**	**	**	**	**	**

**** significant at 001%**

TABLE A8. 5 Interaction between nitrogen H landrace H spacing on sucrose, brix dry mass, leaf dry mass, and number of leaves on final harvest

Treatments				
Nitrogen	Landraces	Spacing	Leaf dry mass per plant (g)	No of leaves per plant
N0	L1	S1	36.5	19.8
N0	L1	S2	50.1	23.5
N0	L2	S1	44.5	22.0
N0	L2	S2	93.1	38.0
N1	L1	S1	41.7	23.3
N1	L1	S2	79.3	28.8
N1	L2	S1	51.8	23.5
N1	L2	S2	122.9	45.0
N2	L1	S1	37.4	20.8
N2	L1	S2	64.3	28.5
N2	L2	S1	59.4	26.8
N2	L2	S2	72.0	30.5
N3	L1	S1	35.3	19.8
N3	L1	S2	80.9	35.3

Treatments				
N3	L2	S1	56.6	28.5
N3	L2	S2	93.5	43.5
			**	**

** significant at 0.01%

Table A8.6 Summary of ANOVA table for effect of planting date and spacing on the stem and juice components of sweet sorghum

Source								
	Stem fresh mass		Stem dry mass	Number of tillers	Stem fibre	Pol %	Brix %	Purity %
	df	Prob.	F-prob.	F-prob.	F-prob.	F-prob.	F-prop.	F-prob.
Treatment								
Nitrogen	3	0.0551	0.0160	0.1206	0.0011	0.0001	0.1002	0.0001
Landrace	1	0.0001	0.0001	1.0000	0.0001	0.0001	0.0001	0.0001
Spacing	1	0.0001	0.0001	0.0001	0.0748	0.0001	0.0021	0.0001
Rep	3	0.5564	0.2429	0.0560	0.7034	0.1794	0.4902	0.1097
N x LR	3	0.2528	0.4459	0.1462	0.2276	0.0001	0.0260	0.0016
N x SP	3	00675	0.0479	0.0933	0.2245	0.0056	0.7928	0.2008
LR x SP	1	0.2809	0.1760	1.0000	0.9888	0.3230	0.8032	0.6091
N x LR x SP	3	0.0010	0.0395	0.1131	0.5507	0.0023	0.9170	0.2342
Error	45							
Total	63							
C. V. (%)	20.481		18.989	26.893	8.896	11.274	5.322	12.676