

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 the 1995/96 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 annum*; Demir & Ellis, 1992); tomato (*Lycopersicon esculentum* Mill.; Demir and Ellis, 1992) barley (*Hordeum vulgare* L.; Filho & Ellis, 1992a), barley and wheat (*Hordeum vulgare* 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 (GI) 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.

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

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

$$\text{formula: Seed mass at 0\% MC} = \frac{(100 - \text{MC})}{100} \times \text{mass of 50 seeds}$$

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 cm³ 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 to 14% 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 cm³ capacity were filled with 250 cm³ 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 $\mu\text{S cm}^{-1} \text{ g seed}^{-1}$ (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.

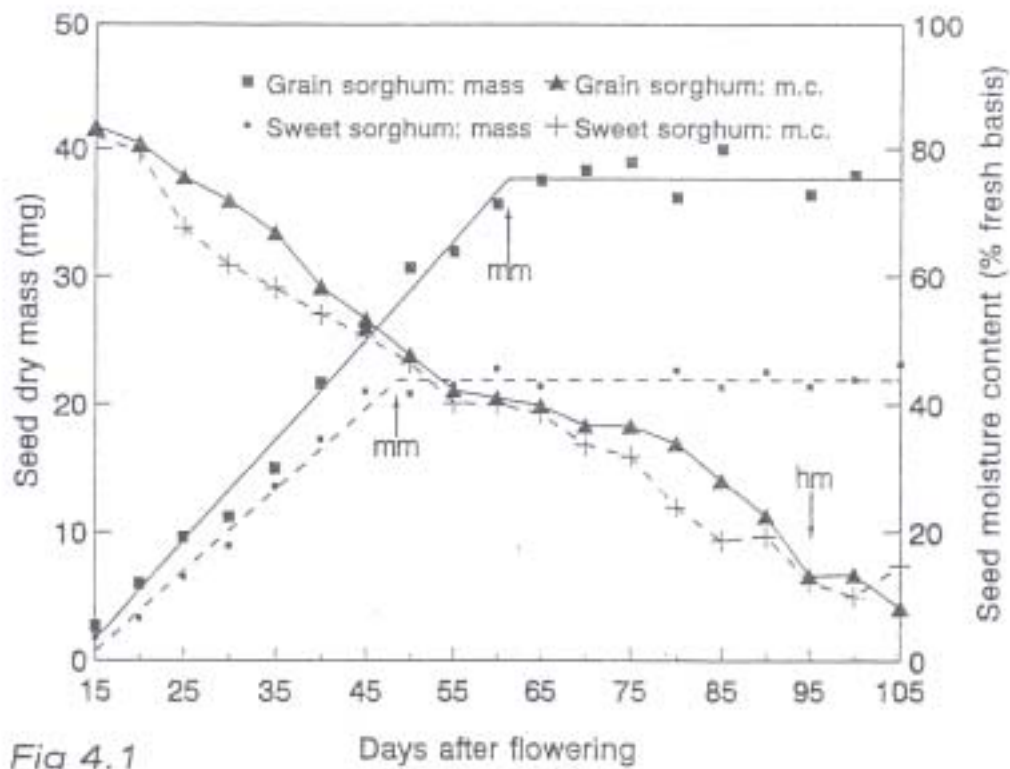


Fig 4.1

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)

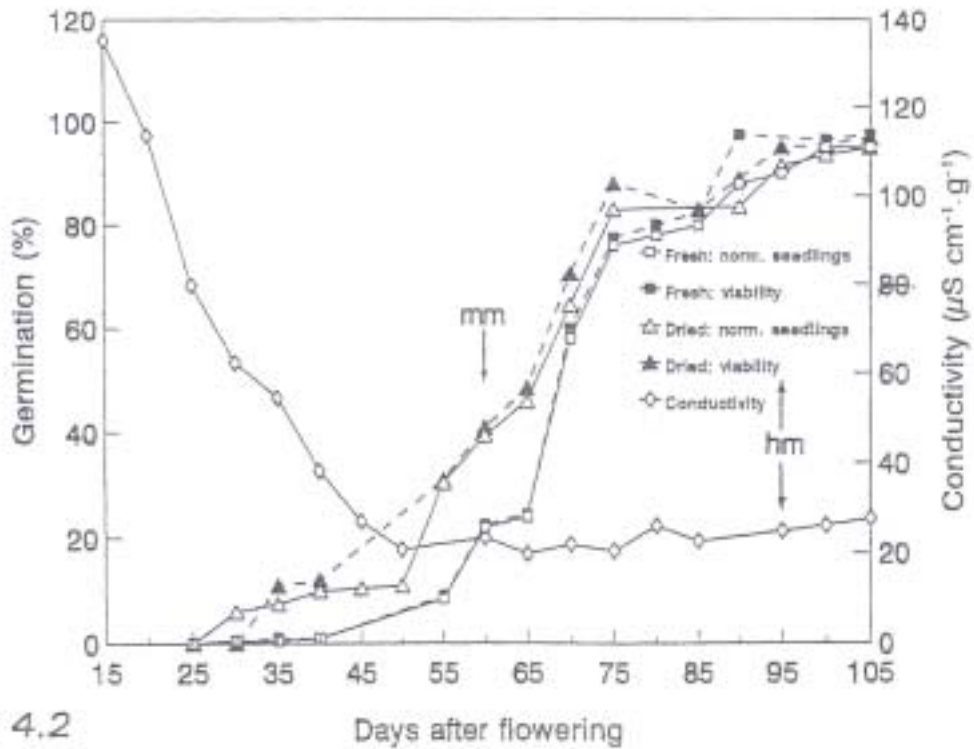


Fig 4.2

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)

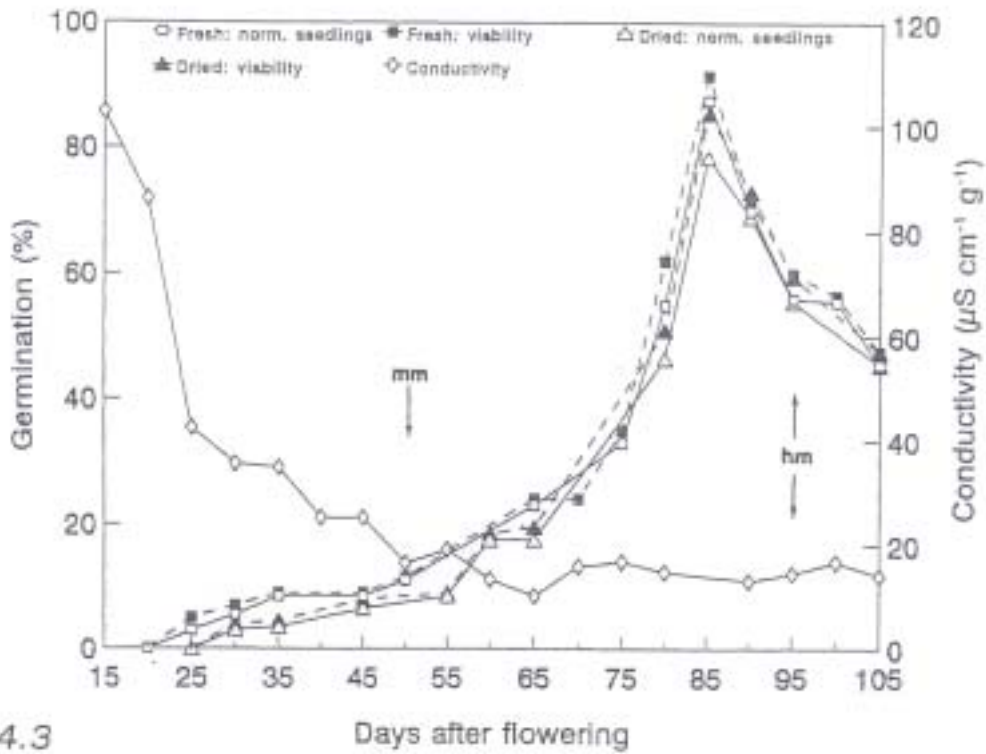


Fig 4.3

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)

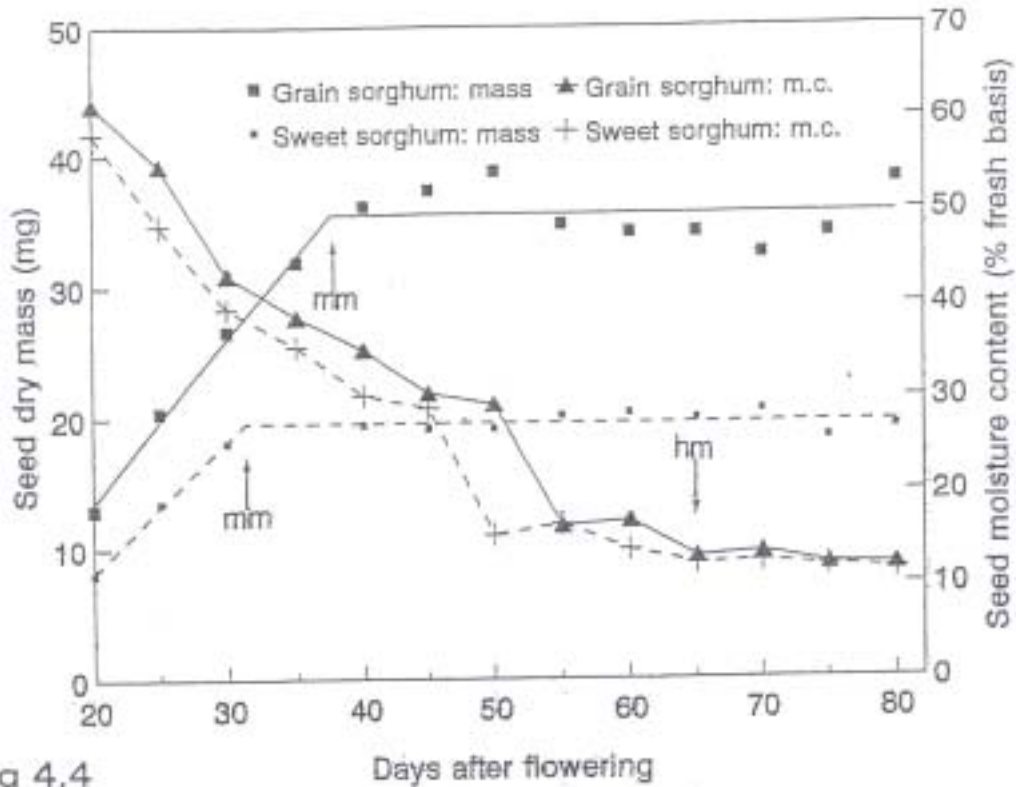


Fig 4.4

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)

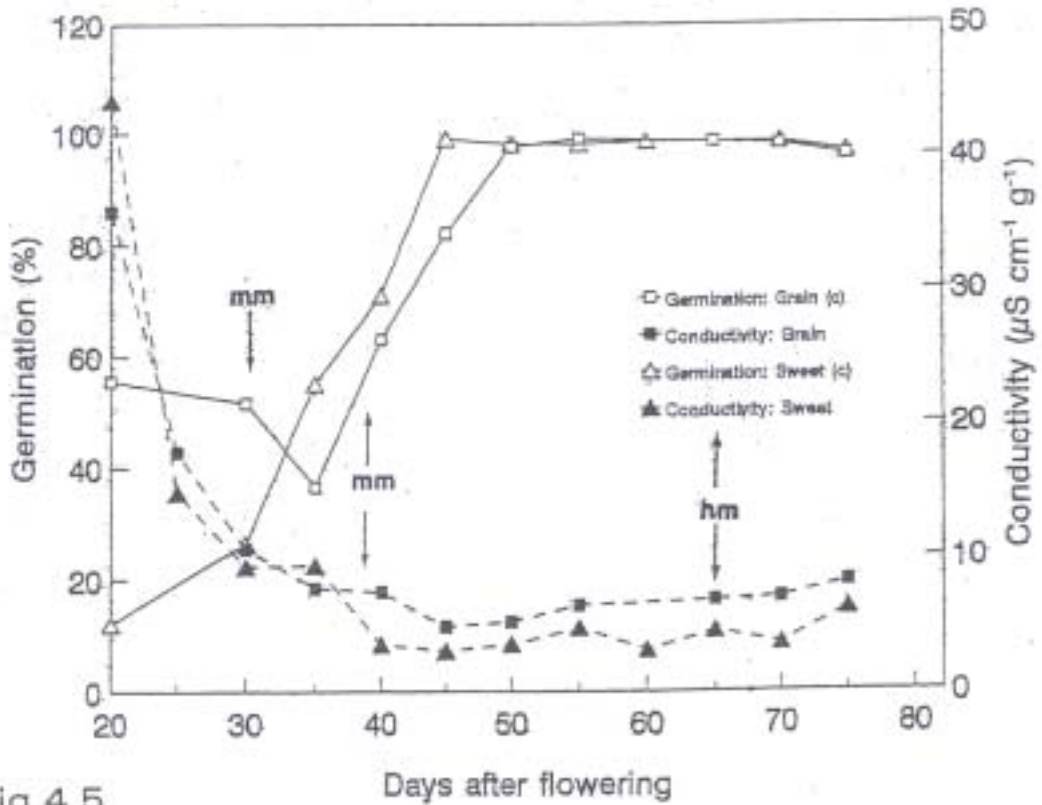


Fig 4.5

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 glaucum*, (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.