EVALUATION OF EXOTIC SORGHUM GERMPLASM LINES FOR YIELD AND ADAPTATION IN THE SEMI-ARID REGION OF LIMPOPO PROVINCE (MANKWENG), SOUTH AFRICA

by

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DISSERTATION

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DECLARATION

I KgasagoM.M, declare that the dissertation submitted to the University of Limpopo, for the degree of Master of Agricultural Management (Plant production) has not been previously submitted by me for a degree at this or any other university; that it is my work in design and in execution that all material contained herein has been duly acknowledged.

Kgasago M.M (Ms)	**11/04/2023**
Surname, Initials (title)	**date**

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ABBREVIATIONS

SSA: Sub-Suharan Africa

SA: South Africa

DAFF: Department of Agriculture Forestry and Fisheries

NPGS: National Plant Gemplasm System

ICRISAT: International Crops Research Institute for the Semi-Arid Tropics

OPV: Open Pollinated Varieties

BLS: Bacterial Leaf Streak

RLN: Root lesion Nematodes

ARC-GC: Agricultural Research Council for Grain Crops

AOAC: Association of Official Analytic Chemists

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ABSTRACT

Sorghum (*Sorghum bicolor (L*.) is a grass that is grown for its grain, and is an essential crop, which can be used as a staple food for humans and livestock. It can adapt to drought, salinity, and high temperatures which makes it best suited for future climate change. Sub-Saharan Africa (SSA) is facing a challenge of food insecurity and drought, and sorghum is one of the cereal crops in SSA's food value chain, and effective production, especially by smallholder farmers, will reduce these problems. Sorghum is regarded as a stable crop across the African continent and it is rich in nutrients. 13 exotic sorghum germplasm for evaluation for adaptation and yield in South Africa were introduced to reduce food insecurity with nutritious sorghum. The experiment was conducted at the University of Limpopo farm (Syferkuil), and was laid down in an incomplete block design with three replications and 17 varieties of exotic sorghum germplasm, which were planted in two seasons, 2021 and 2022, to check the adaptation, yield, and nutrient content of the varieties and these were compared with the check line from South Africa (Pan 606). The results show that some of these varieties performed better than the check line. There was a significant difference ($P<0.05$) obtained among varieties in both 2021 and 2022 for 200 seed weight, and the test lines (Fara Kano, ICSG1780727) performed better than the check line in both seasons. Again, there was a significant difference ($P<0.05$) obtained among the varieties in calcium and sodium. ICSG 1780724 and Yarlabe performed above the control in the concentration of sodium while the performance of all the test lines was above the check line on the concentration of calcium. The varieties, which performed better than the check line, can be used by breeders to improve the different traits and be released for smallholder farmers' cultivation

KEY WORDS: Sorghum, germplasm, adaptation, yield sub – Saharan Africa, climate change adaptation, food security,

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GENERAL INTRODUCTION

1.1. BACKGROUND

Sorghum (*Sorghum bicolor (L*.) is a grass that has been grown for its grain and is originally from North Africa (Doggett, 1953). It consists of the primary and secondary root system, with flat grass-like green leaves which are not as broad as those of maize, they have solid dry to succulent and sweet stems with open or compacted panicles (DAFF, 2010). In terms of the world's production, it is the fourth cereal and fifth in terms of acreage cultivated. The world produces over 60 million tons of sorghum per annum and 20 million tonnes are produced in Africa, of which 70% is produced by Nigeria, Sudan, Ethiopia, and Burkina Faso (Taylor, 2003). In South Africa (SA), sorghum ranks third after maize and wheat and is mostly cultivated for human consumption (Mofokeng & Shargie, 2016). The crop is genetically suited for hot, dry agro-ecologies where it is not easy to grow other food grains. In the semi-arid tropics, it is a staple food for millions of poor people and is produced for both domestic and export markets (Srinivasa *et al*., 2015). The production by smallholder farmers is unknown as they consume their production. Sorghum is produced in Free State, Mpumalanga, Northwest, Limpopo, and Gauteng. Free State produces over 300 000 tons on 150 000 hectares (ha) (DAFF, 2010). Sorghum is an essential crop, which can be used as a staple food for humans and livestock. It can adapt to drought, salinity, and high temperatures which makes it best suited for future climate change. James (2019) explains exotic germplasm as the crop cultivars which are not adapted to the environment that the breeder is targeting to obtain some useful traits. Several countries have developed breeding programmes with collections of exotic sorghum germplasm as their resources. The Agriculture Research Service National Plant Germplasm System (NPGS) maintains the largest sorghum collection worldwide consisting of about 41 860 samples. The International Crops Research Institute for the

Semi-Arid Tropics (ICRISAT) in India has 7 904 samples and China has about 16 000 (Cuevas *et al*., 2017).

1.2. PROBLEM STATEMENT

Water stress and food insecurity are the challenges faced by Sub-Saharan Africa (SSA) and these challenges are already growing. If crops, such as sorghum, are promoted in the arid and semi-arid areas of SSA it will improve crop water use and consequently improve productivity and food security due to its drought and heat tolerance, high and stable water use efficiency, high germplasm, and a comparative nutritional value (Hadebe *et al.*, 2017). In most cases, exotic cultivated sorghum is used for genetic improvement of grain yield potential (Cox *et al.,* 1984). The breeding programme of sorghum varieties is limited to Pannar Seed (Pty) Ltd in SA and they produce hybrid seeds for commercial farmers with the financial capability and bigger space to plant every year. Smallholder farmers are limited in their production of sorghum as they need open pollination varieties or multiline which are more adaptable to biotic and abiotic stresses. Unfortunately, such varieties are not available for farmers to cultivate. Personal communications between Asiwe and Borlong indicates that the National Research Institute hardly ever gives out their germplasm. They protect their intellectual property and Ahmed *et al*. (2000) also report that private sector producing seed in South Africa do not show an interest in selling open-pollinated varieties (OPVs) to small-scale farmers because it is not a profitable venture for them. Therefore, this study was aimed at introducing high-yielding OPVs and drought-resistant sorghum varieties that are available in different parts of the world for screening against adaptation and yield potential and nutrients in South Africa. Smallholder farmers will be able to afford these varieties if found promising and well-adapted. Baiphethi & Jacobs (2010) report that smallholder farmers can contribute to the reduction of food insecurity in both rural and urban areas and this can be done if their productivity is significantly increased for that reason. There is a need to come up with strategies that will ensure their enhanced productivity. The introduction of diverse world germplasm lines is one of these strategies.

1.3. RATIONALE

According to James (2019), exotic germplasm is defined as a crop variety that is not adapted to the environment that the breeder has targeted, however it is an essential source for improving the crop because of genetic diversity within elite cultivars. Furthermore, a crop is limited compared to the variability within the species and its relatives worldwide. Crops can be protected against new biotic or abiotic stresses using genes from exotic germplasm, for example, introducing a gene of exotic germplasm that has pathogen resistance can help to protect elite varieties from vulnerability (James, 2019). Different races of sorghum germplasm have been used in India and the world, and yield has increased by about 50% in India and worldwide. However, the usage of a narrow genetic base in the breeding programmes has resulted in the yield becoming stagnated (Aruna & Audilaskshmi, 2008). Introducing high-yielding open-pollinated sorghum varieties with good agronomic traits from different parts of the world for screening in South Africa will increase the productivity of smallholder farmers. The study will help in introducing new high-yielding and drought tolerant varieties. Such varieties will be affordable to smallholder farmers and will increase sorghum production in the region which will invariably lead to increased food security in rural areas. According to Hadebe *et al*. (2017) sorghum is one of the cereal crops in SSA’s food value chain and effective production, especially by smallholder farmers, will reduce food insecurity.

1.4. AIM AND OBJECTIVES OF THE STUDY

1.4.1. Aim

Evaluation of exotic sorghum germplasm performance in the semi-arid region of Limpopo province Mankweng for food security and nutrition in South Africa.

1.4.2. Objectives

The objectives of the study are to:

- Evaluate the performance of 17 exotic sorghum germplasm varieties obtained from the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) for grain yield and adaptation in the semi-arid region of Limpopo province (Mankweng), South Africa.
- Determine the nutrient contents of the 17 exotic sorghum germplasm varieties.

1.5. HYPOTHESIS

- The performance of 17 exotic sorghum germplasm lines for grain yield and adaptation in Limpopo Province (Mankweng), South Africa do not differ.
- The nutrient contents of 17 exotic sorghum germplasm lines do not differ.

LITERATURE REVIEW

1.6. INTRODUCTION

To improve food security, it is important to understand the dynamics of food production, particularly in areas where they rely on subsistence agriculture with little climate change adaptive capacity (Mundia *et al*., 2019). Therefore, due to sorghum's tolerance to drought and the fact that it can do well in a wide range of soils, it has the potential to alleviate severe food insecurity (Mwadalu & Mwangi, 2013). Various improved varieties have been developed and released to the farmers but the farmers still gain the same level of yields. In the last 20 years, the average yield has remained the same, so developing high yielding and adapted varieties is one of the strategies that can be used to resolve the shortage of cereal grain (Kengaa *et al.,* 2004). Early maturing, drought tolerance and high yielding have been identified by farmers as the essential properties of varieties that are improved and there is a lack of these improved varieties (Anandajayasekaram *et al.*, 2007). It is said that germplasm collections provide genetic variation for crop improvement programmes (Cuevas *et al*., 2017). Farmers do not need food security only but they also need income for the growth of social-economic well-being and this can be done by linking small-scale farmers to the market, so the use of good seeds for production is required. Therefore increasing the production of sorghum OPVs as it has a good impact on the national food security and the development of the economy may be a good start (Mulwe & Ajayi, 2020).

1.7. ADAPTIVE TRAITS

1.7.1. Plant morphology and growth stages

1.7.1.1. Plant morphology

Sorghum belongs to the grass family *Poaceae*, their root system is divided into primary and secondary root systems. The root system is finer and branches almost twice as much as maize roots. The primary root system, which appears when the seed germinates, helps the seedling to absorb water and nutrients (Berenji *et al*., 2011). Sorghum has flat grass-like green leaves, which are not broad like the ones of maize and they are covered with a wax layer, they are opposite one another on both sides of the stem and they can number from 8 to 22 depending on the environmental conditions (DAFF, 2010).

1.7.1.2. Growth stages

According to Rao *et al.* (2008) sorghum consists of nine growth stages (emergence, 3-leaf stage, 5-leaf stage, final leaf, booting, flowering, soft dough, hard dough, and physiological maturity. From emergence, to booting at these stages the plant can endure environmental and pest stresses, because new leaves are growing and replacing the ones which are damaged. At this point, yield is not affected unlike from panicle initiation to physiological maturity, where any stress can reduce panicle size and the potential number of kernels per head (Bean, 2019). It takes 3-10 days for emergence, but under warm temperatures, good seed vigour, sufficient soil moisture, and normal sowing depth it takes 3 days to emerge and for the shoot emerged from the seed to push through the surface of the soil (Moore *et al.*, 2014). At the booting stage the plant has its maximum leaf area and 60% of the plant's total dry matter is accumulated, the development of the panicle is completed and is ready for flowering. If drought is experienced at this stage panicles may be prevented from booting, resulting in incomplete flowering, seed set, and loss of grain yield (Moore *et al.*, 2014). At the soft dough stage 75% of grain dry matter has been accumulated, grain cannot be compressed between the fingers, and if there are plant diseases, such as charcoal rot, or pests such as stalk borer, these may result in plants lodging (Gerik *et a*l., 2003). Physiological maturity is reached when a black layer occurs on top of the point of the kernel attachment in the floret next to the kernel's base, there is 30-35% seed moisture, and grains can be harvested without mechanical damage as the kernel has reached its potential weight (Kelley, 2008).

1.7.2. Crop growth requirements

Sorghum is a warm short cycle annual, unlike most cereal crops; and it can withstand higher temperatures. The required temperatures after germination are from 24C to 27C, temperatures below freezing limit the growth of sorghum resulting in many plants dying. The average required annual rainfall is between 350-700mm. The ideal moisture for sorghum is 25-50% of the field capacity. Sorghum can be grown in shallow to medium deep or light to medium textured soil which has a high water holding capacity and is tolerant to wet soils making it able to survive flooding (Mondia *et al.,* 2019). Warm, moist soils are ideal for germination and emergence, cool wet soil is favourable for disease to develop and if you cannot avoid cool, wet soils it is necessary to treat seed with fungicides and plant shallow (Gerik *et al.*, 2003). Sorghum requires short days and long nights before going on to the reproductive stage, flower formation is induced by a day length of 10-11 hours longer then vegetative growth will be stimulated as the plants are sensitive to longer day lengths during flower initiation (Ajeigbe *et al.*, 2020).

1.8. IMPORTANCE AND USES

Sorghum is used in different industries, food as healthy food, feed as feedstock, brewing for malt and beer, and energy as bio-fuel (Mulwe & Ajayi, 2020). The grains are used for different food products such as rice, maize, ground into flour, porridge, and cereals, and can be used to make both alcoholic and non-alcoholic beverages (Australian Government Department of Health, 2017). Sorghum grain foods have recently become more popular for having the potential health benefits against over-nutrition related chronic diseases and there have been indications by epidemiological evidence and studies of animals that a diet consisting of sorghum boosts cardiovascular health better than other cereals, and it can also be beneficial for weight control (Kang *et al.*, 2016). Reports indicate that 51% of sorghum crops are used to feed livestock and 49% are used for human consumption and other uses (Etuk *et al.*, 2012).

1.9. TYPES OF SORGHUM

1.9.1. Hybrid

Siyal (2019) defines hybrid seed production as seeds that are produced by crossing two parents which are genetically different. This is done by crossing pollen from the male parent with the female parent (seed parent) and the seed which will be produced through the process of hybridization, and these seeds when planted produce homogeneous F1 plants with the same characteristics but when the seeds are planted for the next generation, they begin to segregate. According to Vizcayno (2014), small scale farmers rely on the recycling of seeds for the next planting season since they cannot afford the cost of purchasing hybrid seeds yearly.

1.9.2. Open pollinated

In OPVs, pollination is carried out among multiline varieties by natural mechanism, and seeds produced become heterozygous for many generations, meaning seeds can be saved and planted the next season. (Vizcayno, 2014). There is some genetic variation in OPVs and these variations help in reducing the spread of diseases unlike when the plants in the field are genetically identical (Shargie, 2015). Open-pollinated seed may be used for a period of three seasons because if it is used more than then there is the risk of contamination by pollen from fields that are nearby and variety deterioration. Fields of OPV need to be isolated in either space or time, and with space, it can be with a distance of about 250-350m while with time it can be by different sowing times (Setimela *et al.*, 2006). In the scientific trials which were done, an increase in the yield of OPV can be seen where there was good management even though there are lower than those of hybrid varieties (Kutka, 2011). In Zambia, there was an increase from 0.557 tons/ha to 0.904 tons/ha of sorghum production since improved high-yielding OPVs were used and if the farmer manages the varieties well they have the potential to produce about 4.5 tons/ha (Mulwe & Ajayi, 2020).

1.10. FACTORS AFFECTING SORGHUM PRODUCTION

1.10.1. Biotic factors

1.10.1.1. Birds

The production of sorghum is limited by damages caused by birds. Bird species known to consume sorghum include sparrow (*Passer domesticus*), parrot, pigeon (*Columba livia*), and Quelea quelea, these birds provoke lodging, pecking seeds, and sucking immature seeds' juice and prevent full development of grains causing diseases, such as mildew around the panicles (Xie, *et al*., 2019). During the time of seed development when it is at the milk stage, the birds crush the juices from the seeds, afterward the seeds harden then removed and swallowed (Tipton *et al.*, 1970). During the period of hard dough to maturity, birds can perch on panicles and eat the seeds whole or break the seeds by eating a portion of the seed and leaving the other portion on the panicle, causing about 48-70% damage (Buntin, 2012).

1.10.1.2. Insects

According to Guo *et al.* (2011), about 150 insect species damaging sorghum were reported worldwide, and the estimated loss caused by these pests is above US$ 1000 million annually. Major pests worldwide are sorghum shoot fly (*Atherigona toccata*), stem borers (*Chilo partellus, Busseola fusca,* and *Diatraea spp*), Sorghum Midge (*Stenodiplosis sorghicola*), and head bugs (*Calocoris angustatus* and *Eurystylus oldi*) (Sharma *et al*., 2003). Sorghum panicle pests are most important as they can result in the total loss of yield. Examples of panicle pests, are cotton bollworm (*Helicoverpa armigera*) and yellow peach moth (*Dichocrocis punctiferalis*). Greenbugs suck juice from plant tissue, injecting saliva which is toxic and can result in the plant dying, while leaf aphids suck sap from the upper leaves and the leaves of plants that are infested are covered with honeydew which reduces photosynthesis, so the plant may wilt and die (Hong *et al.,* 2008). Sorghum midge is said to be one of the worst pests in the whole world, adults lay eggs on the flowering spikelets, and when the larvae hatch they feed on the seeds that are developing resulting in poor grain development which leads to empty grain. It can damage 10-15% of the sorghum crop and the whole crop in susceptible varieties. Early planting them and having uniform growth development of the crop are some of the ways to control it (Boa *et al.*, 2015). The larva of the sorghum Shoot fly feed on the central leaf which will later wilt and dry up and leave the dead heart symptom characteristic, one week to one month after the sorghum emerges is when the damage occurs. Therefore if the pests attack later it means that the tillers produced by the plant will be affected. Planting late in the rainy season will increase the chances of attack (Ajeigbe *et al.,* 2020).

1.10.1.3. Diseases

Sorghum is attacked by many diseases during its growth in the field. The diseases include the following:

1.10.1.3.1 Fungal diseases

Fungal diseases are some of the factors that limit yield and yield quality in cereal crops causing losses of up to 20% and up to 50% if they occur in large numbers. Simplified tillage, monoculture, high nitrogen fertilisation, and weather conditions throughout the growing season are some of the main factors that influence the occurrence of fungal disease. No-tillage results in increased stem base and root rot diseases (Rozewics *et al.*, 2021). Fusarium grain mould is caused by *Fusarium spp,* the disease's infection severity differs according to growth stage. The species of Fusarium grain mould produces pinkish white mycelium in the early stages which later turns pinkish fluffy and fluffy white (Das *et al.*, 2011). Turcicum leaf blight is caused by *Exserohilum turcicum Setosphaeria* which is an old disease affecting both sorghum and maize and it results in up to 50% grain and fodder yield loss in various tropical conditions and particularly in varieties that are susceptible (Beshir *et al.,* 2012). Yield is mostly lost in susceptible varieties especially if the disease occurs before flowering (Graven, 2016). Different micro-organisms cause grain mould which affects the grains within the ear resulting in different losses, such as grain yield reduction, the quality of processing, and market value. It sometimes induces premature sprouting of grain in the panicles (Desai *et al.*, 2021).

1.10.1.3.2 Bacterial diseases

Bacterial Leaf Streak (BLS) is caused by the bacterium *Xanthomonas vasicola pv*, which can occur at any growth stage, and grain sorghum and related species are more susceptible (Sivits *et al.*, 2018). Stalk rot of sorghum caused by *Erwinia chrysanthemi* is one of the damaging diseases that affects sorghum with symptoms such as water-soaked stems, which will turn a reddish dark brown colour later and can result in up to 60% yield loss, especially in susceptible varieties (Singh *et al.*, 2017).

1.10.1.3.3 Viral diseases

In most cases, crops affected by viral diseases may not be recognised until they become dominant, with different types of symptoms. To detect and identify viral infections different methods can be used including mechanical or vector transmission to identify hosts, the observation of virus particles using the electron microscope, or detection with the use of virus-specific antibodies. It may require experience and skill to be able to identify the viral infections (Geering & Randles, 2012). Plant viruses can cause serious damage to crops but their economic losses are not like the losses caused by other pathogens and can be up to 98% in most subtropical and subtropical regions. Plant viruses can cause severe damage during crop growth stages, although damage caused during harvesting, storage and transportation are not severe (Nazarov *et al.*, 2020). Maize Stripe Viral Disease is caused by plant hopper (*Peregrinus maidis*), the disease infects plants systemically causing stunting. If the infection occurs at the stage of panicle initiation, plants will either produce no panicles or if panicles are produced fewer seeds will set (Pandea *et al*., 2003). The disease is transmitted by the white fly *Bemisia tabaci* and the symptoms first appear in the form of yellow diffused spots scattered on leaf lamina and the entire lamina turns bright yellow in the later stages (Naidu & Nirula, 2012).

1.10.1.3.4 Weeds

Weeds reduce crop yields as they compete with crops for moisture, nutrients, space, and light, and they can also be the host for pests and diseases that infest crops (Ball *et al.,* 2019). When weeds are controlled at critical growth stages this can lead to better crop growth and development of the crop which may result in higher yields (Verma *et al.*, 2017). The parasitic weed *Striga hermonthica* is sorghum's key constraint, it depends on the host plant for carbon when it is below the surface of the soil and results in severe damage when the nutrients and moisture are not enough, causing 80-100% grain loss in field of susceptible varieties that are heavily infected (Werkissa, 2022). Witchweed leaves are bright green and the height of the stems is 30-100cm their flowers are bright and their roots are poorly developed. Their seeds are very small, remaining viable in the soil for years and every plant produces hundreds of thousands of seeds (Boa *et al.*, 2015). There are no varieties that are completely resistant to Striga but some improved varieties are slightly resistant, if the weeds can be removed before flowering and rotated with cotton, groundnut, cowpea, and pigeon pea, the occurrence of this weed in sorghum fields can be reduced (Ajeigbe *et al.*, 2020).

1.10.1.3.5 Nematodes

Globally, crop production plant parasitic nematodes cause great yield losses and in South Africa, root-knot nematodes, *Meloidogyne incognita*, and *M. javanica* are said to be the pests affecting most crops and weeds (Ntidi, 2018). Root-knot causes major losses in crops, particularly those grown under polyhouse conditions, and can result in up to 30 % losses, especially in susceptible crops (Kshitiz & Dubey, 2021). Root-lesion nematodes (RLN*, Pratylenchus spp*.) are worm-like animals that cannot be seen with the naked eye, which extracts nutrients from the plant and causes loss of yield even though the plant has water and nutrients. Plants can be resistant or susceptible to nematodes depending on the species, sorghum is resistant to *P. thornei* but susceptible to *P. neglectus*. Crops which are resistant grow well in the presence of large populations (Daniel, 2013). The damage caused by root-lesion nematode can either be minor or severe, causing moisture stress resulting in stunting and wilting plants, especially when it's hot. The symptoms may look like the ones caused by other diseases and disorders above ground (Jackson-Ziems, 2016).

1.10.2. Abiotic factors

1.10.2.1. Drought and temperature

Sorghum can adapt and be grown in various environments. Heat, salinity, drought, and flooding including water stress at the pre- and post-flowering development stage, can affect the crop. Water stress after flowering reduces 36-55% of the size and the number of seeds per plant resulting in lower grain yield (Kapanigowda *et al*., 2013). If high soil temperature and low moisture are experienced during the grain filing stage, the crop will be affected by Charcoal rot which is caused by *Macrophonia phaseolina* which favours high soil temperatures and low moisture. During grain development, if the crop experiences drought, high soil temperatures, and wet cool conditions towards physiological maturity, the crop will be affected by Fusarium stalk rot (Tesso *et al*., 2012). Drought and high temperatures enhance the occurrence of insects that eat plants, which can result in stresses caused by insect attacks and diseases resulting from insect feeding (Hong *et al*., 2008). To ensure survival, sorghum has physiological ways to ensure that it adjusts to make sure that it continues reproducing and surviving, either by drought avoidance where they preserve water at the level of the whole plant by reducing water loss from the shoot by extraction of more water from the soil or to escape drought by completing the life cycle before the dry period starts (Kidanemaryam, 2019).

MATERIALS AND METHODS

1.11. ACHIEVING OBJECTIVE 1

1.11.1. Study area

The research was conducted at the University of Limpopo experimental farm (Syferkuil, 23°"50' S; 29°"40'E). The climate of the study area is classified as semi-arid, the rainfall occurs in summer and they receive average of 500 mm per annum (Moshia *et al*., 2008). The type of soil at Syferkuil farm is said to be sandy loam. According to Mpangane *et al*. (2004), the average annual temperature ranges from 10°C to 30°C.

1.11.2. Experimental design, procedures and crop management

The experiment was laid out in an incomplete block design with three replications, and seventeen varieties of sorghum were planted in two rows with each row being 1m apart and 0.30m between the plants. Thirteen planted and of the thirteen varieties, we have four which are from South Africa (DLF 236G, Pan 8816, Mr. Buster, and Pan 606), from the four, Pan 606 was used as the check line and test line (Fara Kano, ICSG1780485, ICSG1780724, ICSG1780727, ICSG1780793, Jawa, SW Makarfi, Yarlabe, and ZVS3). The first season (2021) was planted on the 09/12/2020 and the second season on 07/12/2021. Three/four seeds were planted, and three weeks after planting, they were thinned to two seedlings. Fertiliser (NPK fertiliser) was applied at 50kg/ha four weeks after planting and the second application of NPK was done 10 weeks after planting. Eight weeks after planting cypermethrin was applied to control stalk borer and applied again 10 weeks after planting at the rate of 1litre/ha. Weeds were controlled manually using a hand hoe. Sprinkler irrigation was used to apply water at planting to enhance the establishment of the seedlings.

1.11.3. Data collection

1.11.3.1. Growth parameters

Days to 50% flowering were recorded when 50% of plants had developed panicles. Days to 90% maturity were recorded when about 90% of the plants' panicles in each plot had changed colour and started to dry. Girth of the plant was measured using a vernier calliper after plants had reached 100% flowering. Plant height was measured after flowering (from the ground to the tip of the panicle) using a meter ruler. The type or shape of the panicles was recorded when plants had panicles, the colour of the seeds was recorded by looking at the colour at harvest, and the panicle length, circumference, and width were recorded at maturity by measuring the plants with a measuring tape when plants reached 90% maturity.

1.11.3.2. Yield parameters

When panicles were matured and dry, a pruning shear was used to cut the panicles and bagged into 25kg bags and taken to the University of Limpopo plant production lab. The weight of the panicles was recorded after harvesting by weighing the panicles and then dividing by the number of panicles harvested to get a weight per panicle and the number of panicles per plant was counted at harvest. The weight of panicles per plant was measured using an electronic weighing balance (Adam, model: CBK 8H).

1.11.4. Data analysis

Collected data were subjected to a normality test, and parametric data was subjected to an analysis of variance procedure using Genstat Version 20. Means were separated using Tukey at a 5% level of significance. Data was summarised in tables and graphs.

1.12. ACHIEVING OBJECTIVE 2

1.12.1. Study area

Sorghum grains were dried at the University of Limpopo plant production lab, taken to Agricultural Research Council for Grain Crops (ARC-GC) in Potchefstroom for trashing, and nutrients were analysed at The Department of Agriculture Rural Development and Land Reform Dohne Agricultural Development Institute in Stutterheim Eastern cape.

1.12.2. Procedure

After harvesting sorghum grains were taken to the University of Limpopo plant production lab, sorghum grains was weighed using (Adam, model: CBK 8H) then dried at room temperature. Dried sorghum was taken to Potchefstroom for trashing, then brought back to the University of Limpopo plant production lab, ground into powdered form, stored in 15x10cm re-sealable plastic lock bags, and sent for analysis of nutrients at The Department of Agriculture Rural Development and Land Reform Dohne Agricultural Development Institute.

1.12.3. Data collection

The following nutrients were determined by the methods described by the Association of Official Analytical Chemists (AOAC, 2000):

Moisture%, Crude Fibre%, Calcium (Ca)%, Magnesium (Mg)%, Potassium (K)%, Sodium(Na) mg/kg, Copper (Cu) mg/kg, Manganese (Mn) mg/kg, Iron (Fe) mg/kg and Zinc (Zn)mg/kg.

1.12.4. Data analysis

Nutrients analysed were subjected to normality tests and parametric data was subjected to analysis of variance procedure using Genstat Version 20. Means were separated using Tukey at a 5% level of significance. Data was summarised in tables and graphs.

RESULTS AND DISCUSSION

1.13. OBJECTIVE 1: EVALUATION OF THE PERFORMANCE OF EXOTIC GERMPLASM FOR GRAIN YIELD AND ADAPTATION

The chapter consist of the results and discussion of the data which was collected. On achieving objective 1 season 2021 and season 2022 data was used and for achieving objective 2 only season 2021 was used. Some of the nutrients (crude protein, phosphorus (P), and Nitrogen (N)) which were supposed to be analysed was not included because the results were not yet out during the report writing.

1.13.1. Days to 50% flowering

There was a significant difference (P<0.05) obtained among the varieties in 2021, while in 2022 there was no significant difference among the varieties. Varieties in 2021 reached 50% flowering earlier than 2022 with a grand mean lower than the one in 2022 (Table 4.1). The mean days to 50% flowering range from 61.33-94.47 days in 2021 while in 2022 they ranged from 82-100.5 days. In 2021, the check line did better than all the test lines and in 2022 SW Makarfi did better than the check line (Figure 4.1). The difference in flowering dates between 2021 and 2022 may be due to environmental conditions. According to Zhang *et al*. (2018) water and temperature are some of the environmental factors which affect the yield of the crops. DAFF (2010) indicates that flowering is delayed if the day and night temperatures increase. The number of days taken from planting to reach 50% flowering may vary in varieties and it may take 55-80 days depending on the environmental conditions (Moore et al., 2014). While in the study of Upadhyaya *et al*., (2019) the varieties planted took 52-121 days to reach 50% flowering and it is said by Upadyaya *et al*. (2017) that when sorghum is grown at the time of rain, there is an increase in moisture stress that will lead to plant stress as the season goes on. SW Makarfi is identified to be the best variety, as it flowers early and early flowering can lead to early maturity.

Table 0.1 ANOVA table for days to 50% flowering

Sources of variation	**DF**		**SS**		**MS**		**Fpr**		**Grand mean**	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Variety	12	12	2472.4	2360.8	206.03	196.7	0.001	0.29	77.47	86.5
Residual	23	29	746.65	4519.7	32.46	155.9				
Total	37	41	3239.5	6880.5						

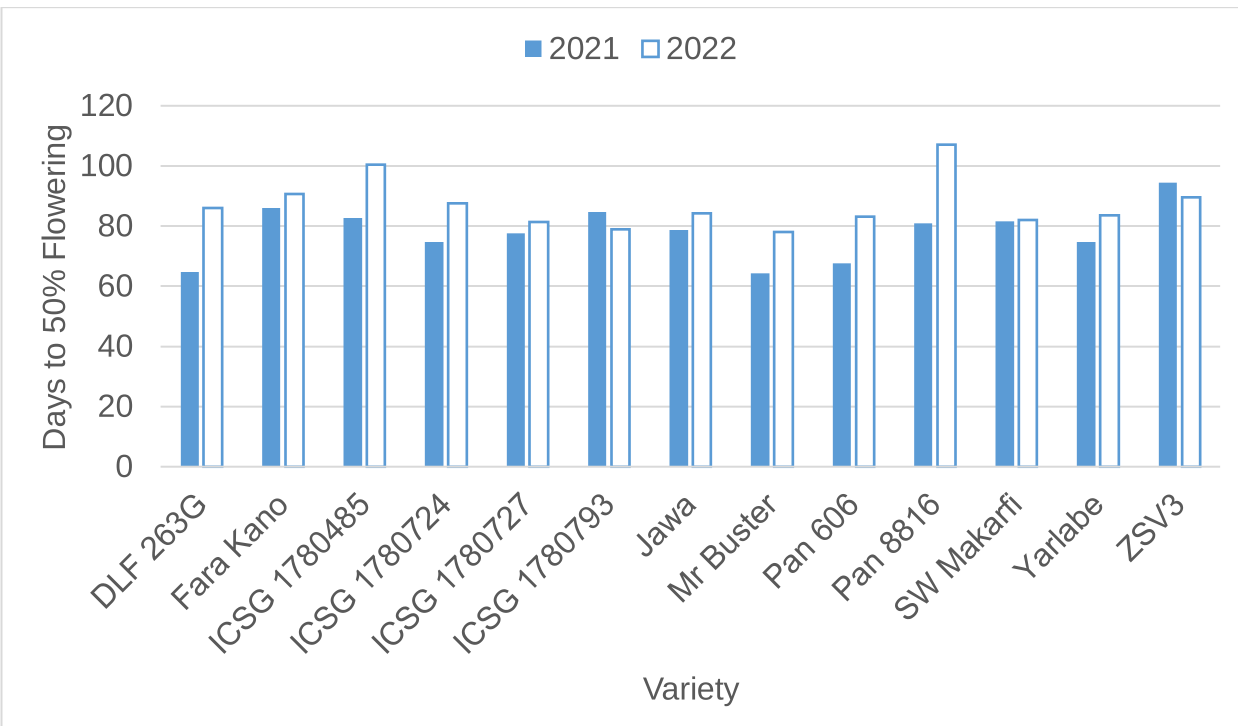

Figure 0.1 Graph showing number of days to 50% flowering

1.13.2. Stem borer incident

There was no significant difference (P>0.05) obtained among the varieties in both 2021 and 2022 (Table 4.2) for stem borer severity. The mean of stem borer score ranges from 1.4-3.34 in 2021 and in 2022 it ranges from 0-2.5. In 2021, the check line Pan 606 did better than all the test lines. In 2022 the test lines (ICSG 1780727, ICSG 1780793, SW Makarfi and ZSV3) scored less than the check line, while Yarlabe and Jawa had the same score as the check line (Figure 4.2). Stalk borers, if not controlled, can cause huge damage especially at an early stage. Gurmess et al. (2018) indicate that stalk borer cannot affect sorghum yield if they are managed with different methods, and in their research, they obtained high yield even though they had a high infestation of stalk borer

Table 0.2 ANOVA Table for stem borer severity score

Sources of variation	**DF**		**SS**		**MS**		**Fpr**		**Grand mean**	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Variety	12	12	16.35	18.69	1.36	1.56	0.107	0.811	2.34	1.20
Residual	23	29	17.31	70.87	0.75	2.53				
Total	37	41	34.55	89.56						

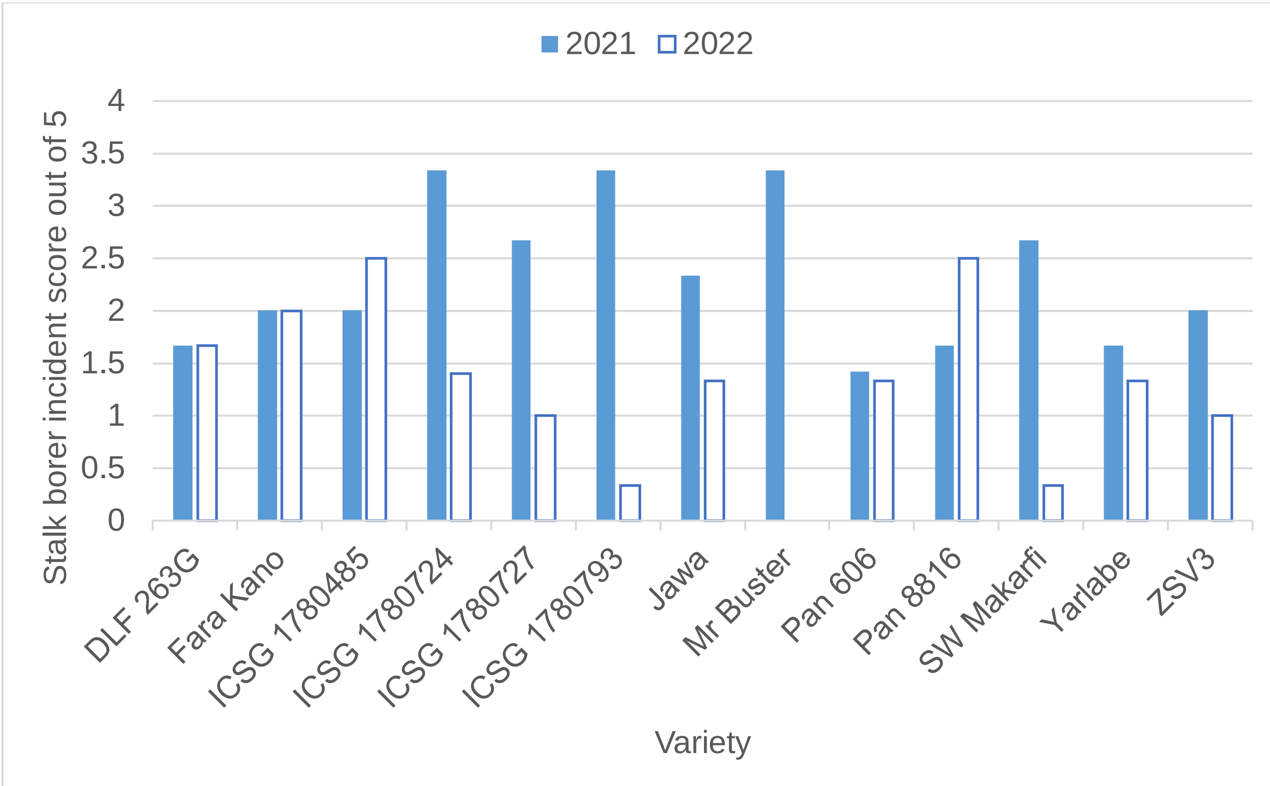

Figure 0.2 Graph showing stem borer severity score (1-5)

1.13.3. Chlorophyll content

There was no significant difference (P>0.05) obtained among the varieties in both 2021 and 2022 for chlorophyll content. The mean in chlorophyll content ranges from17.87-26.93 ccl in 2021 while in 2022 the range is from 19.05-36.03 ccl. All the test lines did better than the check line except SW Makarfi in 2021, while in 2022, all the test lines did better than the check line except ZSV3 (Figure 4.3). Although, there is no significant difference in both years, the grand mean of the varieties in 2022 did better than in 2021 (Table 4.3). Chlorophyll is essential for the overall condition of plant growth and health and indicates when the plant is under biotic or abiotic stress (Zhang *et al.*, 2021). The cultivars with high chlorophyll content are said to be more tolerant to drought according to Khayatnezhad and Gholamin (2012), whose study is in line with this study as they also found no significant difference (P>0.05) in chlorophyll content in their study. All the check lines except for SW Makarfi and ZSV3 are promising varieties that can be planted in Mankweng, since they are drought tolerant.

Source of variation	***D.F.***		***S.S.***		***M.S.***		***F pr.***		***Grand mean***	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
VARIETY	12	12	228.99	1046.32	19.08	87.19	0.656	0.210	23.37	27.78
Residual	24	29	579.36	1773.32	24.14	61.15				
Total	38	41	819.55	2819.64						

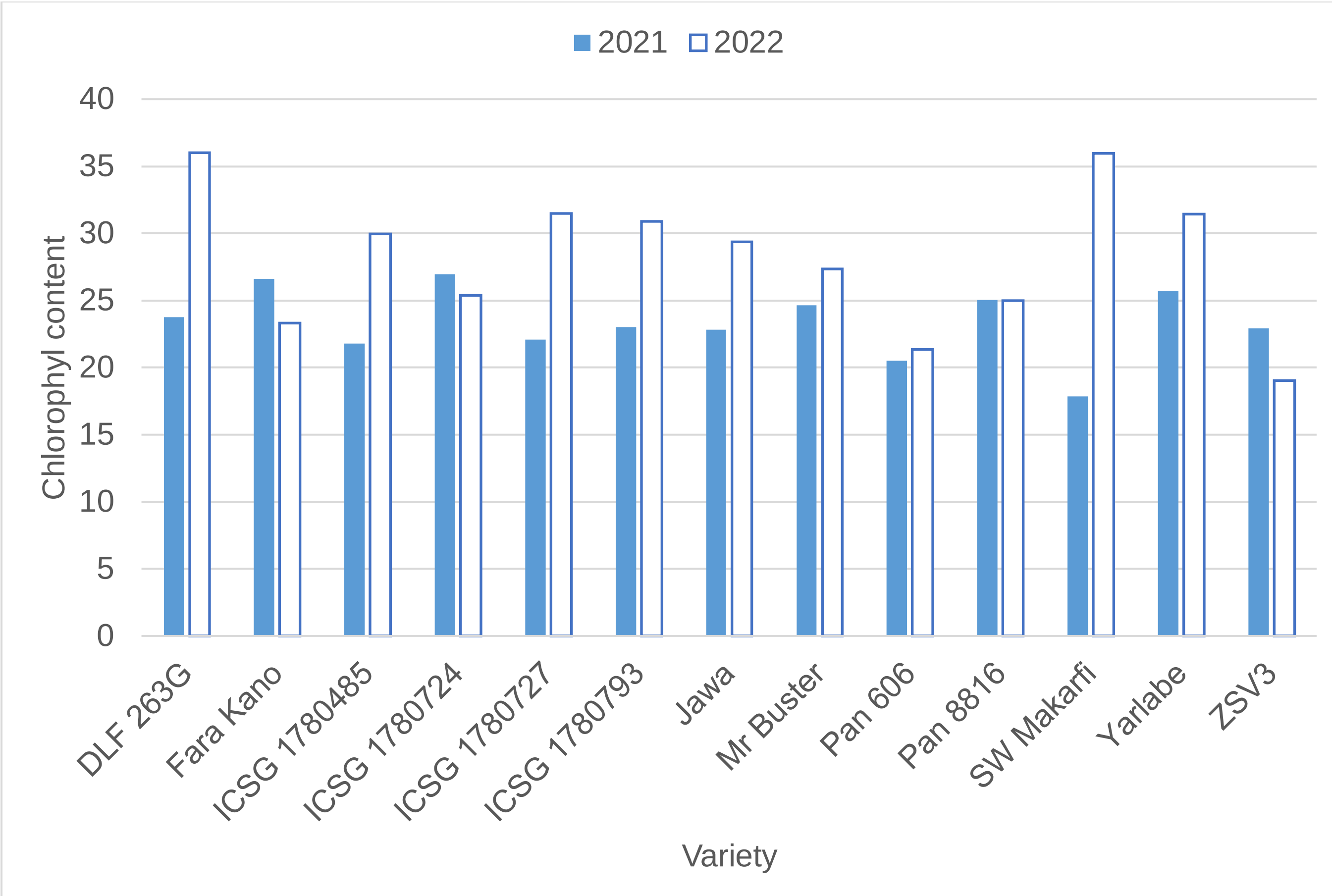

Figure 0.3 A graph showing chlorophyll content

1.13.4. Plant girth

Plant girth showed no significant difference (P>0.05) among the varieties in both 2021 and 2022 (Table 4.4). The mean of the varieties in 2021 ranges from 17.81-26.44mm while in 2022 it ranges from 14.41-29.87mm. Test line (ZSV3, Fara Kano and Yarlabe) obtained plant girth thicker than the check line in 2021, while in 2022 Yarlabe, SW makarfi, ICSG 1780727 and ICSG 1780793 exhibited plant girth thicker than the check line (Figure 4.4). The grand mean obtained in 2021 was higher than the one obtained in 2022, thus indicating that 2021 had a better performance. The plant girth from the study of Naharudin et al. (2021) ranged from 16.16-19.13 mm and this again indicated that plants with thicker stem produced higher total soluble solids. Varieties with thicker plan girth can be best used for animal food, roofing and firewood.

Table 0.3 ANOVA for plant girth

Source of variation	***D.F***		***S.S***		***M.S***		***Fpr***		***Grand mean***	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
VARIETY	12	12	288.17	549.23	24.01	45.77	0.164	0.146	22.64	20.93
Residual	24	29	364.89	828.88	15.20	28.58				
Total	38	41	730.00	1378.10						

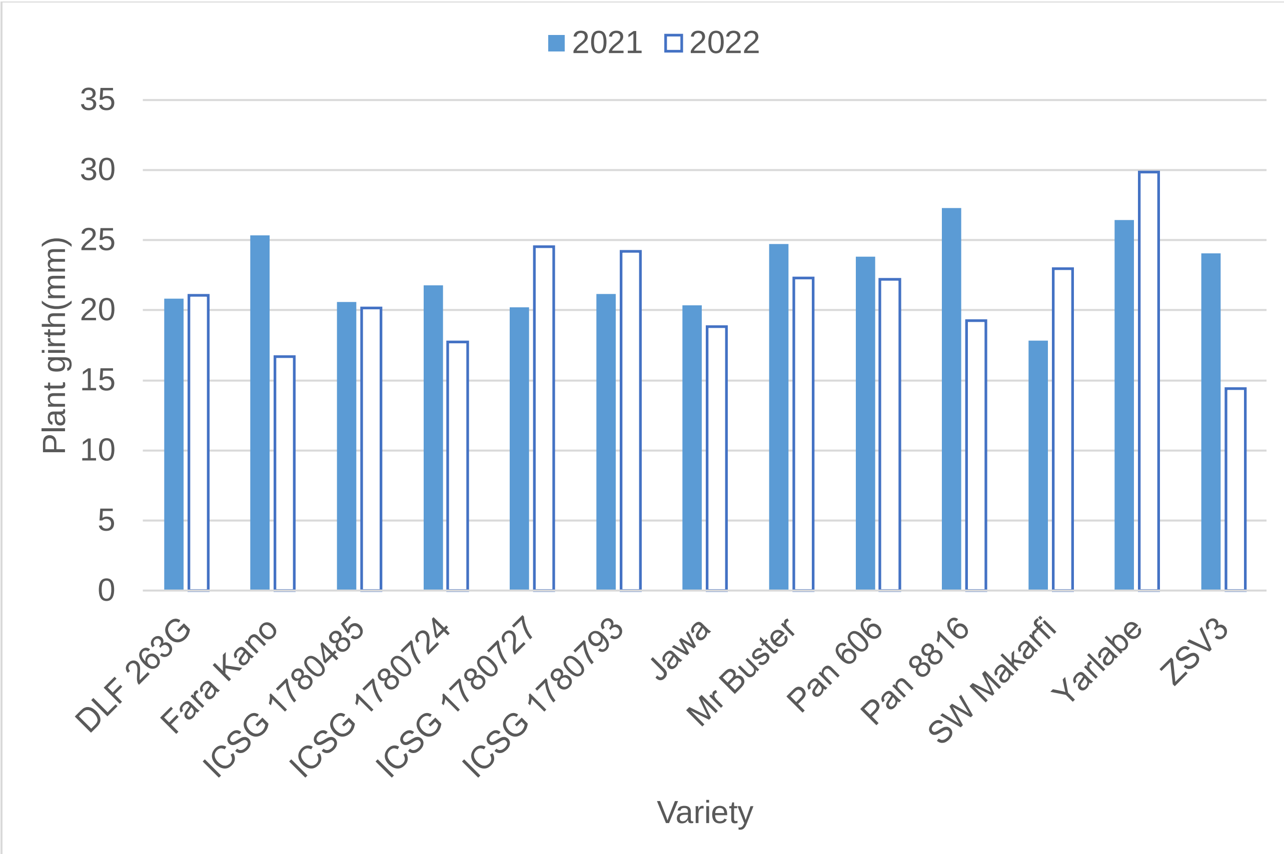

Figure 0.4 Graph showing plant girth

1.13.5. Plant height

Plant height showed a significant difference among varieties in both 2021 and 2022. The mean plant height ranged from 1.1-2.37 in 2021 and from 1.25-2.01 in 2022. The test lines performance was better than the one of the check line in both seasons, except for in 2022 where the check line performance was better than the test line of ICSG 1780485 (Figure 4.5). Out of the traits of the crop, plant height is said to be one of those which indicates the growth of the plant and final grain yield can be predicted based on plant height (Wang et al., 2018). In most cases, taller plants have a thicker stem and they do not develop rain mould, especially under warm humid conditions. It is said that they are susceptible to lodging but that is not always the case (Upadyaya et al., 2012). The study is in line with the ones by Maluk, (2018), and Musa and Gunu (2021), who also found a significant difference in plant height among the varieties. In rural communities, the promising test lines can be used for animal food, roofing, firewood and fencing materials.

Table 0.4 ANOVA table for plant height

Source of variation	**D.F.**		**S.S**		**M.S**		**Fpr**		**Grand mean**	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
VARIETIES	12	12	45528.9	36167.7	3794.1	3014.0	<.001	0.002	1.75	1.61
Residual	24	29	13599.4	24022.4	566.6	828.4				
Total	38	41	61580.8	60190.1						

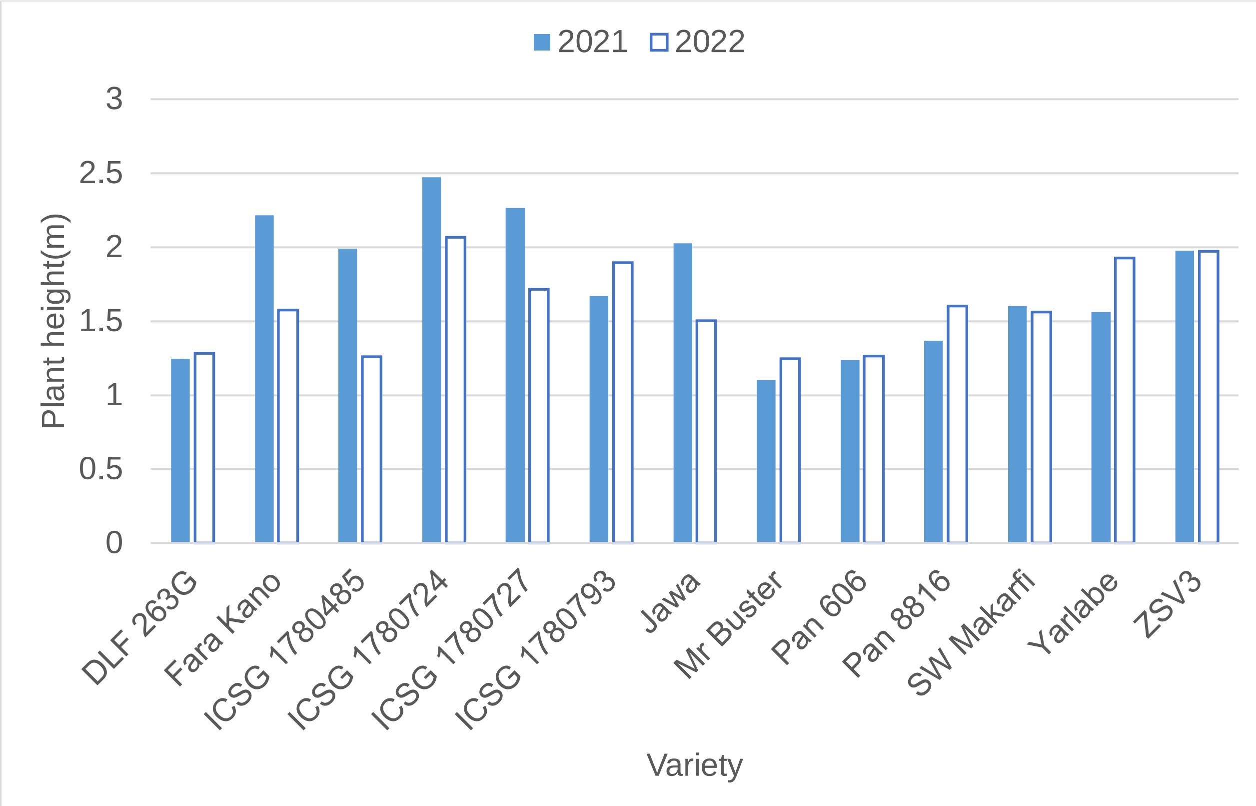

Figure 0.5 Graph showing plant height

1.13.6. Days to 90% maturity

Table 4.6 shows that a significant difference was obtained during 2021, but not 2022, for plant maturity. The mean of the varieties during 2021 ranged from 102-119.7 days, while it ranged from 118-134.7 days in 2022. Fara Kano, ICSG 1780485, ICSG 1780724, and ICSG 1780727 had the same performance as the check line and ICSG 1780793 performed better than the check line in 2021. While in 2022, Fara Kano, ICSG 1780724, ICSG 1780727, ICSG 1780793, Jawa and Yarlabe performed better than the check line (Figure 4.6). It takes 115-140 days for sorghum to reach maturity, depending on the rate at which it grows, and the rate of plant growth depends on temperature and moisture, which are primary factors, but soil fertility, damage by insects and diseases could also have an impact (Moore et al., 2014). Early flowering ensures adaptation to high latitudes by allowing the plant to reach maturity before the first frost (Schaffaz *et al.*, 2019). Almost all stages are affected by drought but the reproductive stage is one of the stages which is more prone to critical moisture stress which will then affect the yields (Rajendra Prasad *et al.*, 2021). The results in 2022 are in line with the ones obtained by Eniola *et al.* (2019) who also noted no significant difference among varieties. Varieties maturing earlier can be used especially in areas where frost falls early. In this study, test lines that performed better than the control varieties are climate smart varieties and can be recommended for cultivation in Limpopo province where rainfall duration limits crop production. The control varieties can be used as part of the climate change adaptation strategies, therefore, smallholder farmers need to use these type of seeds

Table 0.5 ANOVA table for days to 50% maturity

Source of variation	***D.F***		***S.S***		***M.S***		***Fpr***		***Grand mean***	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
VARIETIES	12	12	972.36	1158.4	81.03	96.5	0.003	0.627	109.87	126.43
Residual	24	29	513.03	3401.9	21.38	117.3				
Total	38	41	1494.36	4560.3						

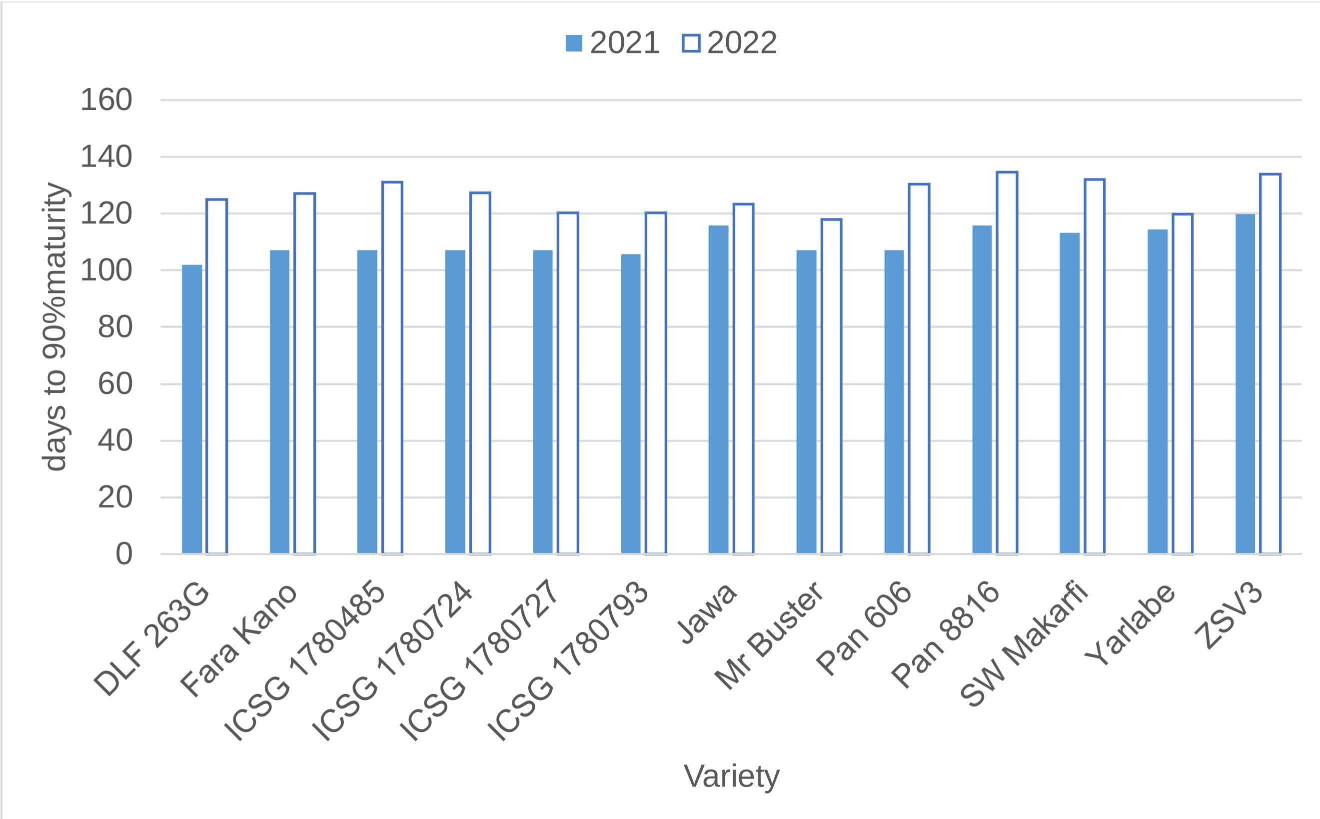

Figure 0.6 A graph showing number of days to 90% maturity

1.13.7. Panicle length

Panicle length varied significantly (P<0.05) during the two seasons. The mean ranged from 14.23-32.4cm in 2021 while in 2022 it ranged from 10.5-27.37cm. Yarlabe performed better than the check line in both 2021 and 2022 (Figure 4.7). On the basis of season, 2021 performed better than 2022 with the highest grand mean (Table 4.7). Panicle length is an essential aspect that contributes to the yield of sorghum and should be taken into consideration when planning breeding strategies for increased yield per panicle (Eniola *et al*., 2019). The study corroborates the findings of Sujatha & Pushpavalli (2015), Enioia *et al*. (2019), and Musa and Gunu (2021) who also noted significant differences in panicle length among the varieties. Varieties with longer panicle length can be best used for increased yields.

Table 0.6 ANOVA table for panicle length

Source of variation	d.f		s.s		m.s		Fpr		grand mean	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
VARIETIES	12	12	1210.29	884.01	100.86	73.67	<.001	<.001	23.07	19.85
Residual	24	27	65.47	453.74	2.73	16.81				
Total	38	39	1279.87	1337.76						

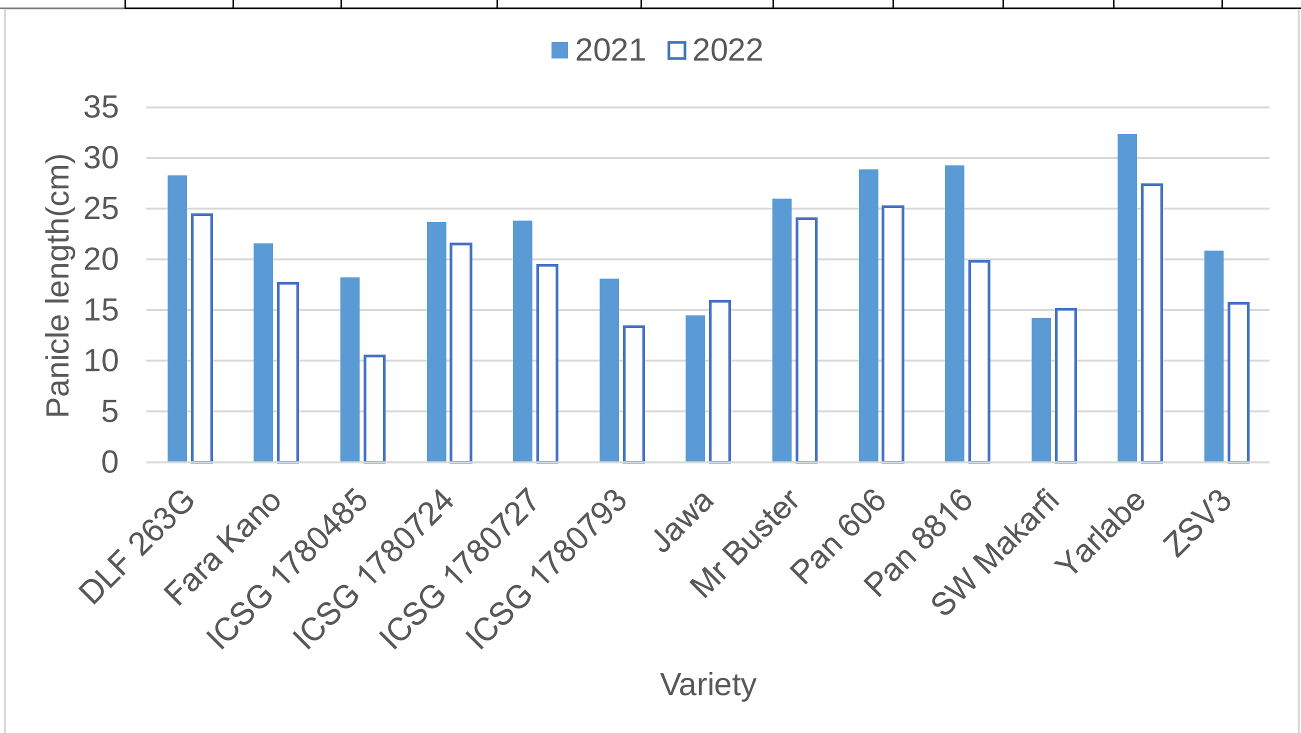

Figure 0.7 A graph showing panicle length

1.13.8. Panicle width

Table 0.7 ANOVA table for panicle width

A significant difference (P<0.05) was obtained among the varieties in 2021 for the panicle width, but not during 2022 (Table 4.8). The mean ranged from 7.7-12.67 in 2021 while it ranged from 11.75-14.5 in 2022. Fara Kano, ICSG 1780485, ICSG 1780727, ICSG 1780793, Yarlabe, and ZSV3 performed better than the check line in 2021 and 2022 all the test lines performed better than the check line (Figure 4.9). Although there was a significant difference (P<0.05) obtained among the varieties in 2021, 2022 had the highest grand mean and performed better than 2021 (Table 4.8). The results in 2021 are in line with the ones noted by Sihag et al. (2019), who also observed a significant difference in panicle width among varieties planted. While the results in 2022 are in line with the ones obtained by Eniola et al. (2019) who also observed no significant different in panicle width among the varieties. Varieties with wide panicle width are promising and can be used for breeding to improve this trait.

Source of variation	**D.F**		**S.S**		**M.S**		**Fpr**		**Grand mean**	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
VARIETIES	12	12	63.45	48.91	5.29	4.08	0.003	0.101	10.25	13.03
Residual	24	29	34.32	66.64	1.43	2.30				
Total	38	41	110.76	115.55						

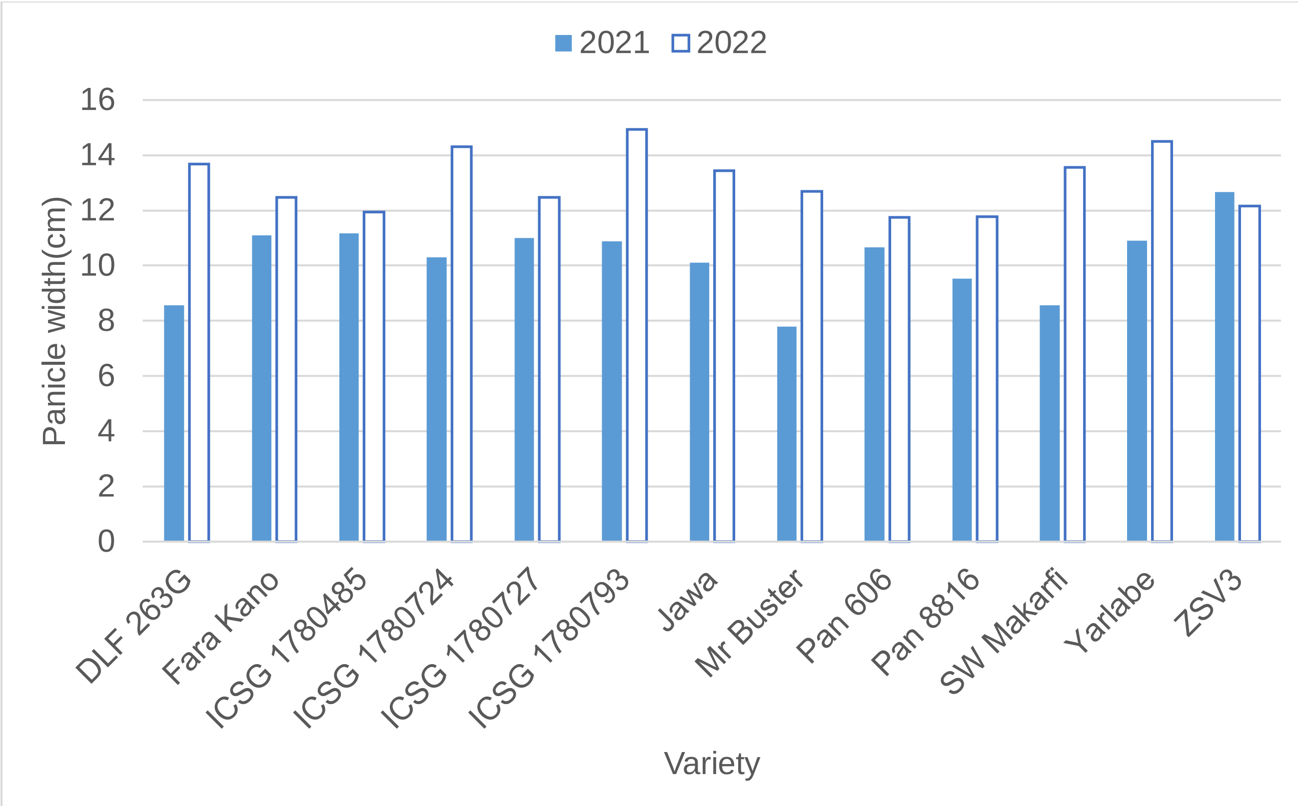

Figure 0.8 Graph showing the panicle width

1.13.9. Number of panicles harvested

A significant difference (P<0.05) was obtained among the varieties in 2021 for the number of panicles harvested, but not during 2022 (Table 4.9). The mean ranged from 7.33-14.67 in 2021, while it ranged from 3-7 in 2022. All the test lines did better than the check line except for ICSG1780727 and SW Makarfi, which had the same performance as the check line. Whereas, in 2022, ICSG1780724, ICSG1780727 and ICSG1780793 performed better than the check line (Figure 4.9). 2021 obtained a higher grand mean of panicles harvested, meaning that it performed better than 2022 (Table 4.9). This indicates that the weather variables during 2021 enhanced the production of panicles, which may directly be translated to high grain yield. Water stress has a negative impact on plant metabolic processes resulting in reduced yield and yield-related traits (Derese *et al.*, 2018). Varieties, where most panicles are harvested, are promising as more panicles means high yield and can be planted in Limpopo province Mankweng.

Table 0.8 ANOVA table for the number of panicles harvested

Source of variation	**D.F**		**S.S**		**M.S**		**Fpr**		**Grand mean**	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
VARIETIES	12	12	367.46	192.34	30.62	16.03	<.001	0.068	25.95	24.52
Residual	24	29	126.82	237.19	5.28	8.18				
Total	38	41	518.82	429.53						

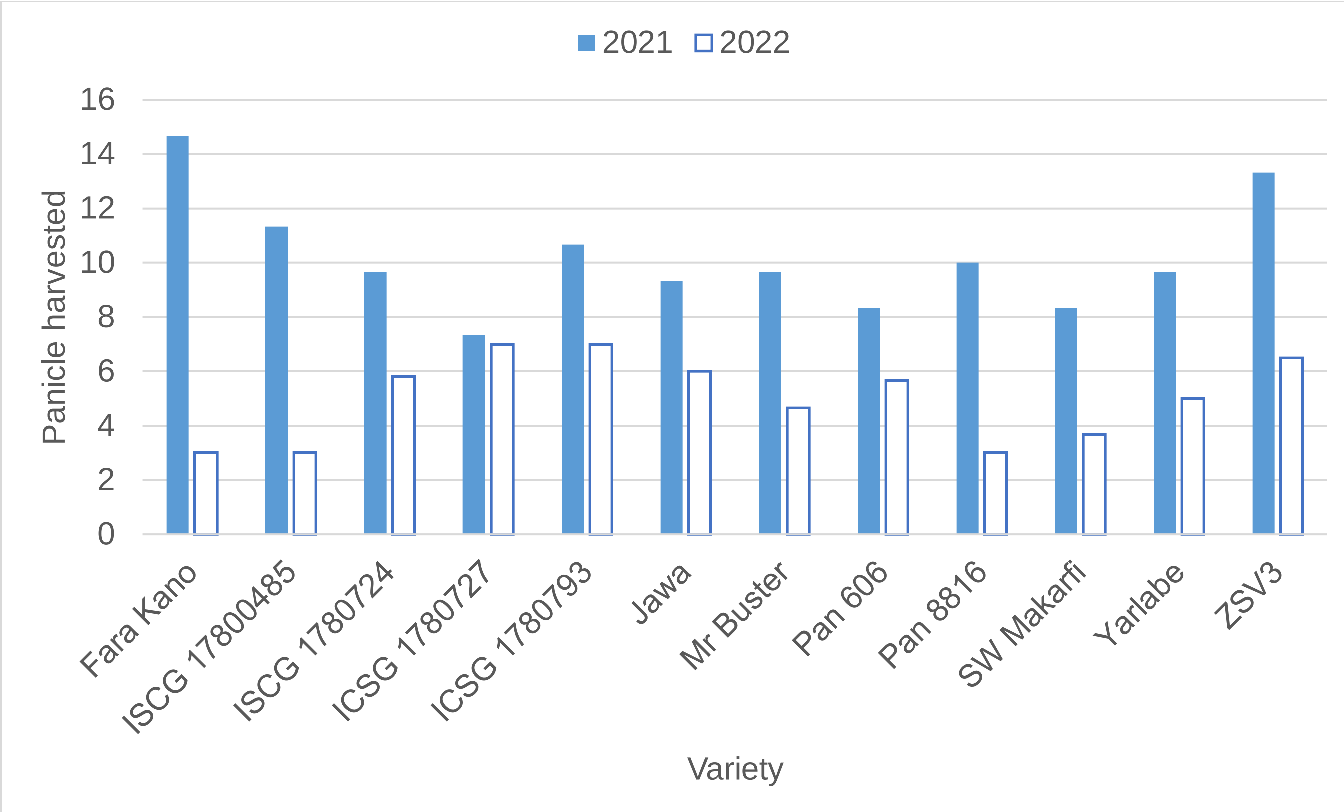

Figure 0.9 A graph indicating the number of panicles harvested

1.13.10. Weight of panicle

A significant difference was obtained for weight of panicle during 2022 and not 2021 (Table 4.10). During 2022, Jawa and ICSG1780485 were the only test lines that did not perform better than the check line (Figure 4.10). The mean ranged from 99.2-207.2g in 2021 and in 2022 it ranged from 155.6-279.9g. Most of the test lines performed better than the check line in 2021 except for Jawa, SW Makarfi, and ICSG1780727, while in 2022, Jawa and ICSG1780485 were the only test lines that did not perform better than the check line (Figure 4.10). Mean performance of the varieties was higher during 2022. The results in 2021 are supported by Ayalew *et al. (*2018) who also found a significant difference ($P \leq 0.05$) in the panicle weight in their study. Varieties with the highest weight per panicle are promising and can be planted in Limpopo province (Mankweng) as it is indicated that there will be high yields.

Table 0.9 ANOVA table for weight of panicle

Source of variation	D.F		S.S		M.S		Fpr		grand mean	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
VARIETIES	12	12	148.26	75.20	12.36	6.27	0.135	0.011	10.10	5.17
Residual	24	29	176.67	64.63	7.36	2.23				
Total	38	41	343.59	139.83						

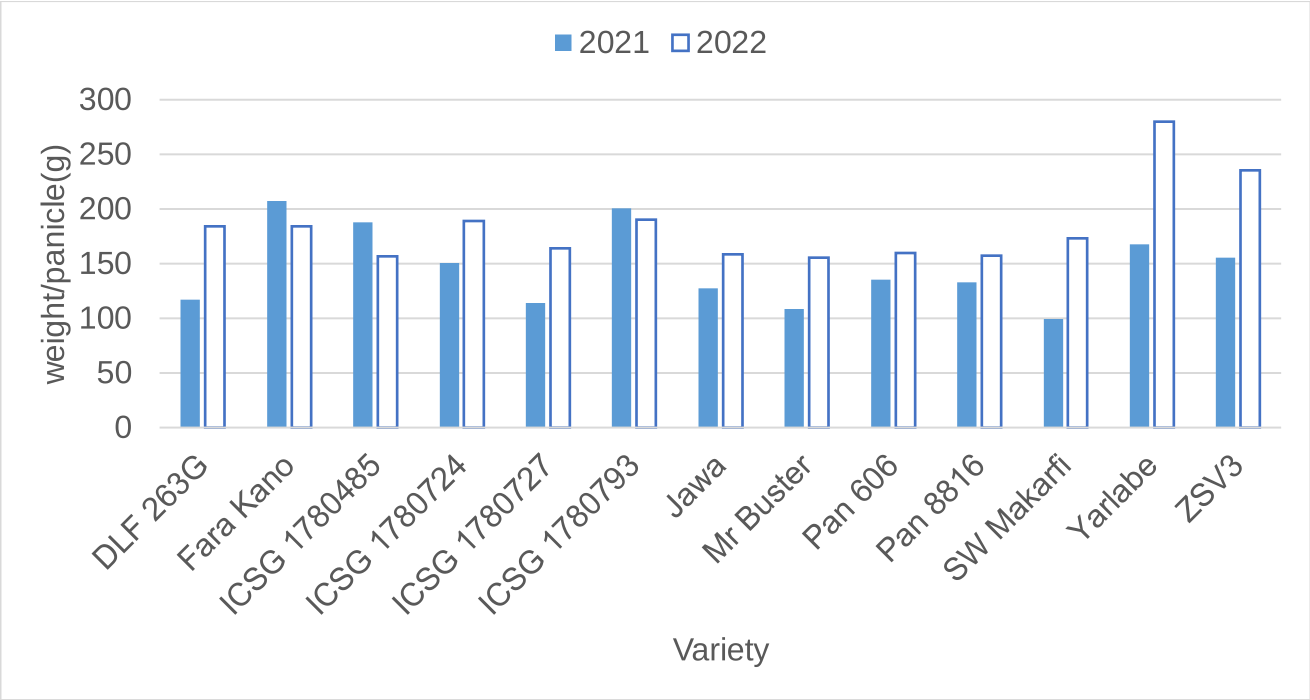

Figure 0.10 A graph showing weight of panicle

1.13.11. 200 seed weight

Two hundred seed weight is an important variable for determining the seed size of the varieties and this trait also influences consumer preference and malting quality in brewing. There was a significant difference (P<0.05) obtained among the varieties in 2021 and 2022 (Table 4.11). The mean ranged from 5.32-9.84g in 2021 and ranged from 6-9.84g in 2022. In 2022 Jawa and the check line had the same performance while Fara Kano, ICSG1780727, and ZCV3 performed better than the check line and in 2022 Fara Kano, ICSG1780724, ICSG1780727, ICSG1780793, Jawa, SW Makarfi performed better than the check line (Figure 4.11). During 2022 a high grand mean for 200 seed weight was obtained, which indicates a cumulative good performance of varieties in the panicle and weight per panicle.

Table 0.10 ANOVA table for 200 seed weight

Source of variation	**D.F**		**S.S**		**M.S**		**Fpr**		**Grand mean**	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
VARIETIES	12	12	45528.9	45909.	3794.1	3826.	<.001	0.211	146.5	179.09
Residual	24	29	13599.4	77897.	566.6	2686.				
Total	38	41	61580.8	123806.						

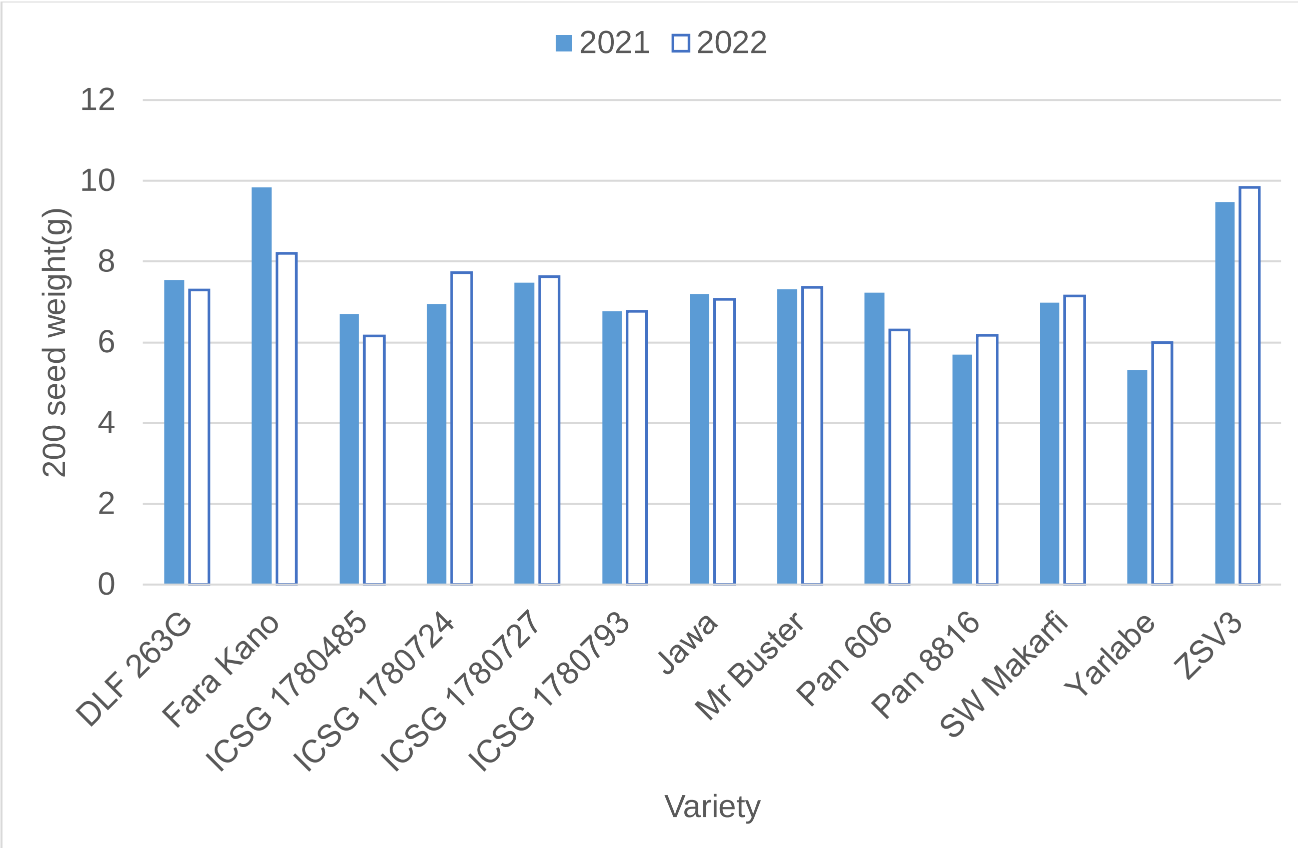

Figure 0.11 Graph showing 200 seed weight

1.13.12. Grain colour

Figure 4.12 and Figure 4.13 present the grain colour of the varieties. It was observed that in 2021, 46% of the varieties' grain colour was red while 54% was white whereas in 2022, 21% of the varieties' grain colour was white and 79% was red. In both 2021 and 2022 most varieties had red grain colour. Most of the varieties were white but due to sunburn they turned red. The colour of sorghum grain can either be red, lemon, brown, or white and factors such as being exposed to sunlight, being attacked by insects and mould affect the colour of sorghum (Hikeez, 2010). The white varieties are preferred by consumers and brewing companies as they have less tannin.

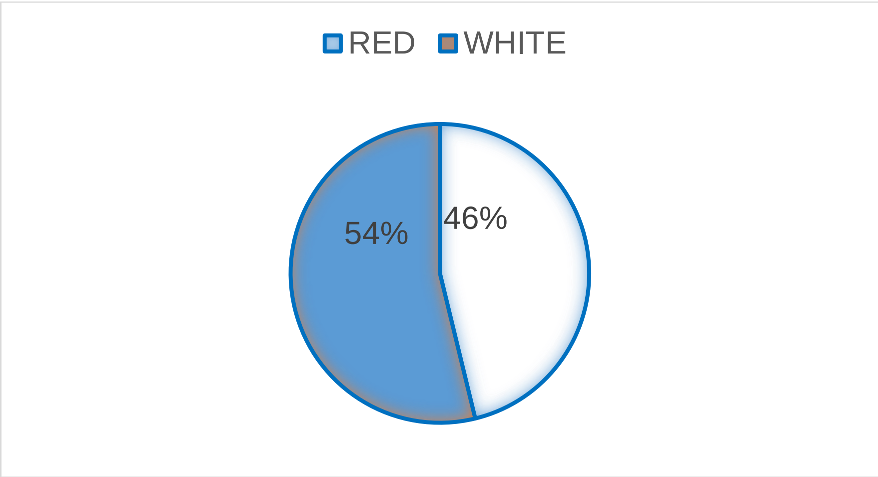

Figure 0.12 Pie chart for grain colour during 2021

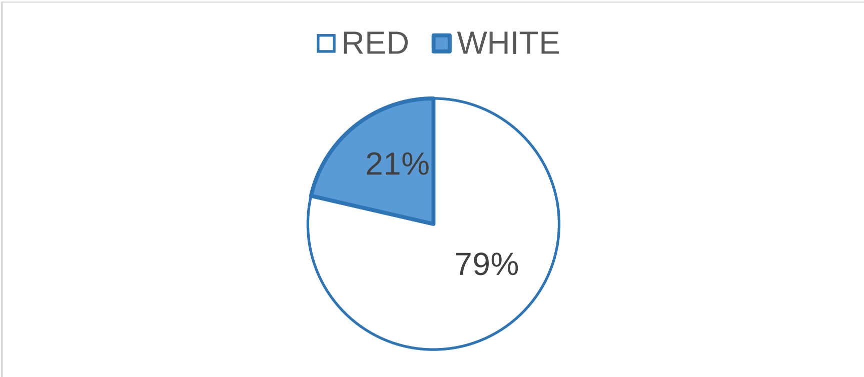

Figure 0.13 Pie chart of grain colour during 2022

1.13.13. Panicle type

It was observed that in 2021, 23% of the panicle type was compacted, another 23% was loose and 57% was semi-loose, while in 2022, 29% of the panicle was loose, 14% was compacted and 57% was semi-loose. According to DAFF (2010), different varieties have different panicle types. Compacted panicles are less affected by birds and most of them are red in colour. Morphological traits of different varieties influence the quality of the grain, grain yield, and panicle traits. Varieties with compacted panicles can resist grain mould and insect damage (Diallo *et al.*, 2018). The compacted varieties can be used by smallholder farmers as they are less affected by insects.

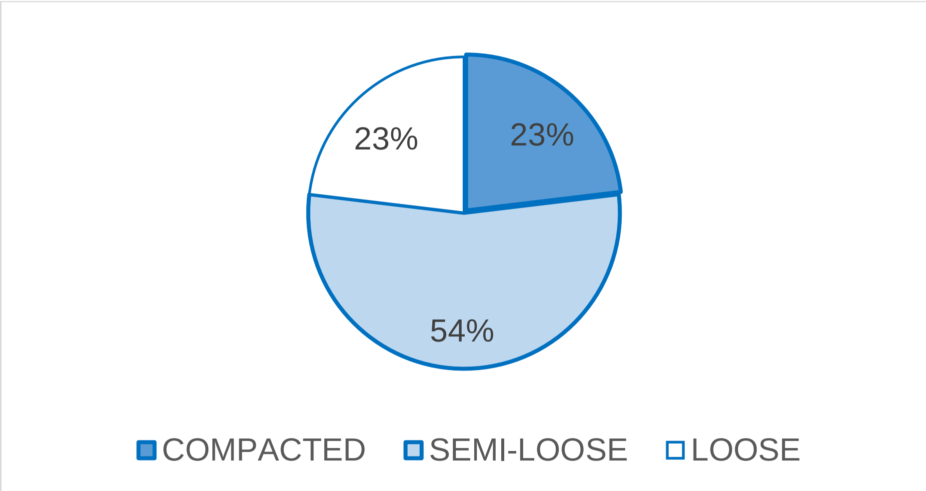

Figure 0.14 Pie chart of the panicle type for 2021

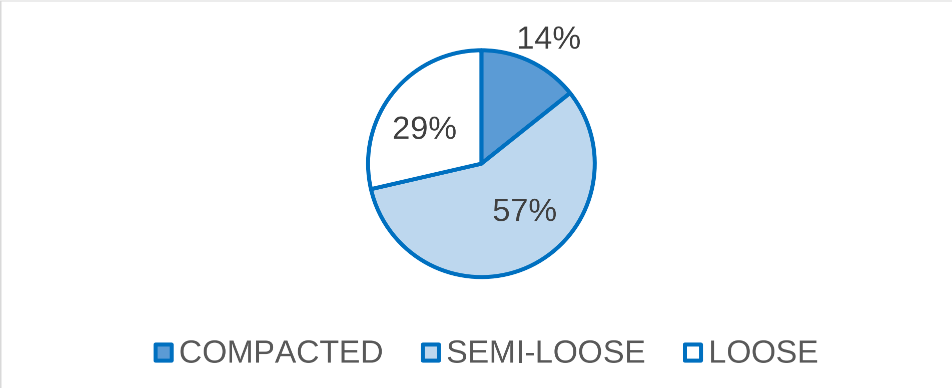

Figure 0.15 Pie chart of the panicle type for 2022

1.14. OBJECTIVE 2: DETERMINING NUTRIENT CONTENT DURING THE SEASON 2021

1.14.1. Calcium and Sodium

Table 4.14 indicates the results of calcium % and sodium mg-kg. The calcium ranged from 0.22-0.67% while for sodium ranged from 16.9- 103.84 mg-kg. Analysis of variance shows that there was a significant difference ($P<0.05$) obtained among the varieties for both minerals (Table 4.12 and 4.13). ICSG 1780724 and Yarlabe performed above control in the concentration of sodium while all the test lines performed above the check line on the concentration of calcium. Variation in mineral contents among varieties may be due to differences in genotypes and their ability to mine the nutrients from the soil (Tasie & Gebreyes, 2020). Calcium is known to be essential in improving bones and building muscles (Emmanuel *et al.*, 2022), the varieties with high calcium can help in maintaining healthy bones. Sodium helps ensure that the body's cell water is balanced and helps make sure that levels of blood water are stable (Tasie & Gebreyes, 2020, Asiwe 2022). There are a lot of people suffering from high blood pressure and these varieties might help maintain the level of blood pressure.

Table 0.11 ANOVA table for calcium

Source of variation	d.f.	s.s.	m.s.	v.r.	Fpr	Grand mean
REP stratum						
VARIETY	12	0.47048	0.03921	2.06	0.053	0.3507
Residual	30	0.56996	0.01900			
Total	42	1.04044				

Table 0.12 ANOVA table for sodium

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Grand mean
REP stratum						
VARIETY	12	27841.	2320.	2.03	0.057	55.71
Residual	30	34312.	1144.			
Total	42	62153.				

Table 0.13 The results of calcium and magnesium contents in sorghum grain

Variety	*Calcium%*	*Sodium mg-kg*
DLF 263G	0,22	52,55
Fara Kano	0,33	16,90
ICSG 1780485	0,37	31,17
ICSG 1780724	0,42	73,69
ICSG 1780727	0,30	60,11
ICSG 1780793	0,28	18,29
Jawa	0,40	19,29
Mr Buster	0,29	90,71
Pan 606	0,27	65,82
Pan 8816	0,32	71,52
SW Makarfi	0,67	51,95
Yarlabe	0,38	103,84
ZSV3	0,39	54,23

1.14.2. Potassium and magnesium

Table 4.17 indicates the results of potassium and magnesium. The mean for potassium ranged from 1.012-1.1787%, and magnesium ranged from 0.15-0.28%. Analysis of variance indicates that there was no significant difference (P>0.05) obtained among the variety of both minerals (Tables 4.15 and4.16), although there was no significant difference obtained among the varieties all the test lines performed better than the check line in both minerals. Magnesium is known to be essential for antioxidant activity and it protects the body against diseases caused by oxidative stress (Emmanuel *et al.*, 2022).

Varieties can be used in the diets of different people for protection against diseases caused by oxidative stress.

Table 0.14 ANOVA table for potassium

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**Fpr**	**Grand mean**
REP stratum						
VARIETY	12	1.5814	0.1318	0.56	0.857	1.1729
Residual	30	7.0822	0.2361			
Total	42	8.6636				

Table 0.15 ANOVA table for magnesium

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**	**Grand mean**
REP stratum						
VARIETY	12	0.065800	0.005483	1.42	0.210	0.19603
Residual	30	0.115709	0.003857			
Total	42	0.181509				

Table 0.16 The results of the composition of potassium and magnesium %

VARIETY	*Potassium*	*Magnesium*
DLF 263G	1,01	0,18
Fara Kano	1,10	0,15
ICSG 1780485	1,17	0,21
ICSG 1780724	1,08	0,28
ICSG 1780727	1,11	0,21
ICSG 1780793	1,22	0,19
Jawa	1,11	0,16
Mr Buster	1,04	0,18
Pan 606	1,05	0,16
Pan 8816	1,081	0,17
SW Makarfi	1,79	0,26
Yarlabe	1,35	0,21
ZSV3	1,28	0,17

1.14.3. Iron, Zinc and manganese contents

Table 4.21 indicates that the results of the composition of iron, manganese, and zinc. Iron content ranged from 43.93-148.91 mg/kg, manganese from 12.36-31.39, and zinc from 22.38 mg/kg. Analysis of variance indicates that there was no significant difference (P>0.05) obtained among the varieties of all three minerals (Tables 4.18, 4.19 and 4.20). Although there was no significant difference obtained among the varieties in the three minerals, eight varieties except for ICSG 1780485 performed better than the check line in iron, while in manganese and zinc contents, all the test lines performed better than the check line. Iron is the nutrient that helps with the transportation of oxygen and the generation of cellular energy, and the world health organisation estimated over 2 billion people around the world, particularly in developing countries live with an iron deficiency. The varieties can be used as a source of iron in developing countries. Zinc is an important co-factor of enzymes and in developing countries the deficiency of Zinc is ranked in the top five risk factors and death, which is caused by consuming a diet with low zinc leading to dermatitis, growth retardation, diarrhea, mental disturbances, and recurrent infections (Tasie & Gebreyes, 2020; Asiwe, 2022). Varieties high in zinc and iron will reduce the chances of getting diseases such as dermatitis, growth retardation, diarrhoea, mental disturbances, and recurrent infections.

Table 0.17 ANOVA table for iron content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Grand mean
REP stratum						
VARIETY	12	36335.	3028.	0.89	0.568	84.09
Residual	30	102328.	3411.			
Total	42	138663.				

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Grand mean
VARIETY	12	36335.	3028.	0.89	0.568	84.09
Residual	30	102328.	3411.			
Total	42	138663.				

Table 0.18 ANOVA table for zinc content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Grand mean
REP stratum						
VARIETY	12	1757.86	146.49	1.59	0.147	29.501
Residual	30	2760.38	92.01			
Total	42	4518.24				

Table 0.19 ANOVA table for manganese content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Grand mean
REP stratum						
VARIETY	12	1439.85	119.99	1.62	0.139	19.517
Residual	30	2222.10	74.07			
Total	42	3661.95				

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Grand mean
VARIETY	12	1439.85	119.99	1.62	0.139	19.51
Residual	30	2222.10	74.07			

Total	42	3661.95

Table 0.20 The results of the composition of iron, manganese and zinc mg-kg

Variety	*Iron*	*Manganese*	*Zinc*
DLF 263G	69,65	16,25	25,81
Fara Kano	88,98	15,80	26,59
ICSG 1780485	51,65	19,05	25,94
ICSG 1780724	86,32	31,11	41,50
ICSG 1780727	79,88	17,60	33,41
ICSG 1780793	148,91	18,67	24,26
Jawa	122,69	16,61	30,26
Mr Buster	60,11	16,82	24,54
Pan 606	57,73	12,36	22,38
Pan 8816	43,93	15,93	22,58
SW Makarfi	111,7	23,39	40
Yarlabe	75,43	20,27	29,56
ZSV3	114,44	31,39	36,11

1.14.4. Crude fibre

Table 4.23 shows the results of crude fibre content. The mean ranged from 0.47- 1.58. Analysis of variance indicates that there was no significant difference obtained among the varieties on crude fibre (Table 4.22), although there was no significant difference observed among the varieties seven test lines performed better than the check line except for Yarlabe and ICSG 1780727 in crude fibre. Crude fibre causes minerals to bind making them unavailable for absorption, this can cause imbalances and deficiency of essential important minerals and it is not advisable to consume varieties with high crude fibre but they can be used in products that require hydration, for yield improvement (Tasie &

Gebreyes, 2020). To reduce the chances of people getting sick varieties with high crude fibre may not be used for consumption.

Table 0.22The results of the crude fibre content

Variety	*Crude fibre*
DLF 263G	0.53
Fara Kano	0.74
ICSG 1780485	0.86
ICSG 1780724	1,58
ICSG 1780727	0,47
ICSG 1780793	0,70
Jawa	0,88
Mr Buster	0,70
Pan 606	0,59
Pan 8816	0,83
SW Makarfi	1,46
Yarlabe	0,47
ZSV3	0,96

Table 0.23 ANOVA table for crude fibre

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Grand mean
REP stratum						
VARIETY	12	5.1181	0.4265	0.89	0.567	0.8262
Residual	30	14.3925	0.4798			
Total	42	19.5106				

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Grand mean
VARIETY	12	5.1181	0.4265	0.89	0.57	0.82
Residual	30	14.39	0.48			
Total	42	19.51				

SUMMARY AND COLCUSION

This study evaluated 17 exotic sorghum germplasm which were obtained from the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) for yield and adaptation in Mankweng (South Africa) to reduce food insecurity and nutrition. The study has shown that Fara Kano, ICSG 1780724, and ICSG 1780727 matured earlier than the check line and Fara Kano, ICSG1780727 performed better than the check line in 200 seed weight. It was also found that most of the varieties, especially those with semi-loose and loose panicles, have white grain colour but turned red due to sunlight. Nutrients were analysed and the varieties have been found to be nutritious and can help improve the health of the people.

It was revealed in the study that in terms of potassium and magnesium all the test lines performed better than the check line and the minerals can help with protection against diseases. The study again revealed that in most traits the test lines perform better than the check line, for instance when it comes to plant girth, Yarlabe in both seasons exhibited thicker plant girth and it can be best used for roof and animal feed. In terms of panicle length, which contributes to the yield of the crop, Yarlabe has been observed to have a longer panicle length than the check line and can be used for increased yield. These varieties can be released to smallholder farmers to improve their yield,food security and nutrition.

Early maturing varieties like SW Makarfi can be planted at areas where there is frost as they will mature early before frost start falling. Yarlble can be planted as it have high panicle length and panicle width which lead to increased yield. These varieties can be planted to other parts of Limpopo to check their adaptation in other places.

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APPENDIX

Appendix 3.1.Sorghum panicle 1

Appendix 3.2.Sorghum panicle 2

Appendix 3.3.Sorghum panicle 3