Sudan University of Science and Technology
College of Graduate Studies

EVALUATION OF FIVE SORGHUM GENOTYPES (*Sorghum bicolor* (L.) Moench) UNDER WATER STRESS IN NORTH KORDOFON STATE.

تقييم خمسة طرز وراثية من الذرة الرفيعة تحت تاثير الإجهاد المائي بولاية شمال كردفان.

Thesis Submitted to Sudan University of Science and Technology in Fulfillment of the Requirements for the Degree of Philosophy Doctor in Agronomy

By

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DEDICATION

This work is dedicated to:

The soul of, my father, to my mother

To my wife and beloved children

To my brothers, sisters, Friends, relatives, and colleagues

With love and respect

Abdelrhim

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Before all, I would like to thank Almightily Allah for giving me provision, health and patience to finalize this study successfully.

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ABSTRACT

The study was conducted during two successive seasons (2014/015–2015/016) with four experiments (two field experiments which were carried out at the Crop Sciences Experimental Farm, Faculty of Natural Resources and Environmental Studies, University of Kordofan and two other laboratory experiments which were carried out at the Regional Seed Center Laboratory, Agricultural Research Corporation (ARC), Elobied. The aim of these experiments was to evaluate five sorghum genotypes under water stress and to examine the effect of water limitation on seed quality during seed filling period. In the field experiments, two factors were studied, namely; genotypes and water regime. The five sorghum genotypes were: Taggat 9, Taggat 10, Taggat 14, Taggat 19 and Gadambalea and the three water regimes were: well watering every seven days as control (IR_0), withholding irrigation at three-leaf stage for 21 days as stress one (IR_1) and withholding irrigation at eight-leaf stage for 21 days as stress two (IR_2). The field experiment was laid out in a Randomized Complete Block Design (RCBD) with four replications within split-plot experimental arrangement. The main plots were specified to water stressed treatments, while genotypes were placed as subplots. The laboratory treatments were conducted as factorial experiments in a Randomized Complete Block Design with four replications. The parameters that measured from the field experiment were plant height, number of leaves/plant, days to 50% flowering, days to 95% physiological maturity, number of heads/plot, number of grains/panicle, panicle length and weight, 100-grain weight, grain yield/plant, grain yield/m^2, grain yield (ton/ha), harvest, drought tolerance and seed indices, soil moisture content and consumed moisture in the soil. At laboratory experiment, parameters were: germination%, seedling vigor traits. Statistical analysis revealed significant effects of each of water regimes, genotypes, and their interactions for most of the studied traits in both seasons. In this respect, withholding irrigation at eight-leaf stage consistently resulted in reducing growth, yield, and yield components and seed quality compared with well-watering and withholding irrigation at three-leaf stage. Results also showed that stressed plants at three-leaf stage exhibited the highest estimates in plant height (between 141 and 144 cm), number of grains per head (between 1385 and 1577) and seedling relative moisture content (between 1.95 and 1.97). The results revealed that Taggat10 and Taggat 14 were the late matured genotypes and showed the best perform once for yield (4.2 and 4.5 ton/ha, respectively) and in seed vigor, whereas, the early matured genotypes (Gadambalea and Taggat 9) performed best in drought tolerance index (0.8 and 0.9, respectively).

ملخص البحث

أجريت الدراسة خلال الموسميين (2015/2014 – 2015/ 2016) علي أربع تجارب، تجربتين حقليتين تم تنفيذهما في المزرعة التجريبية لقسم علوم المحاصيل، كلية الموارد الطبيعية والدراسات البيئية، جامعة كردفان وكذلك تجربتين معمليتين تم تنفيذهما في معمل مركز البذور، هيئة البحوث الزراعية – الأبيض. هدفت الدراسة الي تقييم خمسة طرز وراثية من الذرة الرفيعة تحت تاثير الإجهاد المائي وكذلك دراسة تاثير الإجهاد المائي علي الصفات النوعية للبذور خلال فترة إمتلاء الحبوب. إشتملت المعاملات علي خمس طرز وراثية إشتملت المعاملات علي خمس طرز وراثية من الذرة الرفيعة وهي طقت 9 وطقت 10وطقت 14 وطقت 19 و قدمبلية بالإضافة الي ثلاثة مستويات للري وهي: رية كل سبعة أيام (IR_0)، تعطيش في مرحلة الثلاث أوراق لمدة 21 يوماً (IR_1) و تعطيش في مرحلة االثمانية أوراق لمدة 21 يوما (IR_2). في التجربة الحقلية أستخدم تصميم القطاعات العشوائية الكاملة (RCBD) بأربعة مكررات بتوزيع القطع المنشقة، حيث خصصت القطع الرئيسية لمعملات الري فيما خصصت القطع الفرعية للطرز الوراثية. بينما في التجربة المعملية أستخدم تصميم القطاعات العشوائيه الكاملة بأربعة مكررات. القياسات التي تمت في التجربة الحقلية شملت طول النبات وعدد الأوراق في النبات وعدد الأيام لـ 50% إزهار و 95% نضج فسيولوجي وعدد القناديل في الحوض وعدد الحبوب في القندول وطول ووزن القندول ووزن الـ 100 حبة وإنتاجية النبات والإنتاجية قي المتر المربع والإنتاجية (طن/هكتار) ودليل مقاومة الجفاف ودليل الحصاد ودليل البذرة بالإضافة الي المحتوي الرطوبي في التربة. أما في التجربة المعملية فقد تم قياس نسبة الإنبات وبعض القياسات المتعلقة بقوة الإنبات. أظهرت نتائج التحليل الإحصائي وجود تاثيرمعنوي ($P \geq 0.05$) لكل من مستويات الري والطرز الوراثية والتفاعل المشترك في أغلب الصفات المدروسة خلال الموسمين، حيث أوضحت النتائج أن التعطيش في مرحلة الثمانية أوراق أدي الي الإنخفاض في صفات النمو والإنتاجية ومكوناتها وكذلك في نسبة وقوة الإنبات مقارنة بالمعاملة بدون تعطيش والتعطيش في مرحلة الثلاث أوراق.

أيضا أشارت نتائج التحليل إلي أن النباتات التي تعرضت للعطش في مرحلة الثلاث أوراق سجلت أعلي طول للنبات حيث تراوح ما بين (141 و 144 سم) وأكثر عدد للحبوب في القندول (1385 – 1577 بذرة) وأعلي محتوي في الرطوبة النسبية للبادرات (1.95 – 1.97). أظهرت نتائج الدراسة أن الطرز الوراثية متاخرة النضج مثل طقت 10 وطقت 14 هما الأفضل أداءً حيث سجلا أعلي إنتاجية (4.2 و 4.5 طن/هكتار علي التوالي) وكذلك تفوقا في قياسات قوة الإنبات. بينما الطرز الوراثية المبكرة النضج مثل قدمبلية وطقت 9 هما الأفضل في دليل مقاومة الجفاف حيث سجلا (0.8 و 0.9 علي التوالي).

List of contents

List of tables

List of figures

List of plates

CHAPTER ONE
INTRODUCTION

In Sudan, sorghum is the main staple food crop and comprises 80% by weight of the cereal crops grown in the country. Sudan is self sufficient in sorghum production and is able to export some, in years of good production. Grain sorghum, a well-adapted crop for central Sudan, is grown extensively under irrigated and dry land conditions. Grain sorghum is annually cultivated in around 5.6 and 40.5 million hectares in Sudan and the world, respectively. Sudan produces only 2.63 million tones of the 55.64 million tones of the world (FAO, 2012). The areas devoted to sorghum in Sudan represents about 14% of the total areas devoted to sorghum worldwide. While the Sudan annual production is less than 5% compared to world productivity. Environmental stresses such as water stress, decrease productivity in many crops. There is no doubt water stress represents the main factor limiting crop yield under dry land farming conditions (Mohammed *et. al.*, 2010). The effect of drought stress on crop growth and yield has become more common worldwide in the last two decades. Drought stress affects crop growth and yield during all developmental stages, maturity and final yield. One approach to improve crop performance in water limited environments is to select for genotypes that have improved yield in this environment (Ali and Ahsan, 2012).

Therefore, knowledge of how to produce crops in low rain fall areas need to be understood for saving the reduction of the yield of the crops in these areas. Grain sorghum, is grown extensively under irrigated and dry land conditions. Vulnerability of rainfall among seasons and long drought spells within the same rainy season imposed frequent water stress during vegetative and reproductive growth of sorghum plant (Mohammed, *et. al.*, 2010). Elmunsor *et.al* (2014) concluded that there was a wide range of genetic variability detected among the grain sorghum genotypes for drought tolerance, and there was highly significant negative correlation for drought tolerance parameters in yield under stress with yield under non stress. Thus, it is very important for plant breeders and physiologist to practice selection among genotypes for drought tolerance to maintain sorghum yield from reduction. Yield reduction is the common result among all crops when grown in water stress environment, but its extent greatly varied among sorghum genotypes. Mohammadai *et. al.*, (2012) reported 35 to 41% reduction in sorghum yield when drought stress was imposed during seed filling in two green house experiments, but they found no effect on germination or vigor. Water stress at the vegetative stage alone can reduce yield more than 36%, and water stress at the reproductive stage can reduce yield more than 55% (Assefa, *et. al.*, 2010). Poor seed germination and seedling growth are prime causes of losses in crop yield each year. The losses are partially due to inadequate conditions for seed germination and partially to poor seedling growth due directly to reduced seed vigour. With increased emphasis on improving productivity it is imperative that potential crop yield is achieved (Ibrahim, 2016).

Germination and seed vigor of sorghum was not significantly affected by irrigation levels. The highest germination and seedling growth rate were obtained in the harvested seed at physiological maturity stage. Thus, it doesn't seem that water limitation would have a direct effect on seed quality.The yield of viable and vigorous seed is an important goal for sorghum seed producers and farmers. This implies good understanding of how stress affects seed viability and vigor. Water stress effects on grain yield, plant growth and development were thoroughly studied, but little information is available about its effects on physiological qualities of the seeds (Younesi and Moradi, 2009).Therefore, more investigations are needed.

The general objective of this study is:

- To estimate the drought tolerance of five sorghum genotypes under three water intervals, and potentiality of each genotype to resist water stress.
- To evaluate the effect of water intervals at different stages of growth on grain yield and its attributes and seed quality of sorghum.

CHAPTER TWO

LITERATURE REVIEW

2.1 General background

Sorghum [*Sorghum bicolor* (L.) Moench; 2n = 2x =20] is one of the oldest plants used by human. Its main lands are India and South Africa and the record of its implanting is more in Asia than in Africa (Mobasher *et.al*., 2012). It is the world's fifth most commonly grown cereal crop after wheat, rice, maize and barley, and it has many types of cultivated varieties (as grain genotypes, fodder, fiber and sugar genotypes and dual purpose genotypes. Sorghum species have been utilized worldwide for the production of grain, forage, sugar, and more recently biofuels (Hamid, 2001). Millions of people in Africa and Asia depend on sorghum as the staple food. It is the dietary staple of more than 500 million people in more than 30 countries, and it was ranked as the fourth food grains of the world (ICRISAT, 2009). In addition, the fodder and stover is fed to millions of animals providing milk and meat for man. Over 55% of grain produced globally is used for human consumption and about 33% of grain used in feeding livestock, especially in the Americas. Globally, sorghum is cultivated over an area of about 42.7 million ha with a production of about 58.7 million tonnes in many parts of the world (AghaAlikhani *et.al.*, 2012).

Sorghum production in 2009 was about 59 million tonnes of grain from 40 million hectars with an average productivity of 1.4 tonne/ha (FAO, 2011). Sorghum has been used traditionally for various foodstuffs, such as porridge, unleavened bread, cookies, cakes, couscous and various soft drinks and alcohols. Traditional cooking of sorghum is plentiful, cooked sorghum grain is one of the simplest products. Whole grains can be presented as ground flour or shelled before grinding, which then are used in different traditional foods (Munteanu and Tabara, 2012). In the Sudan, it is the main staple food for most of Sudanese and it comprised 80% by weight of the cereal crops grown in the Sudan. It is consumed in a number of ways, most notably as a flat bread or pancake (known as "*kisra"* and as a pudding known as "*acida"*). Large quantities of sorghum, particularly in the western and southern states are made into beer known as "*marisa*" (Hamid, 2001). Recently, sorghum has received significant attention because of the newer use as a Biofuel feedstock (Turki *et.al.*, 2011). The total area under sorghum production in the Sudan is estimated to be about 6.0 million ha. This area is about 73% of the total cropped area (Abdalla and Gamar, 2011). Only 10% of this area is irrigated and 90% under rain-fed conditions. Ishag and Ageeb (1987) reported that the average yield in the Sudan (250kg/fed) was 18% of that obtained at the research stations. Ahmed (2004) stated that sorghum yield in the Sudan is about 573.7 kg\ha. According to (FAO,2012) the average yield of sorghum varies widely from the high productivity country averages of 4.7 ton\ha (in the United States and Argentina) and 4.3 ton\ha (in China) to low productivity levels of 0.6 ton\ha (in Sudan), and 1.0-1.5 ton\ha (in India, Burkina Faso or Ethiopia).

Generally, average sorghum grain yields on farmers' fields are as low as 0.5–0.9 ton\ha because sorghum is often grown in marginal areas under traditional low input practices based on landraces. Alagab, (2005) reported that the average yield per unit area is very low (540 kg\ha) compared to the world average (1300 kg\ha). In Sudan, the crop is grown in rainfed areas and is highly affected by drought stress. These climatic changes adversely affect traditional sorghum growing areas in Sudan in North Gadaref, Gezira, Sennar, White Nile and North Kordofan States, Sudan is self sufficient in sorghum production and is able to export some, in years of good production (Mohammed *et.al.*, 2010). The relative adaptation to harsh environments makes sorghum a crop of outstanding potential to meet the global increasing demand of food (Mohamed *et.al.*, 2011).

2.2 Environmental requirements of sorghum

Sorghum belongs to C_4 plants, it tolerates abiotic stresses more than many crops (Turki *et.al.*, 2011). It requires warm climate but can be grown under a wide range of climatic conditions. The plant can tolerate high temperatures throughout its life-cycle better than any other cereal crop. It is adapted to a wide range of environmental conditions and particularly it is adapted to drought. This adaptation is relevant to morphological and physiological characteristics, such as an extensive root system, waxy bloom on the leaves that reduces water loss, and the ability to stop growth in periods of drought and resume when conditions become favorable again. The root system consists of fibrous adventitious roots that are normally concentrated in the top 0.9 m of soil but may extend to twice that depth and can extend to 1.5 m in lateral spread (Mohammed *et.al.*, 2010). Sorghum is a water efficient crop which makes it an important cereal in semiarid and arid environments where water is the main limiting factor of production. However, it must compete economically with other cereal crops, and to meet this challenge, the yield of sorghum must increase significantly (Tilman *et.al.*, 2002). Grain sorghum is often grown in environments where water stress is expected. However, sorghum yields under dryland conditions are much less than irrigated sorghum yields (Assefa *et.al.*, 2010).

2.2.1 Photoperiodism in sorghum

Sorghum is ashort-day annual grass (Rohbakhsh, 2013). In the tropics it often shows acute sensitivity to photoperiodism and the response is very closely adapted to latitude and the normal growing season (Craufurd *et.al*., 1999). Plessis, (2008) reported that sorghum is a short-day plant its optimum photoperiod (that induce flower formation) is between 10 and 11 hours. Photoperiods longer than 11 to 12 hours stimulate vegetative growth. He observed also that the tropical varieties are usually more sensitive to photoperiod than the quick, short-season varieties. Kenneth *et.al* (1976) stated that the vegetative bud does not flower until the day is short enough for the initiation of floral bud, which is called the critical photoperiod. Tropical sorghum appeared to be more photosensitive than temperate sorghum, and critical photoperiod varied greatly among tropical sorghum. (Miller *et.al., (*1968) reported *that* the flowering of tropical sorghum is delayed when day length is between 11.1 and 12.6 hr. Therefore, understanding of the control of flowering and growth in sorghum is important, because it relates to grain yield. Maiti, (1996) and Prasad *et.al.*, (2008a) stated that the tropical varieties are usually more sensitive to photoperiod than the quick, short-season varieties.

2.2.2 Temperature requirements

Temperature plays an important role in growth and development after germination. Sorghum is one of the crops that tolerates the harsh climate (as hot heat of air, little precipitation and most in semi-arid tropics) (Mobasher *et.al.*, 2012). The minimum temperature for germination of sorghum seed is 7-10 ^{o}C. It needs 26-30 ^{o}C temperature for its optimum growth. Though it can withstand temperatures up to 45 ^{o}C, but the lower temperatures (<8 ^{o}C) limit its cultivation owing to impaired flowering and pollination (Gangaiah, 2012). The mean optimum temperature range for grain sorghum is 21 to 35°C for seed germination, 26 to 34°C for vegetative growth and development, and 25 to 28°C for reproductive growth (Maiti, 1996 and Prasad *et.al*, 2008b). Plessis, (2008) stated that the minimum temperature for germination varies from 7 to 10 °C. He reported also 80 % of seed germinate within 10 to 12 days at 15 °C. Therefore, he concluded that best time to plant is when there is sufficient water in the soil and the soil temperature is 15 °C or higher at a depth of 10 cm. A temperature of 27 to 30 °C is required for optimum growth and development.The temperature can, however, be as low as 21 °C, without a dramatic effect on growth and yield. Under field conditions, a minimum soil temperature in the range of 15–18 ^{o}C is required for 80 percent emergence in 10-12 days. The crop thrives well in the temperature range of 16° to 40°C, though its performance is optimized at a mean temp of 27 °C (FAO, 2012).

2.2.3 Soil requirements

Sorghum is adapted to poor soils and can produce grain on soils where many other crops would fail **(**Mohammed *et.al.*, 2010). It is grown successfully in all types of soils with pH range from 5.5 to 8.5, but fertile and drained soil is important to optimize grain yield (Folliard *et.al.*, 2004)**.** Sorghum performed well in well irrigated clay soils. In places where irrigation or precipitation is not sufficient, loam soil is preferred for grain sorghum production because of its high plant-available water holding capacity. In soils having high bulk density, root growth might be restricted and water use will be negatively affected. The crop also can be grown in very heavy textured soils or in high rainfall areas (Assefa *et.al.*, 2010).

2.2.4 Water requirements

Crop water requirement is the water required by the plants for its survival, growth, development and to produce economic parts. This requirement is applied either naturally by precipitation or artificially by irrigation. The amount of water for sorghum is about 400 – 550 mm during growing season. The consumptive use (ET) of 110 to 130-day sorghum crops range between 450 and 750 mm, depending on evaporative demand. Seasonal water use is higher for late maturing genotypes because of longer growing periods (Chardrasekaran *et.al.*, 2010). Sorghum tolerates water logging and can also be grown in areas of high rainfall with 400 to 600 mm that are too dry for maize or in environments where water stress is expected (Mohammed *et.al.*, 2010). Sorghum water use is mainly affected by its growth stages and environmental conditions such as rainfall, temperature, relative humidity, solar radiation, and wind. For high production, a medium-to-late maturing sorghum cultivar (maturity within 110 to 130 days) requires approximately 450 to 650 mm of water during a growing season (FAO, 2002). However, the daily requirement varies greatly depending on the growth stage. Early in the growing season, average daily water use is low. Approximately 1 to 2.5 mm/day could be enough to avoid water stress. This period is roughly the first 25 to 30 days (up to approximately the 7-leaf stage), the water requirement then increases to around 7 to 10 mm/day until the boot stage. Maximum daily water use occurs from the boot stage until after anthesis. The daily water requirement then decreases gradually during grain filling as the crop begins to senesce leaves and matures (McWilliams, 2003, Stichler and Fipps, 2003). About 90% of the total water used by sorghum is extracted from a soil depth of 0 to 1.65 m. The rooting depth of sorghum, however, can extend to about 2.50 m. The water depletion zone for sorghum will vary with growing stage. Water stored at deeper soil depths (below 1.0 m) are an important source of stored water at the end of the growing season (Assefa *et.al*, 2010 and Assefa, 2010). In dry areas with low and/or erratic rainfall, the crop responds well to supplemental irrigation. However, considerable differences exist among cultivars in their response to irrigation. The timing of irrigation should aim to avoid water deficits during the critical growth stages of the crop, the period that starts at panicle initiation and ends at early grain filling. The number of irrigations normally varies between one and four, depending on climatic conditions, and soil texture (FAO, 2012). Although sorghum can tolerate short periods of water deficit, extended moisture stress slows plant growth and grain development that can reduce yields, especially if it occurs during critical reproductive stages when water needs are high (New, 2004).

2.3 Sorghum diversity in Sudan

Sorghum is a very important crop in the Sudan serving as a primary source of food, beverage, and total livelihood for millions of people in the country. The crop originated in the Northeast quadrant of Africa, and the Sudan is widely recognized as a major center of diversity. Although Sudanese sorghum germplasm has been assembled and stored over the last 50 years (Grenier *et.al*, 2004). Beyond the economic importance of the crop, Sudan is within the geographical range where sorghum is believed to have been domesticated for the first time, and where the largest genetic variation for both cultivated and wild sorghum is found (Suliman and Abdelbagi, 2016). Sudan's flora includes all the three wild sorghums believed to be the progenitors of cultivated sorghum (viz. *S. aethiopicum, S. verticilliflorum* and *S. arundinaceum*). It is also the home of perhaps five or six other wild Eusorghums, including S. sudenense (Sudan grass) which attained international importance for forage. These wild sorghums, and the sorgos, are represented in the World Collection (especially in Dr. J. Harlan's collection). The World Collection now includes some 3,000 entries of cultivated and wild Sudanese sorghums.

Removing the replicates may reduce them to 2,000 - 2,500 entries. FAO sorghum collection covered western and southern Sudan, from Gedarif, Singa, Roseiris and Kurmuk areas. Also researchers in Kadugli and El Obied made big collections in their respective areas, this collection well represents Sudan grain sorghums (Mohamed, 2011).

Collections from Kassala showed a higher frequency of landraces with kernels that were more difficult to thresh. Landraces from Blue Nile tended to have greater agronomic eliteness with higher proportion of landraces with white kernels, poorly covered and that were easy to thresh. Sorghums from the Upper Nile State tended to have loose panicles with poorly covered kernels that may result from adaptation to high rainfall of the Southern region. Although distinct distributions of sorghum types were represented by geographical origin, a high level of within-region diversity was present among all Sudanese sorghums (Grenier *et.al*., 2004). In adaptation zone (Gadarif area), the morphological characters of Feterita, Mugud, and Milo typess, indicating the strong differentiation among the sorghum materials (Abu Assar *et.al.*, 2005). Internationally, Sudan's sorghum germplasm has been utilized extensively and beneficially specially in USA. Other than the kafirs of southern Africa, no sorghum contributed to the crop's current high international status as did Sudan's feterita, milo, hegari, mugud, ziraizeera and Sudan grass types. Milo is one of the two parents whose combination gives the cytoplasmic malesterility which made sorghum hybrids possible (Mahmoud *et.al.*, 1995). Grenier *et.al* (2004) concluded that phenotypic diversity among Sudanese sorghum landraces was high, as expressed by the large range of variation for mean quantitative traits. Landraces from Gezira-Gedarif tended to be shorter in stature, earlier in maturity and less sensitive to changes in photoperiod. They also had long, narrow and compact panicles that may result from adaptation to low rainfall and early adoption of mechanized farming practices. Suliman and Abdelbagi (2016) studying the genetic variation of sorghum genotypes collection from Sudan. They reported that the considerable genetic diversity exists among the sorghum accessions collected from the three deferent regions (northern, eastern and western Sudan). Mohamed, (2011) studied 95 newly collected Sudanese sorghum accessions, he reported a highly significant difference among accessions for all of the traits. The result showed different distribution frequencies of morphological classes of panicle compactness and shape.

2.4 Improved and local sorghum genotypes in Sudan

Sorghum research has succeeded in diffusing a large number of new cultivars on farmers' fields. The last two decades of research have resulted in the release of some sorghum cultivars, most of the new cultivars are open-pollinated and early maturing, because the short-seasoned cultivars are generally adopted by farmers as part of a portfolio with other longer-season cultivars and it gives drought escape to take advantage of the years when rainfall is adequate or good (Miller *et.al*., 1996). In the Sudan many new sorghum cultivars were introduced in the early 1970s as combinable, high- yielding cultivars such as Dabar-1 and Gadam Elhamam-47 (Nichola and John, 1996). In the 1990s, three new cultivars were introduced (SRN-39, IS-9830 and M- 90393). From 1985 up to1996, irrigated sorghum increased its yield by 3%, whereas the mechanized sorghum decreased its yield by 0.3% per year. A sorghum hybrid, Hageen Dura-1 was released by the plant propagation and variety Release Committee in 1983. On average, this hybrid had a yield of 5789 kg/ha under irrigation and 2968kg/ha under rain-fed conditions (Smith and Frederiken, 2000). The contribution of Hageen Dura to yield has attracted interest over years, and a sound private seed industry might yet develop in the Sudan (Ejeta, 1993). The yield increases in the Gezira resulted from a combination of a high yielding cultivar (Hageen Dura-1), fertilization, and improved agronomic practices (Ahmed and John, 1992). ICRASAT and Sudan Agricultural Research Corporation (ARC) released many improved high yielding cultivars in irrigated and rain-fed areas. These are: Wad Ahmed cultivar (selected from a NARS cross from NARS parents and was released in 1992), Tabat cultivar (was selected from an ARS cross with ICRISAT parents and was released in 1996) and Dabar (was selected from an introduced landrace and released in 1978). Economic importance of sorghums to the Sudan encouraged sorghum scientists to release more productive varieties. According to the Sudan sorghum experts, three productive varieties (Wad Ahmed, Tabat and Dabar) account for more than half of the area under improved varieties (1.5 million hectares) (Ndjeunga *et.al.*, 2015). The cultivars Arose-Elremal and Yourwasha released by ARC its early maturing varieties, drought tolerant and suitable for rain-fed areas (Ahmed, 2009). Sudan's National Crop Variety Release Committee recently approved the release of four *Striga*-resistant varieties in the genetic backgrounds of popular, but *Striga*-susceptible, improved sorghum varieties "Tabat", "Wad Ahmed" and "AG8". These four experimental varieties released were "ASARECA.T1" (T1BC3S4); "ASARECA.W2 *Striga*" W2BC3S4; "ASARECA.AG3" AG2BC3S4; and "ASARECA.AG4" (AG6BC3S4). In Sudan, targeting different agro-climatic zones (Gezira, Damazine, Sinnar and Gedaref), a third popular, on the background of drought-tolerant, AG8 was added to that of recurrent parents "Tabat" and "Wad Ahmed," and the crossing program advanced to the third backcross generation (ICRISAT,2009). Sorghum lines $AG6BC_3S_4$, and $AG2BC_3S_4$ are promising varieties for drought prone areas of Sudan, because of their widely-effective for resistance of *Striga* and early maturity. Whereby sorghum lines $W2BC_3S_3$ and $T1BC_3S_3$, are promising varieties for *Striga* prone areas with intermediate to high rainfall and irrigated areas, because of their wide domain of resistance *to Striga* and intermediate maturities. This coupled with their high yield potentials as well as their large white grains. Compared to their parents Tabat, Wad Ahmed and AG-8 (*Striga* susceptible).The lines, $W2BC_3S_3$, $T1BC_3S_3$, $AG2BC_3S_3$, and $AG6BC_3S_3$, were compared with Ajab-Sedo and Korokolo, at Gedarif State in grain yield and quality, a satisfactory grain yield was obtained even under unfavorable low inputs environments. Farmers also reported that, these lines have high kisra (sorghum bread) making qualities and plants are leafy with juicy and sweet stems which improve forage quality (Mohamed *et.al.*, 2014).

Also in The Sudan, there are many land races and varieties of grain sorghum, the diversity of local varieties expresses a wide range of adaptability to different conditions, including different genotypes from early to late maturing, dwarf to tall, loose to compacted heads, white and red seeded (Elnaim *et.al.*, 2012). In Gadarif state the dominant varieties grown are the traditional Feterita types e.g. Arfa Gadmek, Abdalla Mustafa and Korolo. Tetron, Abu teman, wad Elmubark and Dabar are grown on a limited scale. Some progressive farmers in south Gadarif grow the improved varieties, Wad Ahmed and Tabat (Abu Assar *et al*., 2005). Adam and Ali (2014) reported that the local varieties Karamaka, red Mogod and Yellow Mogod dominant in South Kordofan, the variety red Mogod showed a high yield in spite of severe stem borer infestation that means this variety is tolerant to stem borer damage. In North Kordofan State, Nagad landrace from Feterita types and Zinnari group were domesticated there. Zinnari varieties (Qusari, Wad-mergani, Sefera Red-Zinnari, Fraikh, Hamadi, Nilla and Kelash) are known to out yield local varieties on sandy soils of Kordofan under low rain fall conditions. Zinnari lines are white- seeded types that meets the consumption habits of peoples, thus selection of adapted high yielding lines is highly accepted by consumers (Elnaim *et.al.*, 2012).

2.5 Sorghum water deficit (moisture stress)

Water deficit (commonly known as drought) can be defined as the absence of adequate moisture necessary for a plant to grow normally and complete its life cycle (Moosavi *et.al*., 2011 and Malala, 2010). Drought occurs in high as well as low rainfall areas. Farmers term drought as deficient rainfall, lack of moisture or a dry spell resulting in low crop yields including crop failure. Drought is a condition relative to some long-term average condition of balance between rainfall and evapotranspiration in a particular area, a condition often perceived as normal. Agricultural drought is usually defined as a period when insufficient water is available to support the normal activities of a crop over a fairly normal long period of time of a fortnight or more depending on stage of crop. Intensity of drought is a ratio of actual evapotranspiration (AET) to potential evapotranspiration (PET) during the growing season. (Vittal *et. al*., 2003 and Mohammadai *et.al*., 2012) reported that drought stress is one of the most important environmental factors in reduction of growth, development and production of plants. It can be said that it is one of the most devastating environmental stresses. Drought is a multidimensional stress often coupled with heat stress affecting plant at various levels of their metabolic mechanisms, and is generally accepted as the most widespread a biotic stress experienced by crop plants (Blum, 1996). Ravikumar *et al*., (2003) reported that drought is the main problem as the entire crop growth from germination to maturity depends on residual moisture content. Drought stress response in sorghum depends on the stage of growth in which the drought stress occurs. In general sorghum has three stages. Growth stage I (GS1) is the vegetative stage that begins with germination and ends at panicle differentiation. Growth stage 2 (GS II) is the pre-flowering or reproductive phase of growth ranging from panicle differentiation until the cessation of anthesis. Growth stage 3 (GS III) is the post-flowering or grain fill phase that begins immediately after anthesis and continues until physiological maturity of the grain. This division of growth stages is particularly useful in classifying drought reaction, as in each stage the drought resistance reaction is controlled by different mechanisms (Rosenow *et.al.*, 1997).

2.5.1 Types of agricultural droughts

Drought is a climatic anomaly characterized by deficient supply of moisture in rooting zone of soil resulting either from sub-normal rainfall, erratic rainfall distribution, higher water need or a combination of all the three factors (Vittal *et.al.*, 2003). Drought is a worldwide problem, constraining global crop production seriously and recent global climate change has made this situation more serious (Moosavi *et.al.*, 2011 and Kanbar *et.al.*, 2013).

2.5.1.1 Early season drought

Early season drought generally occurs either due to delayed onset of rain or due to prolonged dry spell soon after the onset of rainy season. This may at times result in seedling mortality needing re-sowing for good establishment of seedling growth. Therefore, for characterization of early season drought, information on optimum sowing period for different crops/varieties, quantum of initial rainfall spell expected and its ability to wet the soil profile enough to meet the water requirements for better germination and establishment is essential. Further, the duration of the water availability for crop growth gets reduced due to the delayed start and the crops suffer from acute shortage of water during reproductive stage due to early cease of rains. The effect of early season drought is less on the crop, because during this period sowing is carried out (Vittal *et.al.*, 2003).

2.5.1.2 Mid season drought

Mid season drought occurs due to inadequate soil moisture availability between two successive rainfall events during the crop-growing period (Vittal *et.al*., 2003). Its effect varies with the crop growth stage and the duration and intensity of the drought spell. Stunted growth takes place if it occurs at vegetative phase and if it occurs at flowering or early reproductive stage it will have an adverse effect on ultimate crop yield (Rohbakhsh, 2013).

2.5.1.3 Terminal drought

Late season or terminal droughts occur as a result of early cessation of rains. Terminal droughts are more critical as the grain yield is strongly related to water availability during the reproductive stage. Further, these conditions are often associated with an increase in ambient temperatures leading to forced maturity (Vittal *et.al.*, 2003). In this context serious attempts have been made in sorghum and other crops to understand the mechanisms of drought tolerance, and to identify and improve genotypes tolerance to moisture stress. Drought tolerance depends on the plant developmental stage at the onset of the stress syndrome, which in sorghum may happen during the early vegetative seedling stage, during panicle development and in post-flowering, in the period between grain filling and physiological maturity (Sabadin *et.al*., 2012).

2.6 Mechanisms of moisture stress tolerance on sorghum

Joffre and winkel (2001) found that under dry environmental conditions plants develop different mechanisms to resist and survive. These mechanisms are commonly based on morphological and physiological responses such as leaf area index (LAI) reduction that delay the water deficit (Nakoda *et.al.*, 2000). Sorghum has some mechanisms that help the plant cope with drought such as, the prolific root system, the ability to maintain stomatal opening at low levels of leaf water potential and high osmotic adjustment (Machado and Paulsen, 2001). Sorghum can extract water from deep in the soil profile and remove most of the apparent available water because it has more secondary roots per unit of primary roots than other cereal crops. And it has the ability to maintain stomatal opening at low levels of water potential and under a wide range of leaf turgors. Also leaves and stems of many sorghum varieties are covered with a waxy bloom substance, beside the cuticle and epicuticular wax structure of the leaf. Under water stress, sorghum leaves can become erect and roll. This will decrease the leaf surface area exposed to incoming solar radiation and, consequently, water loss. Lower leaves in the canopy and older leaves can senesce during water stress that occurs during grain filling and this also allow sorghum to maintain yield under severe stress (Assefa *et.al.*, 2010).

An important of crop adaptation is to match crop development phases or stages with optimum environmental conditions; among others, the timing of flowering is critical. If flowering is too early, plant growth may be insufficient to produce a minimum amount of biomass compatible with reasonable yields (Mayers *et.al*., 1991). Agronomic and physiological differences such as osmotic adjustment, epicuticular wax content, leaf water potential, canopy temperature, leaf rolling and stomatal conductance are some reasons that have been indicated for drought response variation between sorghum varieties (Assefa *et.al.*, 2010).

2.6.1 Drought escape

Drought escape is the ability of a plant to grow and complete its life cycle before soil moisture and plant water deficit develop. This mechanism involves rapid phenological development such as, early flowering and early maturity, developmental plasticity and remobilization of pre-anthesis assimilates to grain (Turner, 1986). Drought escape is a particular important strategy of matching phonological development with the period of soil moisture availability to minimize the impact of drought stress on crop production in environments where season is short and terminal drought stress predominates (Ahmed, 2005). Crop species displaying this type of adaptation are often photoperiod sensitive so that flowering coincides with the average date of the end of the rainy season (Blum, 1979).

2.6.2 Drought avoidance

Blum (1988) defined drought avoidance as the ability of the plant to retain a relatively higher level of moisture content under condition of soil or atmospheric water stress. Mohamed (2013) reported that Avoidance is accomplished by decreasing water loss from the shoot or by more efficiently extracting moisture from the soil. It is an alternate mechanism by which plants can maintain positive tissue water relations even under limited soil moisture conditions. Mechanisms of drought avoidance typically involve water conservation at the whole plant level. The usefulness of dehydration tolerance can be realized when it is placed in a genetic background that has other mechanisms related to maintenance of production under moisture deficit environment. Drought avoidance involves rapid phenological development, leaf rolling, leaf shading, reduced leaf area and increased stomata and cuticular resistance (Ahmed, 2005). Drought avoidance mechanisms can be divided into water conserving mechanisms and water collecting mechanisms. Water conserving mechanisms decrease water loss and reduce leaf growth, increase stomatal and cuticular resistance and accelerate leaf senescence, whereas water-collecting mechanisms are extended root growth and decrease resistance for water up take through the roots (Yambao *et.al.*, 1992).

2.6.3 Drought tolerance

Drought tolerance is defined as the relative ability to sustain plant function under dehydrated state and achieving an economic yield potential (Blum, 2005, and Alhajturki *et.al*., 2011). Rosielle and Hambling (1981) defined drought tolerance as the difference in yield between stress and non stress environment. Hall *et.al* (1993) defined drought tolerance as the relative yield of genotype compared to other genotypes subjected to the same drought stress. Blum (1988) stated that drought tolerance comprises drought escape, dehydration avoidance and dehydration tolerance mechanisms. Plants tolerate drought by maintaining sufficient cell turgor to allow metabolism to continue under increasing water deficits (Machado, 2001). Levitt (1980) reported that tolerance mechanisms as the ability of the crop to survive and maintain all metabolic functions under water stress. Drought tolerance mechanisms are generally those that occur at the cellular and metabolic level. These mechanisms are primarily involved in turgor maintenance, protoplasmic resistance, and dormancy (Beardm and Sifers, 1997).

2.7 Seed quality

Seed is the basic unit which determines the stand establishment and possibly the growth and yield of all crops. Therefore, the use of high quality seeds for planting is a major requirement for high and reliable yield of crops. High quality seed is characterized as being the seed that has the ability to establish a full stand of vigorous and uniform seedling that will grow into productive mature plant (Declouche, 1969). The main aspect of seed quality include physical and genetical purity, high germinability, uniform size, free from seed born diseases and low moisture content. Seed quality can be subjected to various degrees of deterioration during seed processing, such as time of harvesting, mechanical damage during harvesting and handling conveying and cleaning (Abdul Baki and Andrerson, 1973 and Tekrony *et.al*., 1980). Seed quality includes several attributes that lead to near maximum germination capacity to produce seedlings, which emerge rapidly from the seedbed and continue to grow uniformly thereafter (Harrington, 1971).

Sorghum seed with either limited or fully controlled conditions maintained seed moisture, viability, germinability and field emergence close to that of newly harvested seed (Ahmed, and Alamam, 2010).

2.7.1 Germination as index of quality

Association of Official Seed Analysis (AOSA,1996) defined laboratory germination as the emergence and development from a seed embryo those essential structures which for the kind of seed in question are indicative of the ability to produce a normal plant under favorable conditions. It has been further remarked that testing under field conditions or similar conditions is usually unsatisfactory as the results of such tests can be duplicated with reliability. Thus, germination tests must be carried out under favorable laboratory conditions which permit reproducible results. The germination test was inadequate to predict field emergence in most crops under adverse field conditions emphasized further investigation for a more appropriate vigour measurement.

2.7.2 Seed vigour as index of quality

Vigour is the sum of all seed attributes which favour rapid uniform stand establishment in the field. This definition includes both favorable as well as unfavorable field conditions. It also introduces uniformity of stand establishment as a quality factor. Other definitions of seed vigour related to the direct test include those of Ader (1965). Heydecker (1969) defined vigour as the ability to germinate and produce a stand in a suboptimal environment and suggested that vigour is a scientifically vague term which when applied to seeds is taken to denote that they are likely to perform particularly well in the field, better than others which may be equally satisfactory in the laboratory test. Nutile (1964) refers to vigour as the ability of the seeds to produce vigorous seedlings as compared to the maximum vigour attainable for the species under similar conditions. Woodstock (1969) defines vigour as that condition of active good health and natural robustness in seeds which upon planting permits germination to proceed rapidly and to completion under a wide range of environmental conditions. Perry (1972) proposed the following definition: 'seed vigour is a physiological property determined by the genotype and modified by the environment, which governs the ability of a seed to produce a seedling rapidly in soil and the extent to which the seed tolerates a range of environmental factors. Seedling vigor is one of the most important components of crop growth in all environments. In arid areas, crops with high seedling vigor and good stand establishment are capable of using the little available soil water, and ultimately result in higher biomass accumulation and increased grain yield. The effect of seedling vigor can be directly reflected on grain yield since it is associated with vegetative growth processes that ultimately affect production (Cisse and Ejeta, 2003).

McDonald and Wilson (1980) stated that the basic requirements of vigor testing include the ability to provide more sensitive index of seed quality than the germination test and to provide consistent ranking of seed lots in terms of potential performance in the field. Mutava, (2009) reported that seedling vigor under all environments is an important indicator of a successful crop. The major seedling vigor traits include seedling height, dry weight and growth rate. Heydecker (1969) reported that lack or decrease of vigour can express itself in a number of important ways, for instance, rapid deterioration during storage, narrowing of the environmental conditions under which a seed will germinate, uneven or delayed germination, susceptibility to relatively mild microorganisms, slow seedling growth and low yield. According to Grabe (1973), vigour may affect the quickness of stand establishment, density of stand, rate of seedling and plant growth, the time of flowering and maturity, uniformity of flowering and maturity, and when the vigour is low enough, yield can be reduced. Longevity of seeds in storage is also affected by their vigour. He concluded that good seed vigour is related to faster growth, better stands and better performance. Vigour is most critical in those crops that are planted to a stand, than are annual crops, where uniformity of maturity is essential. Funk *et al* (1962) found that corn plants produced from weak seeds, as indicated by vigour tests, were lower in emergence, smaller in the seedling stage and lower in yield than plants from strong (high quality) seeds. Inouye and Ito (1969) stated that the rate of seedling growth has been used as a measure of seed vigour and usually estimated by measuring seedlings after a specified period. Tonkin (1969) reported that vigours seedling showing normal development of leaves and root system and seedlings a quarter or more the size of the largest are classified as normal. Weak seedlings and seedlings which emerge with cotyledons but no true leaves are classified as abnormal. Stahl (1931, 36) used speed of germination as a vigour test because he reported vigorous seeds showed rapid germination, and he defined germination speed as the percentage germination at the first count. In a number of comparative tests he showed that the routine germination test was not dependable as a measure of the plant-producing power of seed samples under field conditions.

2.7.3 Factors influencing seed vigour

Seed vigour is influenced throughout the life of the seed by several factors, the important ones are:-

2.7.3.1 Environmental factors

a. Rainfall and soil moisture: According to Austin (1972) hot and dry periods before and at harvest time generally give good seed. Saler and Goode (1967) reported that for many cereals and other annual crops, the period when the floral organs are developing is particularly sensitive to drought. Mean seed weight can be reduced by drought experienced after fertilization.

b. Temperature: Generally, different species have different temperatures for their germination. Robertson *et.al.,* (1962) working with pea plants grown in a range of controlled temperatures, they found that when photoperiod and light intensity were held constant, the growth of the seeds was much more rapid at high than at low temperatures and that the final seed size attained was greatest. Generally, drying seeds at high temperatures can severely affect their vigour.

c. Photoperiod and light quality: According to Thomas and O'toole (1980), seeds of many species, have light sensitive germination responses which are phytochromecontrolled. Exposure to red or far-red light will stimulate or inhibit germination under favorable environmental conditions. According to the International Seed Testing Association rules, for some kinds of seeds light from a cool white fluorescent source promotes germination, more effectively than either daylight or light from an incandescent filament, which contain far-red radiant energy that is inhibitor to germination.

d. Mineral nutrition: Harrington (1960) working with various species grown under severe nitrogen deficiency, found that deficient plants gave very low yields of seed compared with those from control plants, and much of the seed was abnormal. Fox and Albrecht (1957) found that wheat seeds with high crude protein content (14.4%) germinate and emerge more rapidly and gave greater and more vigorous seedlings than low protein (11%) seeds.

2.7.3.2 Seed moisture content

Harrington (1977) investigated that seed moisture content is the most important determinant of longevity in storage, the rule of them was that for each one percent decrease in seed moisture content, storage life double. Ibrahim and Roberts (1983) reported that there was a decrease in longevity of lettuce seeds, with increase in hydration up to moisture content of 15%. Singh (1987) found that sorghum seeds remain viable maintaining the initial viability percentage of 95% up to 21 months when stored in cloth bags.

2.7.3.3 Seed maturity and size

According to Chen *et.al* (1972) seeds are physiological mature and highest in vigour when they attain maximum dry weight. They regarded seed maturation as a positive process leading to highest physiologically quality. Black (1959) reported that within a species and seed lot, large seed gave superior field emergence especially when the seeds were sown deeply. Kneebone and Cremer (1955) working with five grass species showed that for all the species, within a lot, large seeds were superior in days to 50% emergence, in the final percentage emergence, in seedling height and in fresh weight. Although some reports show no correlation between seed size and vigour, most of the reports show that other factors being equal, larger, heavier or denser seeds are the most vigorous.

2.7.3.4 Genetic effect

Whittington (1973) from his studies on genetic regulation of germination concluded that germination characteristics are at least partially under genetic control and the particular pattern of behavior in a cultivated or wild species is likely to have been the result of selection. Classified genetic effects on germination into those due to major genes, possibly controlling specific inhibitors, and polygenic effects, perhaps related to seed size. He concluded that: much of the variability in germination characteristics is likely to appear to be due to polygenic effects.

2.8 Implication of water stress on sorghum

Among the environmental stresses, water is one of the most severe stress for plant growth and productivity. Water stress affects virtually every aspect of plant physiology and metabolism, it reduces both nutrient uptakes by the roots and transport from roots to the shoots, due to restricted transpiration rates and impaired active transport and membrane permeability. Water stress in plants, particularly in post-rainy season and during dry spells in rainy season is a common phenomenon. It is characterized by decrease in osmotic and total water potential, accompanied by loss of turgor, reduced diffusion of carbon dioxide into plant leaves, and therefore, reduction in photosynthesis and decrease in growth. However, the plant response to water stress is governed by soil, plant, and environmental factors. The degree and duration of water stress and the growth stage, at which it occurs, considerably modify the crop response (Vittal *et.al*., 2003).

Moisture limitation affects yield by depressing both sink and source depending on the timing and severity of stress with respect to plant phenology (Blum, 1996). The effect of water stress is a function of genotype, intensity and duration of stress, weather condition, growth and developmental stages of different crop plant species (Berenguer and Faci, 2000). The major yield components such as panicle weight, panicle length and grain mass are developmentally correlated not only among themselves but also with several physiological traits affecting grain yield (Blum, 1979). During dry periods, sorghum has the ability to remain in a virtually dormant stage and resume growth as soon as conditions become favorable. Even though the main stem can die, side shoots can develop and form seed when the water supply improves (Tuinstra *et.al.*, 1997). Sorghum has the capacity of producing tillers under certain limiting conditions, which contribute in an important way to the final yield of the crop. Thus, a low plant density, under adequate irrigation conditions, can be compensated by a high number of grains per panicle and high weight of the grain. The main effects of water stress on growth stages of sorghum are summarized in the followings:

2.8.1 Effect of Water Stress on Sorghum (growth and yield)

2.8.1.1 Effect of Water Stress on stand establishment

Sorghum stand establishment is dependent on seed germination and emergence; drought can cause loss in a sorghum crop after full emergence before plant establishment (Blum, 1996). Water stress of seedlings could be caused by drought, high soil temperature or high salt concentration during seedling even the drought occurrence under field condition, due to low amount of water requirement at early stage. Water stress at the seedling stage will reduce endosperm weight of the planted seed, radical, shoot and root of sorghum (Jafar *et.al*, 2004). On plant emergence and establishment, the effect of drought in first 2 to 4 weeks may affect initial vigour but may not have dire consequences on yield. Stress during the seedling stage results primarily in poor crop establishment, grain yields are reduced by such stress mainly through losses in plant stand. Stress occurring after crop establishment (but still within the seedling phase) generally has very little effect on grain yields either in millet or in sorghum (Lahiri and Kharbanda, 1965, Lahiri and Kumar, 1966).

2.8.1.2 Effect of Water Stress on growth and development

Plant water stress, often times caused by drought, can have major impacts on plant growth and development. When it comes to crops, plant water stress can be the cause of lower yields and possible crop failure. The effects of plant water stress vary between plant species. Early recognition of water stress symptoms can be critical to maintaining the growth of a crop. The most common symptom of plant water stress is wilt. As the plant undergoes water stress, the water pressure inside the leaves decreases and the plant wilts. Drying to a condition of wilt will reduce growth on nearly any plant (Bauder, 2008). According to Hayat and Ali (2004), moisture stress is a limiting factor for crop growth in arid and semi-arid regions due to low and uncertainty precipitation. Water stress due to drought is probably the most significant a biotic factor limiting plant and also crop growth and development (Hartmann *et.al*., 2005). Water shortage is a critical problem limiting growth through impact on anatomical, morphological, physiological and biochemical processes.

The severity of drought damage depends on stress duration and crop growth stage (Setter *et.al*., 2001, Saeed *et.al.*, 1997, Medeiros *et.al.*, 2000). Increasing water stress resulted in decrease in plant height. Because, water stress led to reduction in water potential of stem cell to a lower level needed for cell elongation and consequently, shorter inter nodes and stem height (Boyer, 1988). Nouri (2005) stated that stressed plants at the end of the season were significantly taller compared to the well-watered plants, and the cultivars differ on mean plant height. Hale and Orcutt (1987) found that water stress reduces the rate of cell expansion and ultimately cell size and consequently, growth rate, stem elongation and leaf expansion. The effect of irrigation stress was significant for stem diameter. One of the effects of low water availability is the reduction of stem diameter due to lower radius growth of stem. In this condition, the main stem and lateral branch growth are suppressed and thus a lower stem dry matter will be obtained (Garg *et.al*., 2004, and Samarah, 2004).

Water-stressed sorghum showed larger root/shoot ratio and root length than without water stress conditions (Joffre *et.al*., 2001, Xu and Bland, 1993). Rohbakhsh (2013) showed that the leaf number and tiller number of sorghum plants decreased dramatically with the increasing of water stress levels, while Nouri (2005) and Kabbashi (1991), stated that the number of leaves per plant was not affected by water stress. Bauder (2008) reported that leaf growth will be affected by moisture stress more than root growth because roots are more able to compensate for moisture stress. Sher *et.al* (2013**)** reported that plant height significantly varied among cultivars and moisture levels in the three growth stages. Garg *et,al*., (2004) and Samarah *et,al*., (2004) found that tiller number of sorghum plants decreased dramatically with the increasing of water stress levels. Karimi and Siddique (1991) stated that water deficit stress through the reduction in the leaf area index and plants photosynthetic capacity reduces crop growth rate and eventually total dry matter.

2.9.2. Effect of Water Stress on reproductive growth

The reproductive stage is the most critical stage for drought stress during crop growth, because it strongly impacts yield and seed quality (Alqudah *et.al*., 2011,) Soil water deficits that occur during the reproductive growth are considered to have the most adverse effect on crop yield (Costa-Franca *et.al*., 2000, Samarah 2004, Samarah *et.al*., 2009). The reproductive period duration, the time period between the beginnings of rapid seed fill and physiological maturity can be affected by water stress (Younesi and Moradi, 2009). The effects of stress on the phenology of sorghum depend upon the severity of the stress itself and on the stage of development of the crop at the time of stress. When the stress is not too severe, as often observed under near-optimum environments, the phenological responses are not apparent; effects are mainly on growth and yield. In the variable moisture environment, however, effects on phenology can be very evident, particularly when stress occurs before flowering (Seetharama *et.al.*, 1984). When water is scarce, vegetative growth may become limiting, increasing the length of the pre-flowering phase, which may increase the size of both canopy and root system. Cultivars with longer vegetative period may have deeper root systems and better capacity of extracting water from deeper soil layers than early flowering ones (Dardanelli *et.al*., 2004). In contrast, long-cycle cultivars may deplete more water before the critical periods (Edwards and Purcell, 2005), generating themselves a stronger stress when crop yield is most sensitive under these circumstances early-flowering cultivars may produce larger yields when moisture stress develops late in the season (Kane and Grabau, 1992).

2.9.2.1 Effect of water stress on flowering stage

Reproductive development at the time of flowering is especially sensitive to drought stress. Therefore, an understanding of how a reproductive process affected by drought is of particular interest for improving drought tolerance (Sinclair and Jamieson, 2006). The flowering period of a crop is a critical growth stage and a yield determinate factor in normal growing seasons and in drought stressed regions in particular. An understanding of how crop plants respond to drought stress during reproductive stage is important in maximizing yields in water-limited (Tewolde *et.al*., 2006).

The appropriate matching of the pattern of flower/inflorescence development, the time of flowering, flowering opening and period to the temporal variation in water availability is recognized as one of the most important traits conferring adaptation to drought, and the time required for flower development under drought stress was less than the time usually required by normal plants (Bidinger *et.al*., 1987, and Passioura 1996). The effects of drought on floral meristems are among the least understood aspects of crop reproductive development under water-limited conditions. Abdelrahman (1985) and Ahmed (1989) reported that there were no differences between stressed and non in number of days to 50% anthesis. In contrast, Nouri (2005) reported that stressed plants significantly had taken stressed sorghum genotypes fewer days to reach 50% flowering compared to the well-watered plants.

Drought stress is a main abiotic stress that limits crop pollination by reducing pollen grain availability increasing pollen grain sterility (Schoper 1986, Al-Ghzawi *et.al*., 2009). Pollen grain is sensitive to drought stress because its early stage in reproductive growth and its need for sufficient water and energy to complete growth/development process. Drought stress affects on pollen grain viability by blocking the process of pollen grain germination and development (Lee, 1988).

Lahiri and Kumar (1966) stated that if the stress is terminated at or before flowering, the reductions in yield are small (less than 20%), because this is a less sensitive stage of development. if the stress extends to the post-flowering period, yield reduction is more severe. Drought stress negatively affects flower pollination by decreasing the amount of viable pollen grain, increasing the unattractiveness of flowers to pollinators, and decreasing the amount of nectar produced by flowers (Alqudah *et.al*., 2011). Water stress detrimentally affects flower induction, pollen production and subsequently leads to failure of fertilization and hence grain set. Water stress during flower induction and inflorescence development leads to a delay in flowering, or even complete inhibition of flowers (Assefa *et.al*., 2010).

2.9.2.2 Effect of Water Stress on seed set stage

Seed set is affected by all development and growth processes in reproductive stage such as pollen grain and ovary development under drought stress. It’s strongly correlated with yield. Drought stress reduces megagametophyte fertility and decreases seed set and seed development and can also reduce seed set percentages (Al-Ghzawi *et.al*., 2009 and Young *et,al*., 2004). Drought stress that was imposed on plants leads to decreased yield through reducing seed set (Al-Ghzawi *et.al*., 2009). Low seed set percentages are regularly related to several factors such as reducing pollen grain availability. Grain yield and seed set reductions in small grains under drought stress are likely due to ovary abortion or pollen sterility (Boyer and Westgate, 2004).

2.9.2.3 Effect of Water Stress on maturity stage

Most of reported research on the effect of drought on seed quality has been on plants exposed to drought stress during seed filling stage (Alqudah *et.al*., 2011). Water stress during the grain filling period (GS3) which is the last critical stage of the plant life cycle, resulted in 14.7% reduction in days to physiological maturity (Ahmed, 1989). Nouri (2005) showed that stressed plants took significantly less days to reach milking and maturity stages compared to the well-watered plants which took more days to reach these stages. Stress during post-flowering stage will affect filling rate and duration and result in a significant reduction in grain weight because of small seed size (Mutava, 2009).

2.10.3 Effect of water stress on yield and its components

As with all crops, sorghum grain yield is dependent on water supply (soil water at planting and in-season precipitation), the relationship between grain yield and water is complex because yield is more sensitive to water deficits at certain growth stages. Therefore, grain yield is more dependent on rainfall or irrigation well distributed over the growing season depending on demand at each stage than on total water available through the growing season (Agueda, 1999 and Samarah, 2004). Water stress had a significant effect on number of grains per head and grain weight, in this regard; number of grains per head and grain weight tended to increase in well watered plants compared to stressed ones (Nouri, 2005). Similar results were reported by Bakhiet (1990) and Ahmed (1989) they found that water stress reduced the mean grain yield per plant, panicle weight and 1000 grain weight due to its effect on flowering and grain filling. Eck and Music (1979) reported that yield decreases due to water stress at early boot were due to both reduced seed size, seed number and yield reduction due to stress at heading. The individual grain weight in cereals was also reduced by drought stress, which could be attributed to shorter grain filling duration and lower accumulation of dry matter in the growing kernels or as a result of the reduction in the rate and duration of starch accumulation in the endosperm (Garcia, 2003 and Samarah *et.al.*, 2009a).

Water limitation had significant effect on grain yield and yield components, plants under full irrigation had more grain yield and yield components than the other irrigation levels due to longer growth season and better use of environmental conditions, while withholding irrigation at eight-leaf stage decreased grain yield and its components. Also the number of seed per head was reduced significantly by drought imposed during vegetative and reproductive growth stages of sorghum (Younesi and Moradi, 2009).

Irrigation treatment had significant influence on number of seeds per row, 1000 seed weight, seed yield, biological yield and harvest index. The highest of seed yield and biological yield was achieved in Irrigation treatment, and had significantly different from other treatments, (Mohammadai *et.al*., 2012). Water stress at the vegetative stage alone can reduce yield more than 36%, and water stress at the reproductive stage can reduce yield more than 55% (Assefa *et.al*, 2010). Water stress during panicle initiation would reduce panicle size and potential grain number, while stress at early grain filling would cause abortion of youngest developing grains and reduce weight per grain (FAO, 2012). Samarah *et al* (2009) and Ekanayake *et.al.*,(1989) found that drought stress decreases straw yield and harvest index. Eck and Music (1979) reported that 13 to 15 days of stress did not affect grain yield, 27 to 28 days reduced the yield by 12 – 27% and the stress at beginning of boot stage reduced grain sorghum yield by 54%. New (2004) reported that short periods of water stress just before and during the booting growth stage reduced yields quickly and reduced both the number and size of seeds per head. Wood *et.al.*,(2006) that a gradual decrease in the grain weight and number per panicle as water stress increased but the weight per thousand grains was less sensitive than grain weight and grain number per panicle. In sorghum, the major yield components like panicle weight, panicle length, panicle width, grain mass and plant height are significantly affected by moisture stress (Ravikumar *et.al*., 2003).

Several studies have shown that water deficits imposed during the reproductive development of dry beans can decrease number of pods per plant and number of seeds per pod (Loss and Siddique, 1997). In general, number of pods per plant seems to be the most yield component affected by drought stress during flowering and can reduce final grain yield up to 70% depending on the duration and intensity of the stress period (Lopez *et.al*., 1996). [Zerbini and Thomas, 2003, Nakoda *et.al*., 2000] were reported that water stress reduced quantitative and qualitative yield in forage sorghum. Mutava, (2009) concluded that grain sorghum the most sensitive to drought stress during panicle initiation before flowering, stress at pre-flowering and flowering period will result in poor seed set and hence lower seed numbers and therefore lower yields.

Mean number of panicles per m^2 and grain weight was reduced by water stress (Blum *et.al*., 1989). Declines in total grain yield under the drought stress treatments are due to the reduction in grain yield components, such as grain number per spike (Garcia 2003, Samarah 2004), and spike number per square meter and individual grain weight (Garcia, 2003). Under water stress, the genotypes of longer growth duration produced more stover and total biomass with a lesser amount of grain per panicle and per unit area, as compared with genotypes of shorter growth duration. However, Harvest index varied extensively among genotypes, and it was decreased or increased by water stress (Blum *et.al*., 1989).

2.10.4 Effect of water Stress on plant physiological processes

In addition to its complexity and frequency, drought can be the core cause for other major sorghum production problems. For example, drought can reduce nutrient uptake by roots and induce nutrient deficiency by decreasing the diffusion rate of nutrients from soil to root, creating restricted transpiration rates and impairing of active transport and membrane permeability. Increasing water stress can cause a decrease in the leaf potential of sorghum. At low leaf potential, stomata will close, the abscisic acid level will become elevated, and the amount of starch in the bundle sheath chloroplasts will be reduced (Assefa *et.al*., 2010). Drought occurs when moisture around the roots is so reduced that a plant is not able to absorb enough water, or in other words with transpiration of water absorption (Benjamin, 2007). Drought stress is physiologically related, because induced osmotic stress and most of the metabolic responses of the affected plants are similar to some extent (Djibril *et.al*., 2005). Water shortage results in inhibitions in the photosynthetic processes causing reductions in nutrient supply (sucrose) to the reproductive organs (Campbell, 1996). An insufficient supply can block the development of reproductive structures and cause kernel abortion (Westgate and Boyer, 1986). Large amounts of carbohydrates were moved from the stems to the grain that made up for the lack of current photosynthesis (Westgate and Boyer, 1985). Drought stress was found to breakdown the ovary starch (Zinselmeier *et.al*. 1999, Andersen *et.al*. 2002) and the delivery mechanisms of sugars more than the release mechanisms of sugars from the carbohydrate reserves in the parent plants. Water stress affects virtually every aspect of plant physiology and metabolism. It reduces both nutrient uptake by the roots and transport from roots to the shoots, due to restricted transpiration rates and impaired active transport and membrane permeability (Yuncai and Schmidhalter, 2005).

The moisture stress decreases assimilate supply by decreasing leaf area and duration and disrupting nutrient intake and transfer and hence, it decreases yield components and yield, although stomata closure generally occurs when plants are exposed to drought, but water stress is a multi-dimensional stress, which causes different physiological and biochemical effects on plants. Such effects may contain reduction in cell division and thus retardation of cellular growth, decrease in photosynthesis, closure of stomata and changes in the amount of chlorophyll (Bohnert and Jennen, 1996, Tabaeizadeh, 1998). Water stress severely affects the seedling biomass, photosynthesis, stomatal conductance, plant water relations and starch metabolism (Farooq *et.al.,* 2009). During moisture stress, stomata close to conserve water, this also closes the pathway for the exchange of water, carbon dioxide, and oxygen resulting in decreases in photosynthesis (Bauder, 2008).

2.10.5 Seed quality under water stress effects

Drought stress not only affects seed production, but also affects seed quality such as germination and vigor tests. . Seed quality, estimated by standard germination, was lower for seeds harvested from plants grown under drought than seeds harvested from irrigated plants (Drummond *et.al.*, 1983). Smiciklas *et.al* (1992) reported that drought stress, at the beginning of seed filling, reduced seed germination percentage, seedling dry weight, and increased the electrical conductivity of seed leachate. The effect of early-season temperature stress was highly significant for seedling height, seedling vigor and seedling dry weight (Mutava, 2009). The reduction in seedling growth under water stress was expected because the growth rate of plant cells and the efficiency of their physiological processes are highest when the cells are at maximum turgor (Achakzai, 2009a, Achakzai and Bazai, 2007). The reduction in germination percentage under the stress was approximately 9% compared with non-stressed plants (Smiciklas *et.al.*, 1992). Abnormal seedlings represented the majority of the non-germinated seeds that were obtained from drought-stressed plants (Smiciklas *et.al.*, 1989). Other researchers reported that drought stress during seed development reduced seed vigor but had no effect on seed germination (Yaklich 1984, Fougereux *et.al* 1997, Iannucci *et.al* 1996, Samarah and Alqudah, 2009). The decrease in seed quality was higher when drought stress occurred during the seed filling stage (Fougereux *et.al.*, 1997). Moisture stress had no effect on germination, germination rate index and seedling growth rate. However, seedling dry weight was significantly reduced under moisture stress (Iannucci *et.al.*, 1996). Seedling root length, seedling shoot length, seedling root fresh weight and seedling shoot fresh weights are recorded higher value by increasing water potential levels (Achakzai, 2009b).

CHAPTER THREE

MATERIALS AND METHODS

3.1 General

This study consisted of four experiments, two field experiments were carried out for two successive seasons (2014/2015 – 2015/2016) at the Crop Sciences Experimental Farm, Faculty of Natural Resources and Environmental Studies, University of Kordofan, Other two laboratory experiments were carried out at the Regional Seed Center Laboratory, Agricultural Research Corporation (ARC), Elobied. The aim of these experiments was to evaluate five sorghum genotypes (*Sorghum bicolor*.L.Moench) under water stress. The state of the experiments lies between latitude (11- 15^{o}) and (16 - 30^{o}) N, and longitude (27 - 30^{o}) E. The climate of the area is semi arid. The soil is sandy, annual rain fall ranges between 250-450 mm (Ahmed, 2009). Average maximum daily temperature ranges between 30-40 C^{o} throughout the year. The two laboratory experiments were carried out to investigate the effect of water stress at different stages of growth on seed quality harvested from three stages of maturity.

The experimental material used in this study consisted of five genotypes of sorghum seeds, four local promising Zinnari which are: Taggat 9, Taggat 10, Taggat 14 and Taggat 19, were selected from farmer's field in Khor-taggat area around Elobeid and tested in previous study (Mohamed, 2013) while the improved cultivar (Gadambalea) was provided by Sudanese Arab Seed Company (Plate. 1).

3.2. Field Experiment and layout

The field treatments consisted of five sorghum genotypes viz: Taggat 9, Taggat 10, Taggat 14, Taggat 19 and Gadambalea cultivar and three water intervals: (**a**) well watering (50 mm per irrigation every seven days) throughout the whole life of the plant as control (IR_0), (**b**) withholding irrigation at three-leaf stage for 21 days as stress one (IR_1) and (**c**) withholding irrigation at eight-leaf stage for 21 days as stress two (IR_2), the period 21 days is the time from water stress in the rain-fed areas and is caused by the cease of rainfall, locally called (Sabana). During this period plastic sheets were used to cover plot area to protect it from rain-fall and moisture (Plate.2). For irrigation treatments pumping machine 2 inch was used, applide water was calibrated by used flow rate/gallon/sec then convered to the plot area/m^2 (Elnaim *et.al.*, 2012).

The experiment was laid out in a split-plot arrangement with four replications, the main plots were specified to water stressed treatments, while genotypes were placed as subplots. Seeds were planted on 15 May during two successive seasons (2014/2015- 2015/2016), plot size was 2 meter wide and 2 meter long, the seeds were sown in holes 50 cm apart with 50 cm between row spacing.

Field parameters: The following Parameters were measured:-

Plant height (cm): It was measured from the ground level to the tip of heads.

Number of leaves per plant: It was estimated by counting the number of leaves per plant at flowering time.

Day's to 50% flowering: The number of days from sowing up to the time when 50 percent of the plants at the treatment were flowered (Plat 3).

Day's to physiological maturity: It was the number of days from sowing till 95 percent of heads matured in the plot.

Number of panicles per plot area: It was estimated by accounting number of panicles per m^2 per plot divided by plot area in m^2.

Panicle length (cm): It was obtained by estimating the length of head from the crown up to their tips using a meter tape.

Panicle Weight (g): It was given by weihing the head using asensitive balance.

Number of grains per panicle: It was obtained by using the following formula:

$$\frac{\text{Grain yield per plant} \times 100}{\text{100 grain weight}}$$

100- grain weight (g): It was given by weighing 100 grains from a sample of grain yield per plot by sensitive balance.

Grain yield/plant (g): It was estimated by the following formula:

$$\frac{\text{Grain yield per plot (g)}}{\text{Number of plants per plot}}$$

Grain yield per m^2 (g): It was estimated by the following formula:

$$\frac{\text{Grain yield per plot}}{\text{Plot area (m}^2\text{)}}$$

Grain yield (ton/ha): It was estimated by the following formula:

$$(\text{Grain yield per m}^2 \times 10000)/1000.$$

Harvest index: It was obtained by the following formula:

$$\frac{\text{Grain yield} \times 100}{\text{Biological yield}}$$

Seed index: It was determined by dividing the grain yield by the head weight.

Drought tolerance index: It was estimated by the following formula:

$$\frac{\text{Grain yield under stress}}{\text{Grain yield under normal irrigation}}$$

Soil Moisture Content (% w/ w): The soil samples were taken by an auger at three depths (0 -15, 15 -30 and 30 - 40 cm) two days prior and post irrigation at stressed one and two periods. The samples were weighed twice (fresh and dry weight). A sensitive balance was used in weighing. Drying was done by rutting in an oven at 105C° for 24 hours).

Consumed moisture in the soil: This parameter denotes for the moisture that consumed by plants and evaporation. It was estimated by the following formula: (Moisture content post-irrigation – Moisture content pre-irrigation).

3.3 Laboratory Experiment:

Two laboratory experiments were conducted in two successive seasons (2014\2015- 2015\2016) at the Regional Seed Center Laboratory, Agricultural Research Corporation (ARC), Elobied, and tissue culture laboratory of crop science Department, Faculty of Natural Resources and Environmental Study, University of Kordofan, to examine the effect of water limitation on seed quality during seed filling of five sorghum genotypes sown in the field. In this experiment

20 grams of grains were harvested from each plot at three stages of maturity, these were: at the beginning of soft dough stage (H_1), at the beginning of hard dough stage (H_2) and at physiological maturity stage (H_3). The laboratory treatments were conducted as factorial experiments in a Randomized Complete Block Design with four replications.

Seed laboratory measurements: The following Parameters were measured:-

Standard Germination Test (%): were estimated from 20 grams of seed samples from each plot. Seeds were germinated in double filter papers and placed in Petri dishes and then transferred into a germinator at a constant 25^0 C for 7 days according to (AOSA, 1996). At the end of the incubation period, the number of normal seedlings was recorded and the germination percentage was calculated as follows;

$$\text{Germination (\%)} = \frac{\text{Number of normal seedling} \times 100}{\text{Number of seeds planted}}$$

Seedling Length (cm): at the end of incubation period, length of 7 days old seedling was measured from the point of attachment to the seed up to the tip of the seedling, and the average shoot length of five seedlings was calculated by dividing the total shoot length of normal seedlings measured, to examine seed vigor test.

3.3.1.4 Seedling Relative Moisture Content: It was estimated by the below formula:

$$\text{S R M C} = \frac{\text{Fresh seedlings weight} - \text{Dry seedlings weight}}{\text{Dry seeds weight}}$$

4.3 Statistical Analysis Procedures:

The data recorded on field and laboratory experiment were statistically analyzed by statistical package for spilt-plot trial, as described by Gomez and Gomes (1984), by using computer program (MSTAT. C). Mean separation was determined for the effect of each significant factor for all studied traits using Duncan's Multiple Range Test (DMRT) at 5% level.

CHAPTER FOUR
RESULTS

4.1 Field experiments:

Two field experiments were conducted for two successive seasons (2014\2015-2015\2016). Morphological, yield and yield related traits were estimated from the two experiments. All the traits were measured after flowering and maturity. The collected data were subjected to statistical analyses. The results are shown in tables (from table 1 up to table 18). The results of each estimated trait in the first and second seasons were illustrated in one table. Effects of each of genotypes, water intervals and their interactions were significant for most of the studied traits in both seasons (Appendix1and 2).

4.1.1 Plant height (cm)

Analysis of variance for plant height showed that water intervals, genotypes and their interaction had significant effects in both seasons (Appendix 1). Mean separation (Table 1) indicated that plants in stress **I** were significantly taller (140.7 and 143.8 cm for season one and two, respectively) compared with the well-watered plants (135.6 and 134.9 cm in season one and two, respectively). With regard to genotypes, Taggat 14 scored the highest plant height in both seasons (155.5 and 172.9 cm respectively), while the improved cultivar Gadambalea scored the lowest plant height for both seasons (116.6 and 124.8 cm, respectively) (Fig.1 and 2). Interactions of Taggat 14 genotype in well watering or stress **I** scored the highest plant height in the two seasons (174.9 and 179 cm, for seasons one and two respectively). On the other hand, Gadambalea in stress **II** scored the lowest estimates in seasons one two (116.9 and 119. cm, respectively).

Table 1: Effect of three water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on

plant height(cm) in field experiment conducted during 2014/ 015 -2015/ 016 seasons in Elobeid.

	Season 2014\2015				Season 2015\2016	
Treatments	Water Intervals				Water Intervals	
Genotypes	IR_0	IR_1	IR_2	Mean	IR_0	IR_1
Taggat 9	126.5^{f}	124.4^{fg}	106.8^{g}	119.2$^{\mathbf{d}}$	128.7^{de}	127.8^{f}
Taggat 10	126.6^{f}	141.0^{gd}	134.9^{e}	134.2$^{\mathbf{b}}$	126.5^{cde}	140.2^{de}
Taggat 14	174.9^{a}	173.2^{ab}	113.5^{i}	155.5$^{\mathbf{a}}$	166.2^{ab}	179.0^{a}
Taggat 19	125.1^{fg}	143.0^{c}	125.3^{fg}	131.1$^{\mathbf{c}}$	125.9^{cd}	144.2^{de}
Gadambalea	124.9^{fg}	121.9^{h}	102.8^{k}	116.6$^{\mathbf{e}}$	127.1^{e}	127.5^{de}
Mean	135.6^{b}	140.7^{a}	117.7^{c}	……...	134.9^{b}	143.8^{a}
Grand mean				**131.3**		
SE±	SE w = 0.33, SE g = 0.57, SE w × g = 0.80				SE w = 1.40, SE g = 2.04	

IR_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.

SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.

*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means.

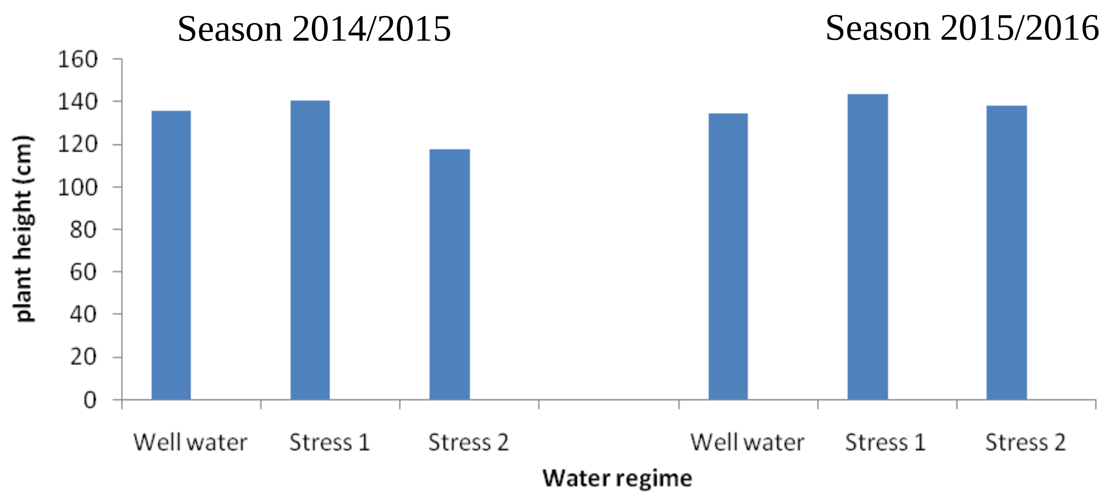

Fig.1 Main effects of water regime on plant height (cm)

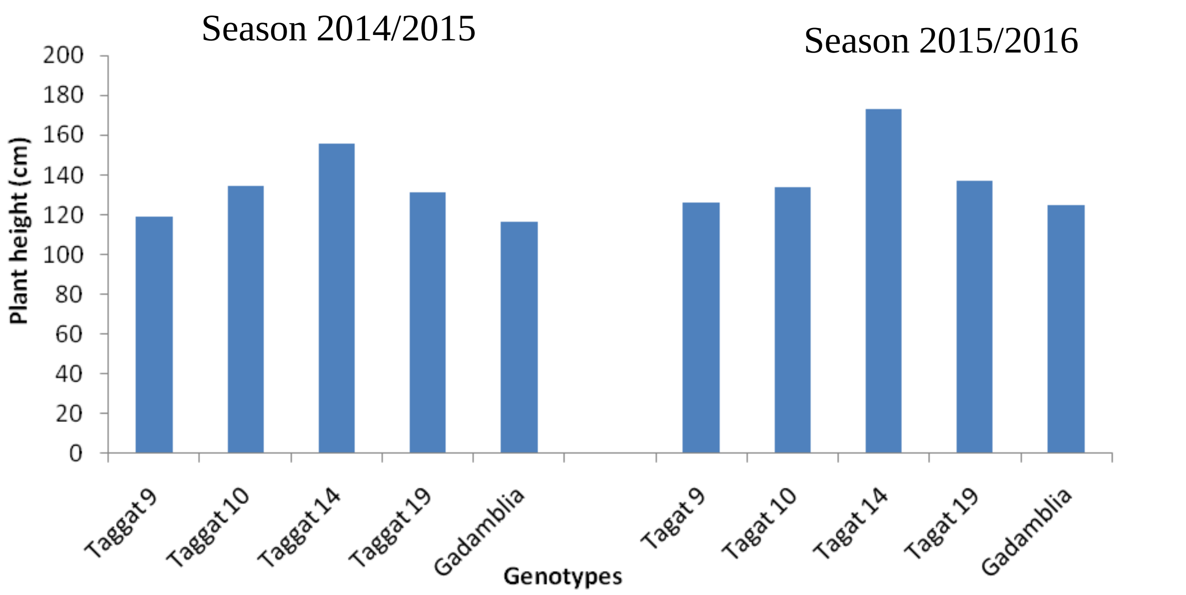

Fig.1 Main effects of sorghum genotypes on plant hieght (cm)

4.1.2 Number of leaves per plant

The significant effect was reported only for genotypes in the two seasons (Appendix1). Taggat 10 and 19 in Table 2 recorded the highest number of leaves per plant in both seasons (between 11 and 13 leaves). On the other hand, Taggat 9 and 14 recorded the lowest estimates (between 10 and 11 leaves per plant).

4.1.3 Days to 50% flowering

Analysis of variance in Appendix 1 showed that only the genotypes recorded the significant effects in both seasons. Table 3 and Fig.3 showed that Gadambalea and Taggat 9 were the earliest genotypes to flower in both seasons (between 62 and 64 days). On the other hand, Taggat 10 was the latest flowering one in both seasons (between 70 and 77 days).

4.1.4 Days to physiological maturity

Analysis of variance for days to 95% physiological maturity (Appendix 1) showed significant effects among each of the water intervals, genotypes and their interaction. The earliest matured plants in the two seasons were reported in well watering, thy matured in a range between 92 and 95 days (Figures 4, 5 and Table 4). In contrast, the late matured plants were reported in stress **II** (in 98 days). Regarding genotypes, the earliest one in the two seasons was Gadamballea (matured between 89 and 91 days) while the late one was Taggat 10 (matured in 101 day in the two seasons). Gadambalea in stress **I** and **II** in the two seasons recorded the lowest days to reach physiological maturity (between 88 and 91 days). On the other hand, the highest significant interactions were reported by Taggat 10 and 14 in stress **II** (matured in a range varied from 101 to 104 days).

Table 2: Effect of three water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on the number of leaves per plant in field experiment conducted during 2014/2015 - 2015/2016 seasons in Elobeid.

	Season 2014/2015				Season 2015/2015			
Treatments	Water Intervals				Water Intervals			
Genotypes	IR_0	IR_1	IR_2	Mean	IR_0	IR_1	IR_2	Mean
Taggat 9	10.5[d]	10.5[d]	11.5[bcd]	10.8**[b]**	10.8	11.3	11.3	11.1**[b]**
Taggat 10	12.2[ab]	12.7[ab]	12.0[abc]	12.3**[a]**	11.5	12.3	11.8	11.8**[a]**
Taggat 14	10.5[d]	11.5[bcd]	11.7[abc]	11.2**[b]**	10.8	11.3	11.3	11.1**[b]**
Taggat 19	13.0[a]	12.5[ab]	12.5[ab]	12.7**[a]**	12.5	12.5	11.8	12.3**[a]**
Gadambalea	11.0[cd]	11.0[cd]	10.5[d]	10.8**[a]**	10.5	11.0	10.8	10.8**[b]**
Mean	11.5	11.9	11.7	……	11.2	11.7	11.4	……
Grand mean				**11.6**				**11.4**
SE±	SE w = 0.17, SE g = 0.22, SE w × g = 0.38				SE w =			

IR_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.

SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.

*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means.

Table 3: Effect of three water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on days to 50% flowering in field experiment conducted in 2014/ 015 -2015 /016 seasons in Elobeid..

Season 2014/2015	Season 2015/2016

Treatments	Water Intervals				Water Intervals			
Genotypes	IR_0	IR_1	IR_2	Mean	IR_0	IR_1	IR_2	Mean
Taggat 9	61[f]	63[d]	62[de]	62**[e]**	64	65	64	64**[c]**
Taggat 10	70[b]	71[a]	70[ab]	70**[a]**	77	77	76	77**[a]**
Taggat 14	62[de]	69[b]	70[ab]	67**[c]**	64	64	64	64**[c]**
Taggat 19	70[ab]	65[c]	70[ab]	68**[b]**	72	71	71	71**[b]**
Gadambalea	62d[e]	65[c]	61[ef]	63**[d]**	62	62	62	62**[d]**
Mean	65*[b]*	66*[a]*	67*[a]*	…….	68	68	68	…….
Grand mean				**66**				**68**
SE±	SE w = 0.36. SE g = 0.46. SE w × g = 0.80				SE w = 0.31. SE g			

IR_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.
SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.
*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means.

Table 4: Effect of three water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on days tophysiological maturity in field experiment conducted during 2014/015 -2015/016 seasons in Elobeid.

	Season 2014/2015				Season 2015/2016			
Treatments	Water Intervals				Water Intervals			
Genotypes	IR_0	IR_1	IR_2	Mean	IR_0	IR_1	IR_2	Mean
Taggat 9	88[cd]	98[b]	96[b]	94***[c]***	93[de]	93[h]	95[def]	94**[c]**
Taggat 10	98[b]	102[a]	104[a]	101**[a]**	101[a]	101[ab]	102[ab]	101**[a]**
Taggat 14	88[cd]	98[b]	103[a]	96**[b]**	91[d]	92[fg]	101[ab]	94**[c]**
Taggat 19	97[b]	97[b]	99[b]	97**[b]**	98[bc]	99[c]	100[bc]	99**[b]**
Gadambalea	91[c]	88[d]	88[d]	89**[d]**	91[fg]	91[fg]	92[g]	91**[d]**
Mean	92*[c]*	96*[b]*	98*[a]*	…….	95*[b]*	95*[b]*	98*[a]*	…….

Grand mean	**95**	**96**
SE±	SE w = 0.42, SE g = 0.54, SE w × g = 0.94	SE w = 0.30, SE g = 0.38, SE w × g = 0.56

IR_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.

SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.

*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means.

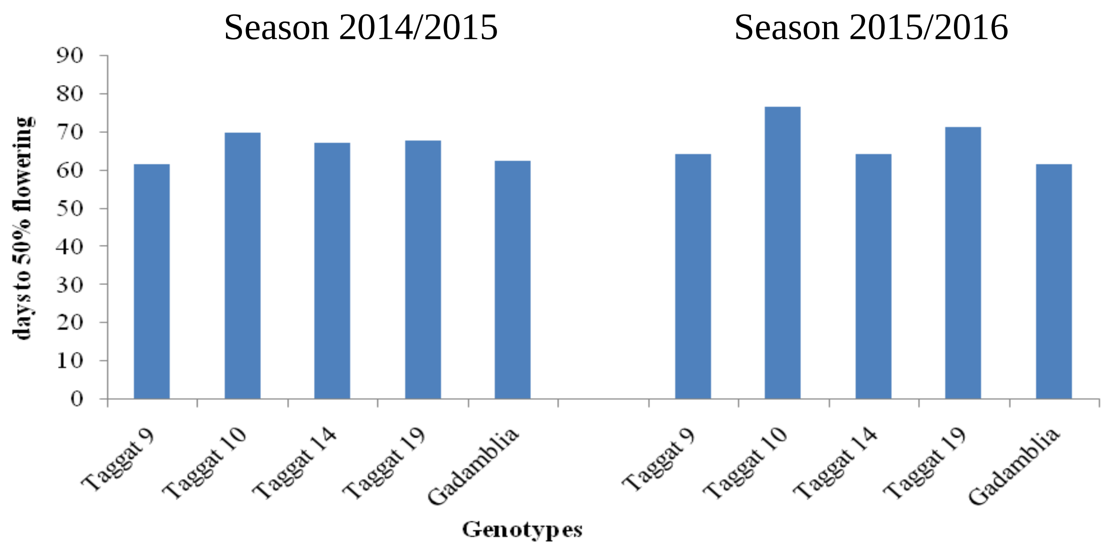

Fig.3 Main effects of sorghum genotypes on days to 50% flowering

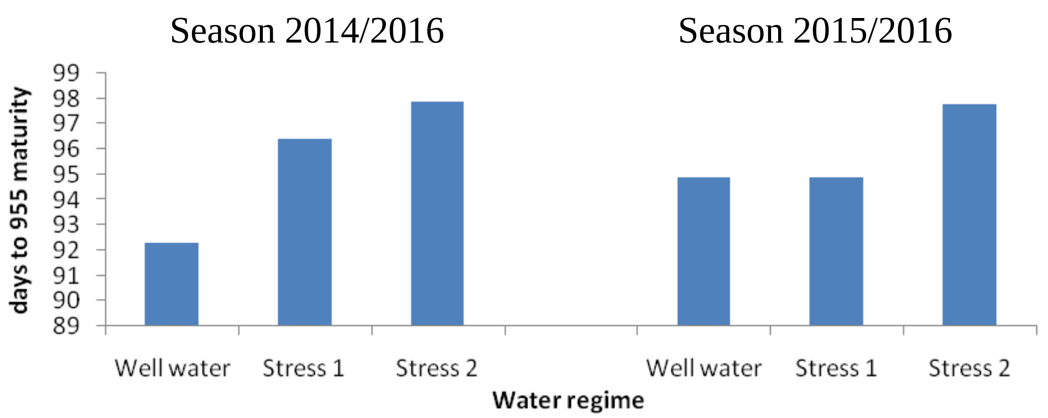

Fig.4 Main effects of water intervals on days to physiological maturity

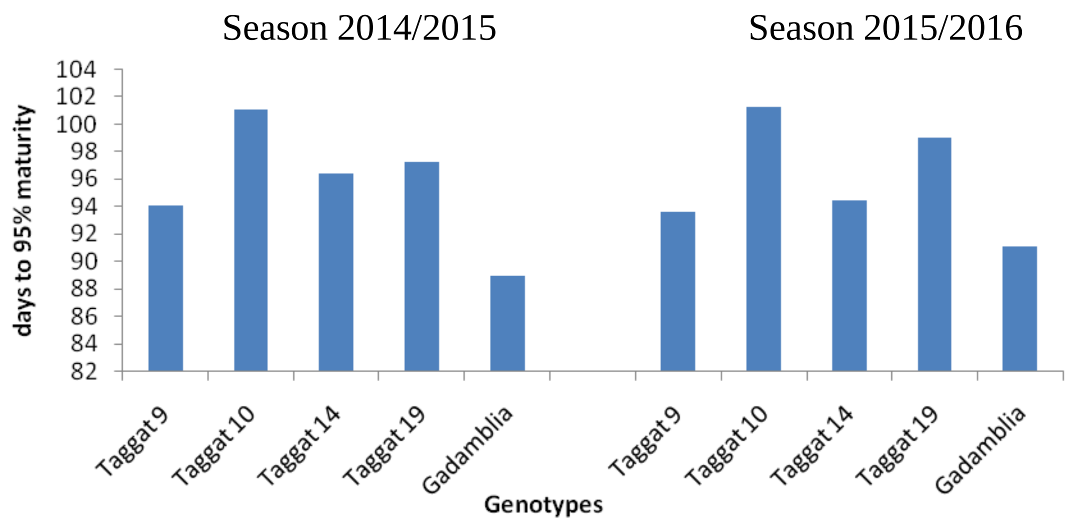

Fig.5 Main effects of sorghum genotypes on days to physiological maturity

4.1.5 Number of panicles per m^2

Statistical analysis for number of panicle per m^2 during both seasons (Appendix 1) showed that watering intervals, genotypes and their interactions had no significant effects on mean number of panicles per m^2 (Table 5).

4.1.6 Panicle length (cm)

Analysis of variance (Appendix 1) disclosed significant effect among each of water intervals and genotypes in the two seasons. Figures 6,7and Table 6 showed that well-watered plants and the stress **I** plants scored the highest panicle length for both seasons(24.4 and 25 cm in season one, 42.2 and 23.6 cm in season two, respectively). On the other hand, stress **II** plants recorded the lowest one (21.2 and 22.6 cm in season one and two, respectively). Taggat 14 and 19 genotypes recorded the highest panicle length (29.1 and 29.8 cm in season one and two respectively for Taggat 14 and 29 cm for Taggat 19 in season one). In contrast, Gadambalea and Taggat 9 recorded the lowest panicle length (18.1and 19.6 cm for season one and two, respectively).

4.1.7 Panicle weight (g)

Effects among each of the water intervals, genotypes and their interactions of panicle length were significant in both seasons (Appendix 1). The heavier panicle weight was recorded by plants under stress **I** (82.4 and 78.9 g) in the same seasons and well-watered plants (80.2 g) in season two (Figures 8, 9 and Table 7). In contrast the lowest panicle weight was recorded by plants in stress **II** in both seasons (57.4 and 74.9 g respectively). Regarding genotypes, the heaviest ones in the two seasons were Taggat 10 and 14 (87.6 and 87.4 g for Taggat 10 in the two seasons, 109.9 and 110.4 g for Taggat 14 in season one and two respectively), while Gadambalea recorded the lowest panicle weight (between 40 and 51 g) in season one and two respectively.

Table 5: Effect of three water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on number of panicles per m^2 in field experiment conducted during 2014/ 015 -2015/ 016 seasons in Elobeid.

	Season 2014/2015				Season 2015/2016			
Treatments	Water intervals				Water intervals			
Genotypes	IR_0	IR_1	IR_2	Mean	IR_0	IR_1	IR_2	Mean
Taggat 9	6.0	5.0	5.0	5.0	6.0	6.0	5.0	6.0
Taggat 10	6.0	6.0	5.0	6.0	6.0	6.0	6.0	6.0
Taggat 14	6.0	5.0	5.0	6.0	6.0	6.0	6.0	6.0
Taggat 19	6.0	6.0	6.0	6.0 .	6.0	6.0	6.0	6.0
Gadambalea	5.0	5.0	4.0	6.0	6.0	6.0	5.0	6.0
Mean	6.0	5.0	5.0	……..	6.0	6.0	6.0	……..
Grand mean				**5.4**				**6.0**
SE±	SE w = 0.07, SE g = 0.08, SE w × g = 0.18				SE w = 0.05, SE g =			

IR_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.

SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.

*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means.

Table 6: Effect of three water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on panicle length (cm) in field experiment conducted during 2014/015 - 2015/016 seasons in Elobeid..

	Season 2014/2015				Season 2015/2016			
Treatments	Water intervals				Water intervals			
Genotypes	IR_0	IR_1	IR_2	Mean	IR_0	IR_1	IR_2	Mean

Taggat 9	19.6^{e}	22.0^{d}	17.3^{f}	19.6$^{\mathbf{c}}$	20.3	20.3	17.4	19.3$^{\mathbf{d}}$
Taggat 10	23.6^{d}	22.7^{d}	19.8^{e}	22.0$^{\mathbf{b}}$	24.6	23.7	23.8	24.0$^{\mathbf{c}}$
Taggat 14	31.2^{a}	30.4^{a}	25.6^{c}	29.1$^{\mathbf{a}}$	30.8	29.6	29.1	29.8$^{\mathbf{a}}$
Taggat 19	28.6^{b}	30.9^{a}	27.3^{b}	29.0$^{\mathbf{a}}$	27.2	26.6	26.7	26.8$^{\mathbf{b}}$
Gadambalea	19.3^{e}	19.3^{e}	15.7^{f}	18.1$^{\mathbf{d}}$	18.2	18.0	16.1	17.4$^{\mathbf{e}}$
Mean	24.4^{a}	25.0^{a}	21.2^{b}	……..	24.2^{a}	23.6^{a}	22.6^{b}	……..
Grand mean				**23.6**				**23.5**
SE±	SE w = 0.25, SE g = 0.33, SE w × g = 0.57					SE w = 0.28, SE g =		

IR_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.
SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.
*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means.

Table 7: Effect of three water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on panicle weight (g) in field experiment conducted during 2014/015 - 2015/016 seasons in Elobeid.

	Season 2014/2015				Season 2015/2016			
Treatments	Water intervals				Water intervals			
Genotypes	IR_0	IR_1	IR_2	Mean	IR_0	IR_1	IR_2	Mean
Taggat 9	41.7^{i}	64.3^{g}	46.2^{h}	50.7$^{\mathbf{c}}$	43.1^{d}	43.0^{d}	41.7^{d}	42.6$^{\mathbf{c}}$
Taggat 10	65.5^{g}	112.9^{a}	84.4^{f}	87.6$^{\mathbf{a}}$	113.6^{a}	113.4^{a}	102.8^{b}	109.9$^{\mathbf{a}}$
Taggat 14	96.7^{d}	101.2^{c}	64.2^{g}	87.4$^{\mathbf{a}}$	114.6^{a}	112.1^{a}	104.5^{b}	110.4$^{\mathbf{a}}$
Taggat 19	104.0^{b}	89.0^{e}	65.6^{g}	86.2$^{\mathbf{b}}$	90.1^{c}	86.7c	87.0^{c}	87.9$^{\mathbf{b}}$
Gadambalea	48.1^{h}	46.9^{h}	26.3^{j}	40.4$^{\mathbf{d}}$	39.8^{d}	39.5^{d}	38.6^{d}	39.3$^{\mathbf{d}}$
Mean	71.2^{b}	82.4^{a}	57.4^{c}	……..	80.2^{a}	78.9^{a}	74.9^{b}	……..

Grand mean	**70.5**	**78.0**
SE±	SE w = 0.40, SE g = 0.52, SE w × g = 0.90	SE w = 0.34, SE g = 0.81, SE w × g = 1.24

IR_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.

SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.

*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means.

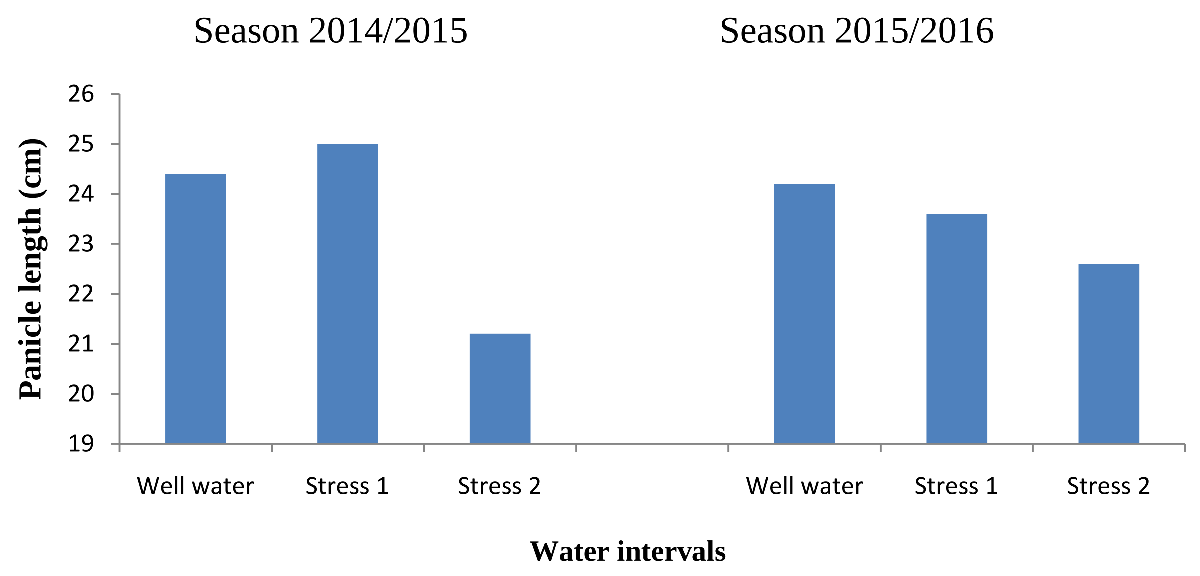

Fig.6 Main effects of water intervals on panicle length (cm)

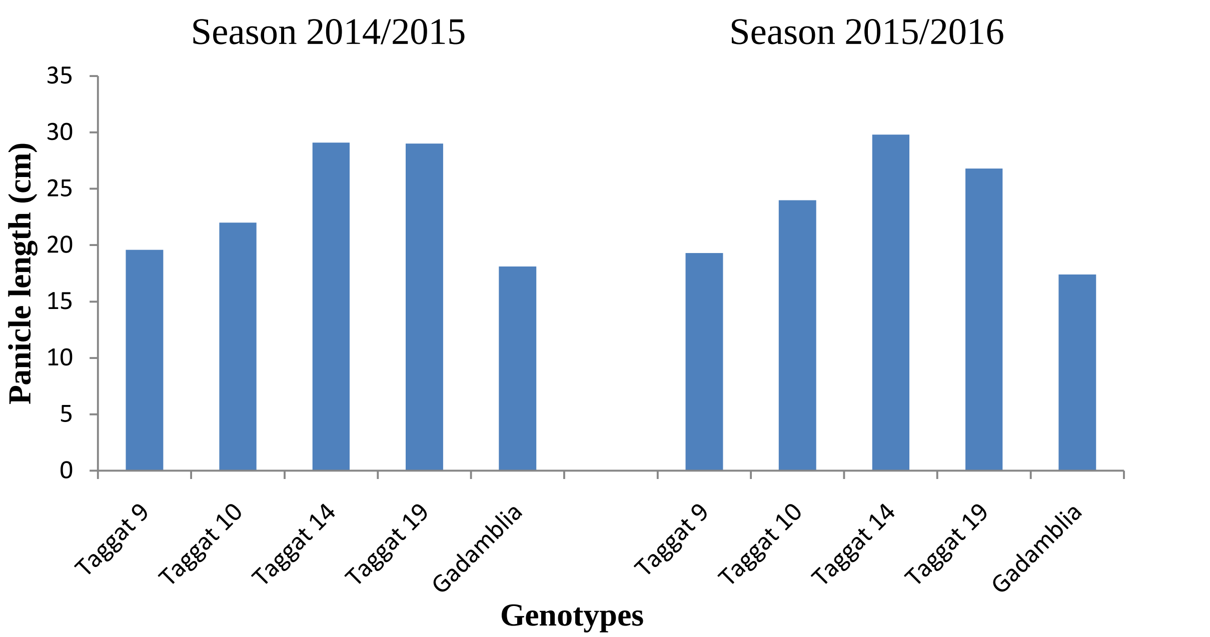

Fig.7 Main effects of sorghum genotypes on panicle length (cm)

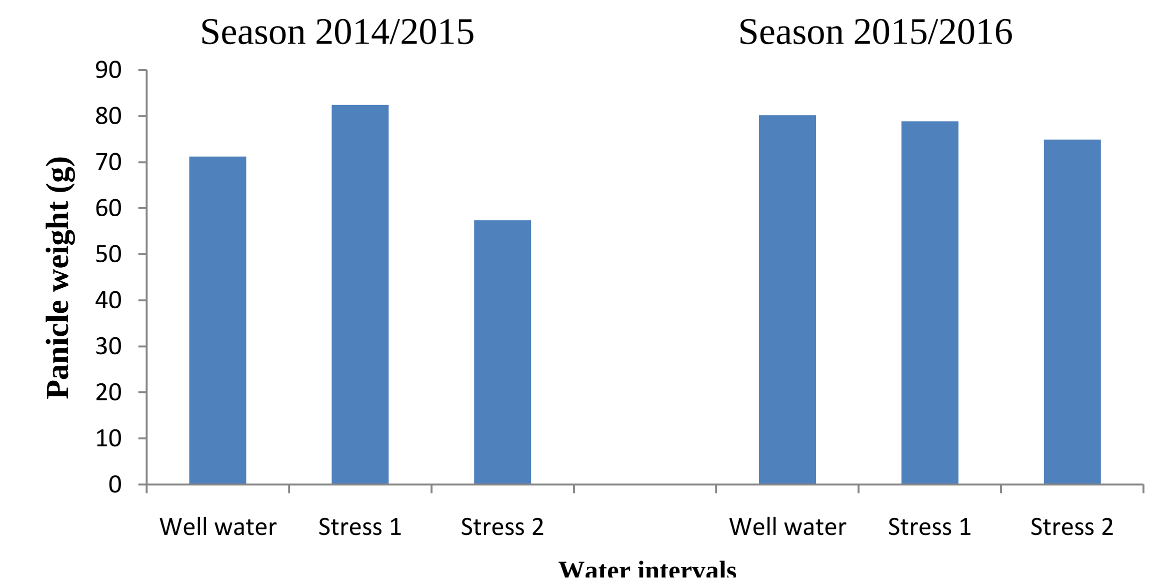

Fig.8 Main effects of water intervals on panicle weight (g)

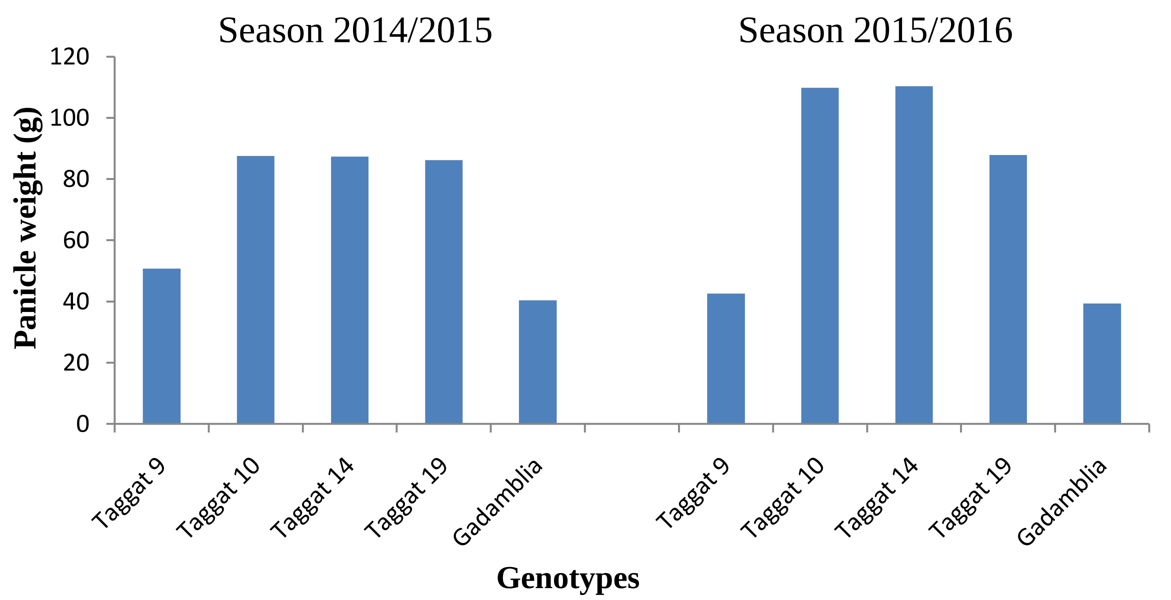

Fig.9 Main effects of sorghum genotypes on panicle weight (g)

In interaction, heavier panicle weight was recorded by Taggat 10 in stress **I** in both seasons (112.9 and 101.2 g) and 113.6 g in well-water in season two and Taggat 14 in well-water and in stress **I** in season two (114.6 and 112.1 g). While Gadambalea cultivar under stress **II** in season one, Taggat 9 and Gadambalea in each water interval in season two recorded the lowest panicle weight (26.3 g in season one and between 38 to 40 g in season two for Gadambalea and between 41 to 43 grams for Taggat 9 respectively).

4.1.8 Number of Grains per panicle

Data presented in Table (8) and Figures 10 and 11 indicated that, the effect of water intervals, genotypes and there interaction had significant differences in number of grain per panicle (Appendix 1). Plants in stress **I** recorded greater number of grains per panicle in two seasons (1577.3 and 1385.2 grains, respectively). However, well-watered plants in season one and plants in stress II in season two scored fewer grains (1249.4 and 1265.7 grains respectively). The genotypes Taggat 14 in season one and Taggat 19 in season two recorded greater number of grains per panicle (1567.6 and 1503.5 grains respectively). On the other hand, Gadambalea cultivar and Taggat 9 scored fewer grains per panicle (1112.1and 1219.3 grains in season one and two respectively). The highest value of interaction was reported by Taggat 14 in stress **I** water regime (1948 grains) in season one and Taggat 19 in stress I and II water regime in season two (1545.7 and 1599.6 grains) and Gadambalea cultivar in stress **II** (1225.4 grains). In contrast, Gadambalea cultivar under well-watering in season one and Taggat 9 under stress **II** water regime in season two scored fewer grains per panicle (745.7 and 1061.1 grains respectively).

Table 8: Effect of three water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on the number of grains per panicle in field experiment conducted during 2014/015 -2015/016 seasons in Elobeid.

	Season 2014/2015				Season 2015/2016			
Treatments	Water intervals				Water intervals			
Genotypes	IR_0	IR_1	IR_2	Mean	IR_0	IR_1	IR_2	Mean
Taggat 9	1219.0^{k}	1215.5^{l}	1223	1219.3$^{\mathbf{d}}$	1213.5^{d}	1217.1^{d}	1061.1^{e}	1163.9$^{\mathbf{e}}$
Taggat 10	1187.5^{n}	1751.2^{b}	1578	1505.7$^{\mathbf{c}}$	1450.7^{ab}	1446.9^{ab}	1353.4^{bc}	1417.1$^{\mathbf{b}}$
Taggat 14	1427.0^{f}	1948.0^{a}	1327	1567.6$^{\mathbf{a}}$	1367.8^{bc}	1452.6^{ab}	1187.9^{d}	1336.1$^{\mathbf{c}}$
Taggat 19	1668.0^{c}	1546.5^{e}	1322	1512.2$^{\mathbf{b}}$	1464.2^{ab}	1545.7^{a}	1500.6^{a}	1503.5$^{\mathbf{a}}$
Gadambalea	745.7^{o}	1425.5^{g}	1165	1112.1$^{\mathbf{e}}$	1201.9^{d}	1263.4^{cd}	1225.4^{a}	1230.2$^{\mathbf{d}}$
Mean	1249.4^{c}	1577.3^{a}	1323	……..	1339.7^{b}	1385.2^{a}	1265.7^{c}	………
Grand mean				**1383.4**				**1330.2**
SE±	SE w = 3.46, SE g = 4.47, SE w × g = 7.74				SE w = 7.86, SE g = 15.01, SE w × g = 34.55			

IR_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.

SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.

*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means.

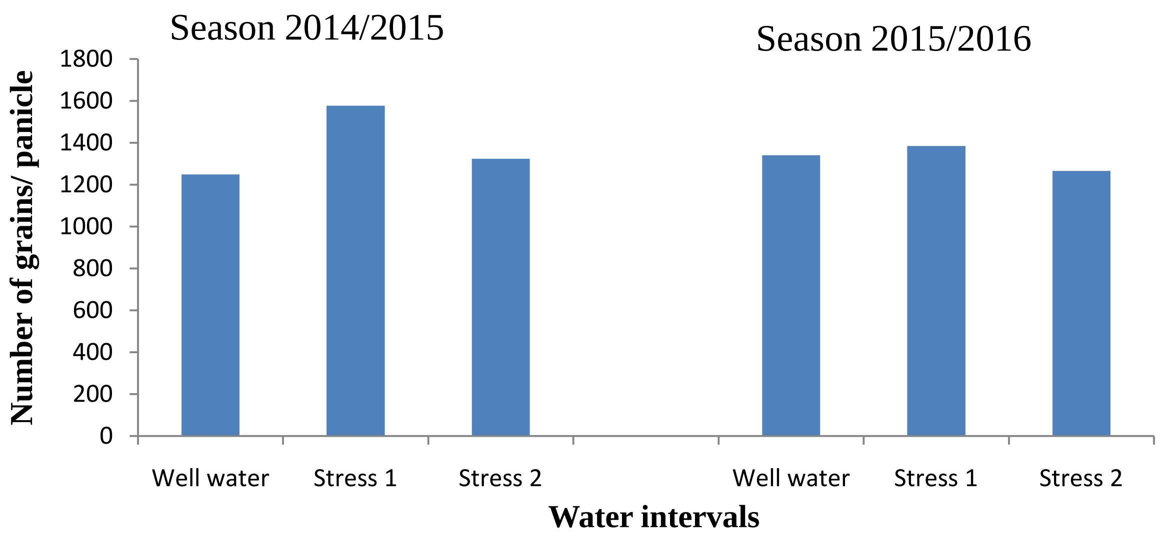

Fig.10 Main effects of sorghum genotypes on number of grains/panicle.

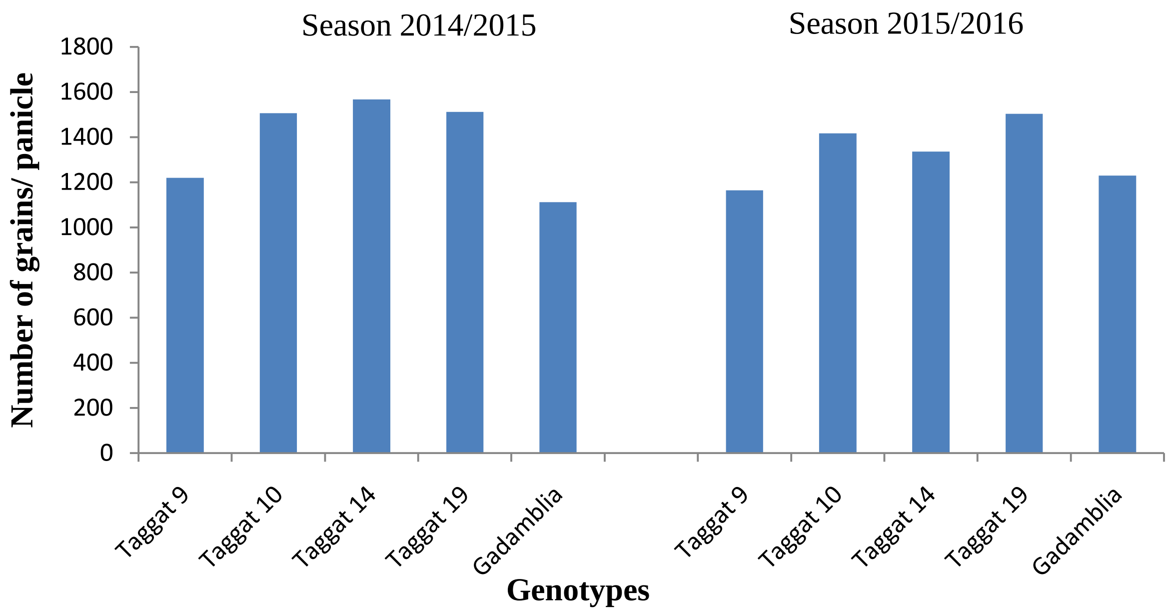

Fig.11 Main effects of sorghum genotypes on number of grains/panicle.

4.1.9 100- grain weight (g)

Analysis of variance for 100-grain weight showed that water regime, genotypes and their interactions had significant effects in both seasons (Appendix 1). Mean separation (Table 9) indicated that plants in well-watered tratments were significantly heavier in 100-grain weight in both seasons (3.1 and 3.7 grams, respectively), while the plants in stress **II** recorded the lowest in season one and two (2.8 and 3.2 grams, respectively). (Fig.12). With regard to genotypes, Taggat 19 in season one and Taggat10 and 14 in season one and two scored the heaviest ones (3.5 and 3.4 grams in season one and 4.3 and 4.2 grams in season two, respectively) (Fig.13). On the other hand, Taggat 9 scored the lowest 100-grain weight in both seasons (2 and 2.6 grams respectively). Interaction between genotypes and water intervals recorded the highest estimates by Taggat 10 and 14 in well-water in both seasons (3.5 and 3.6 grams in season one and 4.6 g in season two), also Taggat 19 in well-water and in stress **I** in season one recorded (3.4 and 3.6 grams, respectively). In contrast, Tagat 9 in stress I water regime in season one and the same genotype in stress **II** in season two reported (2 and 2.2 g, respectively).

4.1.10 Grain yield per/plant (g)

Significant effects among each of water intervals, genotypes and their interactions were reported for grain yield per plant in Appendix 1. Table 10 showed that plants in stress **I** in season one and in well-watered in season two produced the highest grain yield/ plant (45.2 and 50.9 g for season one and two, respectively), while the lowest grain yield per plant (34.4 and 41.3 g) were recorded by plants under stress **II** in both seasons (fig.14). With regard to genotypes, the highest estimates recorded by Taggat 10 in season one and two (48 and 61.5 g, respectively) and Taggat 14 and 19 in season one (48.6 and 49.9.5 g, respectively), while the lowest one (25.1 and 25.3 g) were recorded by Taggat 9 in the two seasons (Fig.15).

Table 9: Effect of three water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on 100- grain weight (g) in field experiment conducted during 2014/015 - 2015/016 seasons in Elobeid.

	Season 2014/2015				Season 2015/2015			
Treatments	Water intervals				Water intervals			
Genotypes	IR_0	IR_1	IR_2	Mean	IR_0	IR_1	IR_2	Mean
Taggat 9	2.3^{d}	2.0^{e}	1.8^{f}	$2.0^{\mathbf{c}}$	2.3^{hi}	2.3^{hi}	2.2^{i}	$2.3^{\mathbf{d}}$
Taggat 10	3.5^{a}	3.4^{a}	3.2^{b}	$3.4^{\mathbf{a}}$	4.6^{a}	4.4^{b}	4.0^{de}	$4.3^{\mathbf{a}}$
Taggat 14	3.6^{a}	3.4^{a}	3.3^{b}	$3.4^{\mathbf{a}}$	4.6^{a}	4.4^{b}	3.7^{f}	$4.2^{\mathbf{a}}$
Taggat 19	3.4^{a}	3.6^{a}	3.3^{b}	$3.4^{\mathbf{a}}$	4.2^{c}	3.8^{ef}	3.8^{ef}	$3.9^{\mathbf{b}}$
Gadambalea	2.8^{c}	2.8^{c}	2.2^{de}	$2.6^{\mathbf{b}}$	2.8^{g}	2.5^{h}	2.5^{h}	$2.6^{\mathbf{c}}$
Mean	3.1^{a}	3.0^{b}	2.8^{c}	……..	3.7^{a}	3.5^{b}	3.2^{c}	……..
Grand mean				**3.0**				**3.5**
SE±	SE w = 0.03. SE g = 0.04. SE w × g = 0.17				SE w = 0.03. SE g =			

IR_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.

SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.

*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means.

Table 10: Effect of three water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on grain yield per plant (g) in field experiment conducted during 2014/015 -2015/016 seasons in Elobeid.

	Season 2014/2015				Season 2015/2016			
Treatments	Water intervals				Water intervals			
Genotypes	IR_0	IR_1	IR_2	Mean	IR_0	IR_1	IR_2	Mean

Taggat 9	27.1^{fg}	24.5^{fg}	23.8^{gh}	$25.1^{\mathbf{b}}$	28.2^{g}	28.3^{h}	23.1^{f}	$26.5^{\mathbf{e}}$
Taggat 10	41.2^{d}	62.2^{a}	42.6^{d}	$48.0^{\mathbf{a}}$	67.5^{bc}	63.3^{a}	53.7^{b}	$61.5^{\mathbf{a}}$
Taggat 14	41.7^{d}	60.0^{a}	41.9^{d}	$48.6^{\mathbf{a}}$	63.5^{d}	63.0^{b}	43.4^{bc}	$56.6^{\mathbf{c}}$
Taggat 19	55.4^{b}	51.3^{c}	42.9^{d}	$49.9^{\mathbf{a}}$	61.2^{cd}	58.7^{bc}	55.9^{cd}	$58.6^{\mathbf{b}}$
Gadambalea	31.0^{e}	27.4^{f}	21.0^{h}	$26.5^{\mathbf{b}}$	34.0^{ef}	31.9^{e}	30.6^{ef}	$32.2^{\mathbf{d}}$
Mean	39.3^{b}	45.2^{a}	$34.4^{\mathbf{c}}$	……..	50.9^{a}	49.0^{b}	41.3^{c}	……..
Grand mean				**39.6**				**47.1**
SE±	SE w = 0.49, SE g = 0.63, SE w × g = 1.10					SE w = 0.47, SE g =		

IR_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.

SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.

*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means.

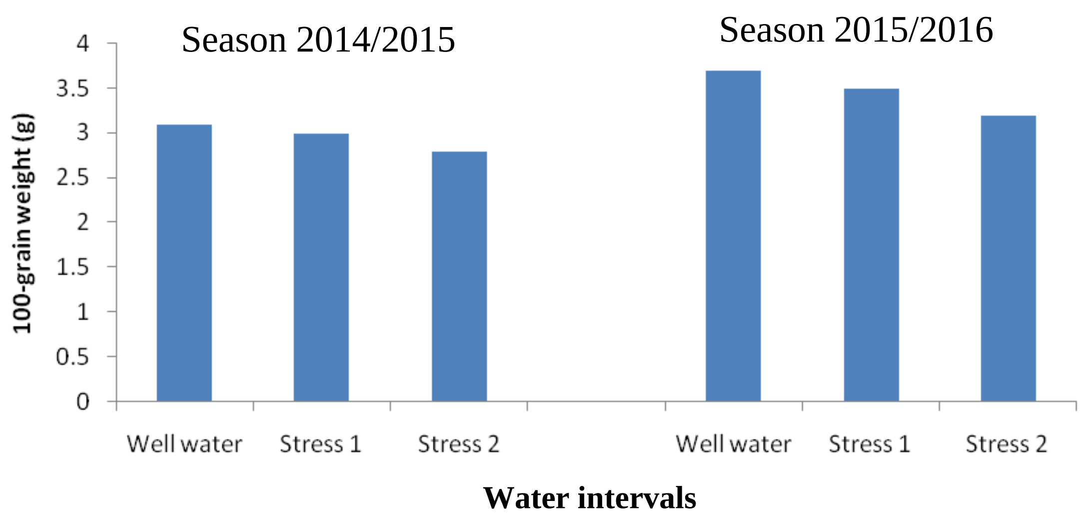

Fig.12 Main effects of water intervals on100-grams weight (g)

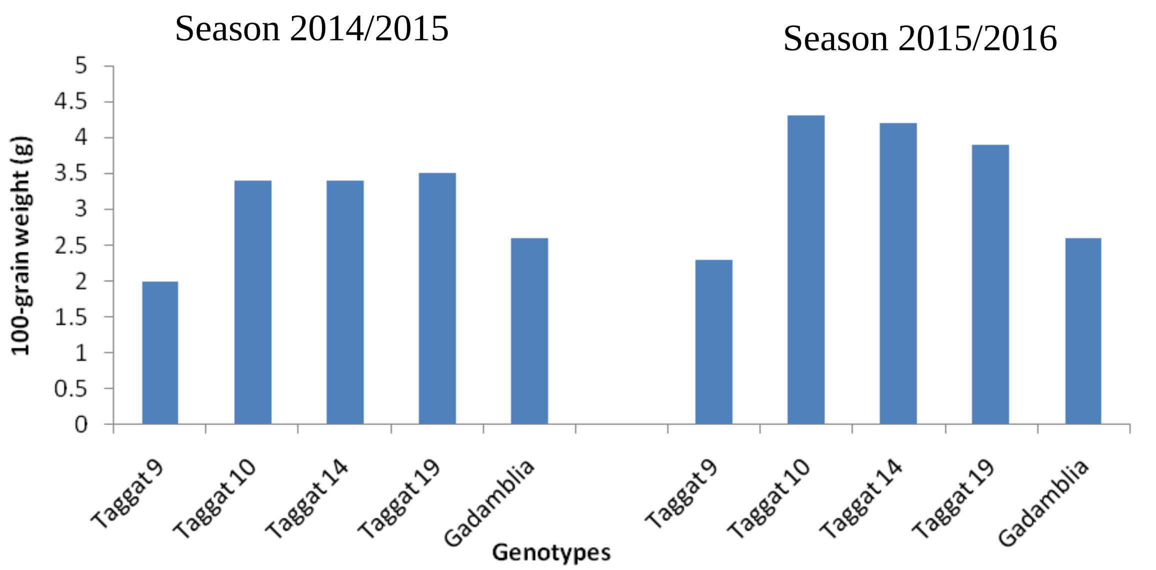

Fig.13 Main effects of sorghum genotypes on 100-grains weight (g)

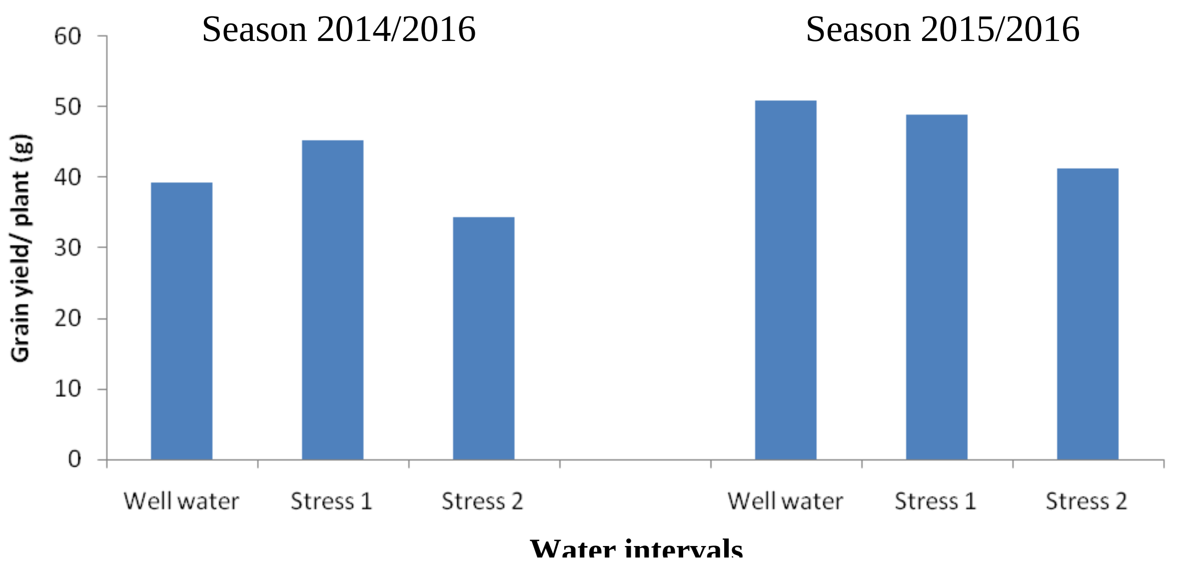

Fig.14 Main effects of water intervals on grains yield/plant (g)

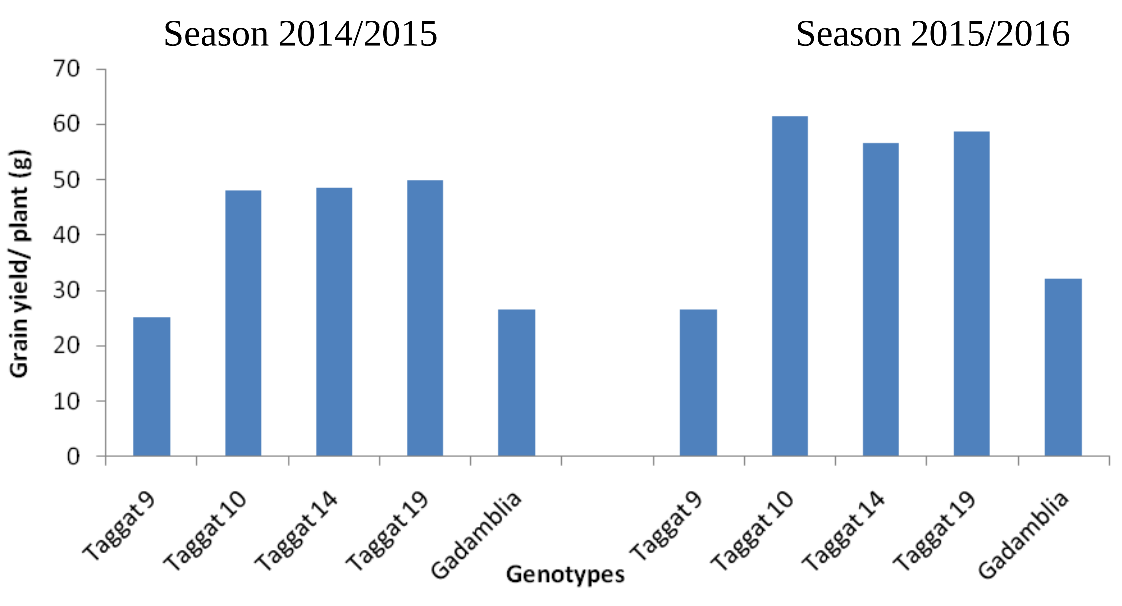

Fig.15 Main effects of sorghum genotypes on grain yield/plant

In interaction, the highest ones recorded by Taggat 10 in stress **I** in both seasons (62.2 and 63.3 g, respectively) and Taggat 14 in stress **I** (60 g) in season one. On the other hand, Gadambalea in season one and Taggat 9 in season two in stress **II** scored the highest estimates (21 and 23.1 g, respectively).

4.1.11 Grain yield per/m^2 (g)

Statistical analysis showed that water intervals, genotypes and their interaction had significant effects on grain yield per m^2 (Appendix 1).Table 11 disclosed plants in stress **I** and plants in well-water scored the highest estimates (364.3 and 406.6 g in season one and two, respectively), while plants in stress **II** recorded the lowest one (270.9 in season one and 330.7 g in season two) (Fig.16). The highest grain yield per m^2 was recorded by Taggat 10 in both seasons (381.6 and 489.4 g, respectively). On the other hand, the lowest estimates were recorded by Taggat 9 and Gadambalea (201.2 and 209.6 g in season one and two, respectively) (Fig.17). Interaction revealed that the highest estimates were reported by Taggat 10 in stress **I** in season one and the same genotype in well-watered treatment in season two (497.5 and 538.7 g, respectively) and Taggat 14 in stress **I** in season one (495.3 g). On the other hand, Gadambalea and Taggat 9 in stress **II** recorded the lowest estimates (164.2 in season one and 184.9 g in season two, respectively).

4.1.12 Grain yield(ton/ha)

Analysis of variance for grain yield ton/ha (Appendix 1) showed significant effects among each of water intervals, genotypes and their interactions. Mean separation (Table 12) showed that plants in stress **I** in season one and well-watered plants in season two significantly recorded the highest estimates (3.6 and 4.1 ton/ha for season one and two, respectively), while the lowest grain yield per plant recorded by plants under stressed **II** in both seasons (2.7 and 3.3 ton/ha) (Fig.18). With regard to genotypes, the highest estimates were recorded by Taggat 10 in season

Table 11: Effect of three water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on grain yield per/m^2 (g) in field experiment conducted during 2014/015 - 2015/016 seasons in Elobeid.

	Season 2014/2015				Season 2015/2016			
Treatments	Water intervals				Water intervals			
Genotypes	IR_0	IR_1	IR_2	Mean	IR_0	IR_1	IR_2	Mean
Taggat 9	217.0^f	196.4	190.1^g	201.2	225.6^h	226.3^h	184.9^i	212.3$^{\mathbf{d}}$
Taggat 10	306.7^d	497.5	340.6^c	381.6	538.7^a	500.3^{bc}	429.2^e	489.4$^{\mathbf{a}}$
Taggat 14	335.9^c	495.3	335.6^c	388.9	508.0^a	503.6^{bc}	346.9^f	452.8$^{\mathbf{b}}$
Taggat 19	405.7^b	400.7	324.2^c	376.9	488.4^b	469.7^{cd}	447.5^{de}	468.5$^{\mathbf{b}}$
Gadambale	262.9^e	231.6	164.2^h	219.6	272.4^g	255.0^g	245.0^g	257.4$^{\mathbf{c}}$
Mean	305.6^{b}	364.3	270.9^{c}	…….	406.6^{a}	391.0^{b}	330.7^{c}	……..
Grand mean				**313.6**				**376.1**
SE±	SE w = 4.46, SE g = 5.76, SE w × g = 9.97				SE w = 3.52, SE g =			

IR_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.

SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.

*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means.

Table 12: Effect of three water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on grain yield ton/ ha in field experiment conducted during 2014/015 - 2015/016 seasons in Elobeid.

	Season 2014/2015	Season 2015/2016
Treatments	Water intervals	Water intervals

Genotypes	IR_0	IR_1	IR_2	Mean	IR_0	IR_1	IR_2	Mean
Taggat 9	2.2^{ef}	2.0^{fg}	1.6^{g}	$1.9^{\mathbf{c}}$	2.3^{h}	2.3^{h}	1.9^{i}	$2.1^{\mathbf{d}}$
Taggat 10	3.3^{c}	5.0^{a}	3.4^{c}	$3.9^{\mathbf{a}}$	5.4^{a}	$5.0b^{c}$	4.3^{e}	$4.9^{\mathbf{a}}$
Taggat 14	3.3^{c}	5.0^{a}	3.3^{c}	$3.9^{\mathbf{a}}$	5.1^{ab}	5.0^{bc}	3.5^{f}	$4.7^{\mathbf{b}}$
Taggat 19	3.8^{b}	4.0^{b}	3.0^{d}	$3.6^{\mathbf{b}}$	4.9^{bc}	4.7^{cd}	4.5^{de}	$4.5^{\mathbf{b}}$
Gadambalea	2.4^{e}	2.3^{e}	1.9^{fg}	$2.1^{\mathbf{c}}$	2.7^{g}	2.6^{gh}	2.5^{gh}	$2.6^{\mathbf{c}}$
Mean	3.0^{b}	3.6^{a}	2.7^{c}	……	4.1^{a}	3.9^{b}	3.3^{c}	……
Grand mean				**3.1**				**3.8**
SE±	SE w = 0.05, SE g = 0.06, SE w × g = 0.11				SE w = 0.03, SE g = 0.05, SE w × g = 0.09			

IR_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.

SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.

*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means

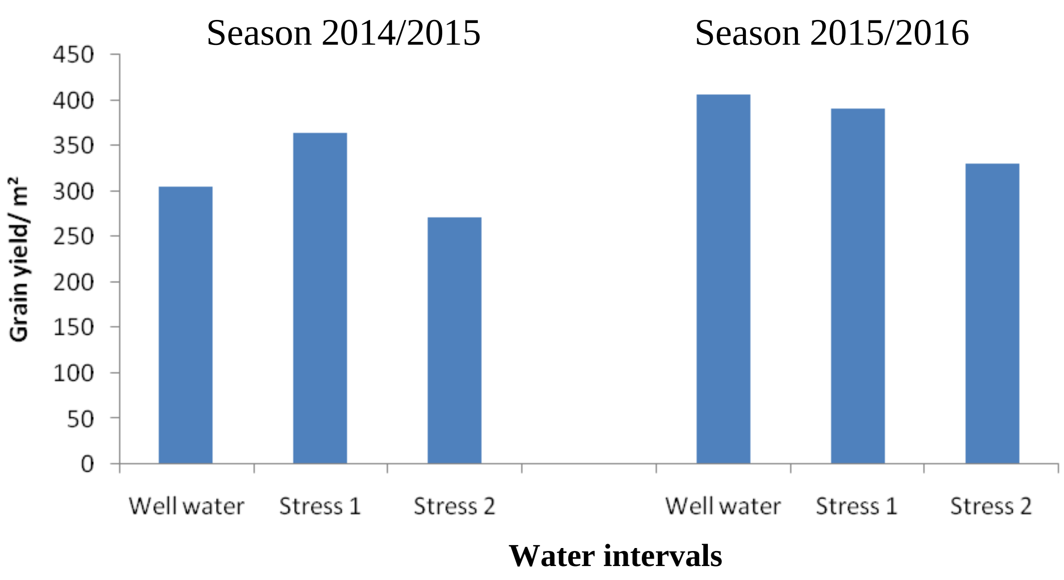

Fig.16 Main effects of water intervals on grain yield/m²

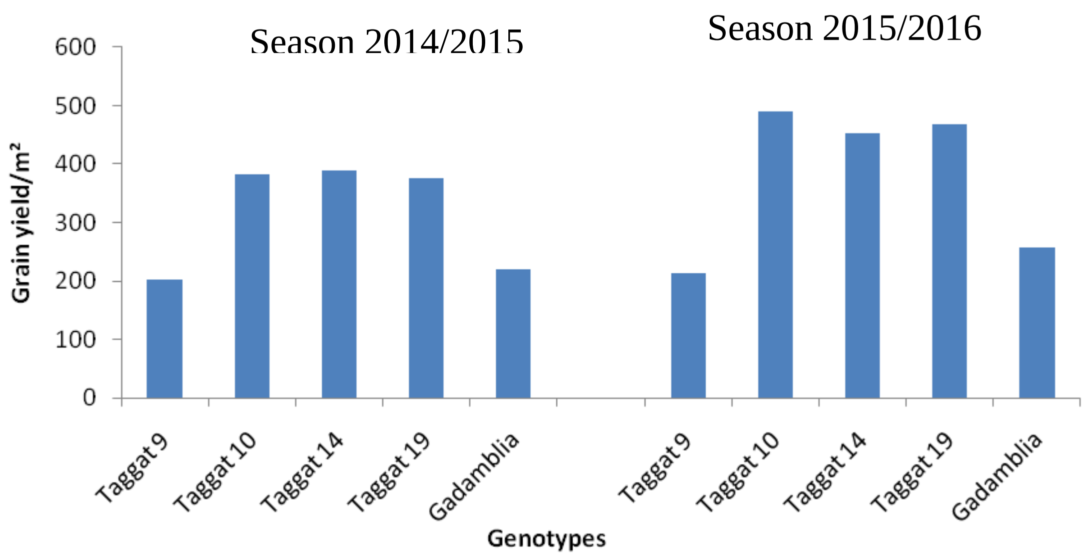

Fig.17 Main effects of sorghum genotypes on grain yield/m²

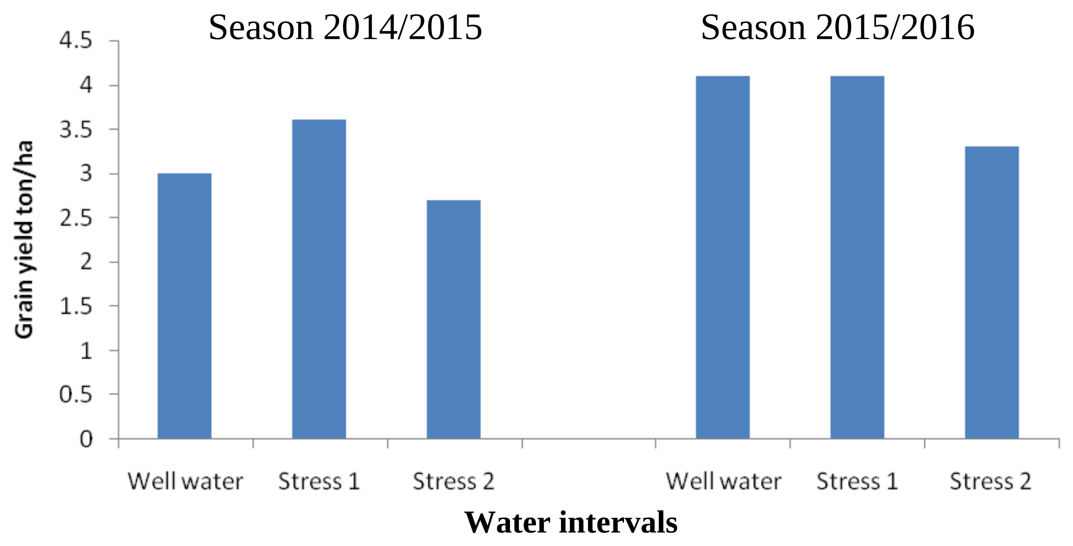

Fig.18 Main effects of water intervals on grain yield ton/ha

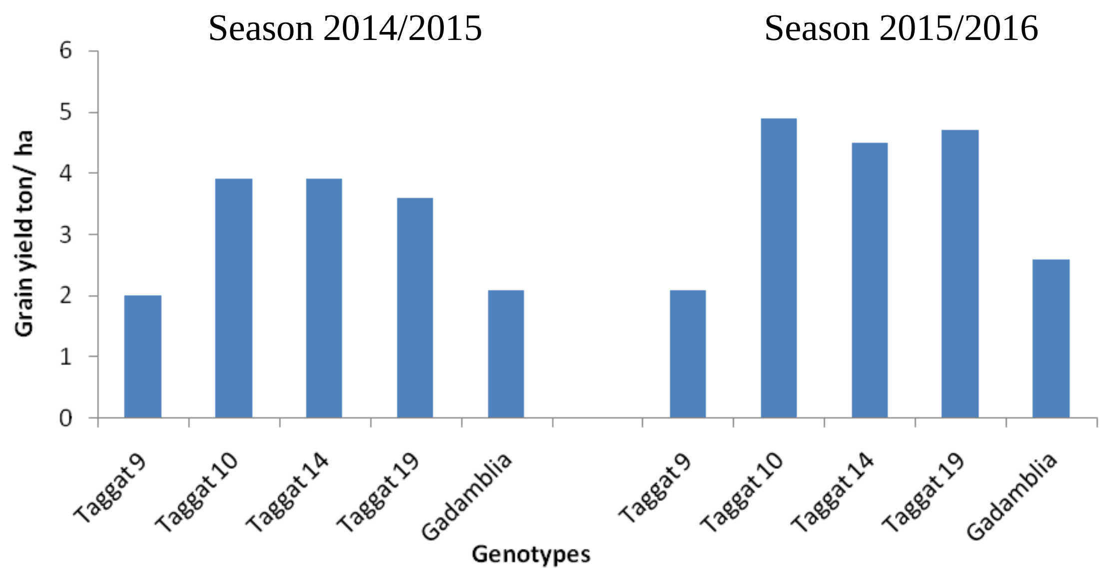

Fig.19 Main effects of sorghum genotypes on grain yield ton/ha

one and two (3.9 and 4.9 ton/ha) and Taggat 14 in season one (3.9 ton/ha), while the lowest estimates were recorded by Gadambalea in the two seasons (2.1 ton/ha. for season one and 2.6 ton/ha for season two) and Taggat 9 (2 ton/ha) in season one (Fig.19).The highest estimate for the interaction recorded by Taggat10 in each of stress **I** water regime in season one (5 ton/ha) and well-watered in season two (5.4 ton/ha). On the other hand, Taggat 9 in stress **II** scored the lowest estimates in season one and two (1.6 and 1.9 ton/ha, respectively).

4.1.13 Harvest index (%)

The effects of water intervals, genotypes and their interactions on harvest index (Appendix 1) were significant in both seasons. Data presented in Table (13) showed that the highest harvest index was recorded by plants under stress **I** (22.6%) in season one and plants under stress **II** (25.3%) in both season**.** Nevertheless, well-watered plants scored fewer harvest index (21.2% and 23.3%) in the two seasons (Fig.20). With regard to the genotypes, the highest harvest index was recorded by Taggat 19 in both seasons (23.3% for season one and 26.8% for season two), Taggat 14 and Gadambalea in season one (22.8 % and 22.6%, respectively).In contrast, the lowest estimates were recorded by Taggat 9 in both seasons (19.4% and 18.6% respectively). Interactions of each of Taggat 19 in stress **II** in both seasons and Taggat 10 in stress **II** in season one recorded the highest estimates (26.3% 31.5%, for Tagat 19 in season one and two, respectively 31% for Taggat 10 in season two). In contrast, the lowest one was recorded by Taggat 9 in stress **II** in the two seasons (17.5% and 17%, respectively) fig.21.

Table 13: Effect of three water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on harvest index (%)in field experiment conducted during 2014/015 - 2015/016 seasons in Elobeid.

	Season 2014/2015				Season 2015/2016			
Treatments	Water intervals				Water intervals			
Genotypes	IR_0	IR_1	IR_2	Mean	IR_0	IR_1	IR_2	Mean
Taggat 9	20.3^{ef}	20.3^{ef}	17.5^{g}	$19.4^{\mathbf{c}}$	19.0^{de}	19.7^{de}	17.0^{e}	$18.6^{\mathbf{d}}$
Taggat 10	20.4^{ef}	22.5^{cd}	20.7^{e}	$21.2^{\mathbf{b}}$	24.0^{bc}	24.1^{bc}	31.0^{a}	$26.4^{\mathbf{ab}}$
Taggat 14	18.9^{fg}	25.0^{ab}	24.7^{b}	$22.8^{\mathbf{a}}$	25.4^{b}	25.9^{b}	21.5^{cd}	$24.3^{\mathbf{c}}$
Taggat 19	22.5^{cd}	$21.0d^{e}$	26.3^{a}	$23.3^{\mathbf{a}}$	24.8^{b}	20.0^{bc}	31.5^{a}	$26.8^{\mathbf{a}}$
Gadambalea	23.8^{bc}	24.2^{b}	19.7^{ef}	$22.6^{\mathbf{a}}$	23.2^{bc}	26.1^{b}	25.7^{b}	$25.0^{\mathbf{bc}}$
Mean	21.2^{b}	22.6^{a}	21.8^{b}	……..	23.3^{b}	24.0^{b}	25.3^{a}	……..
Grand mean				**21.8**				**24.2**
SE±	SE w = 0.24, SE g = 0.31, SE w × g = 0.53				SE w = 0.30, SE g =			

IR_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.

SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.

*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means

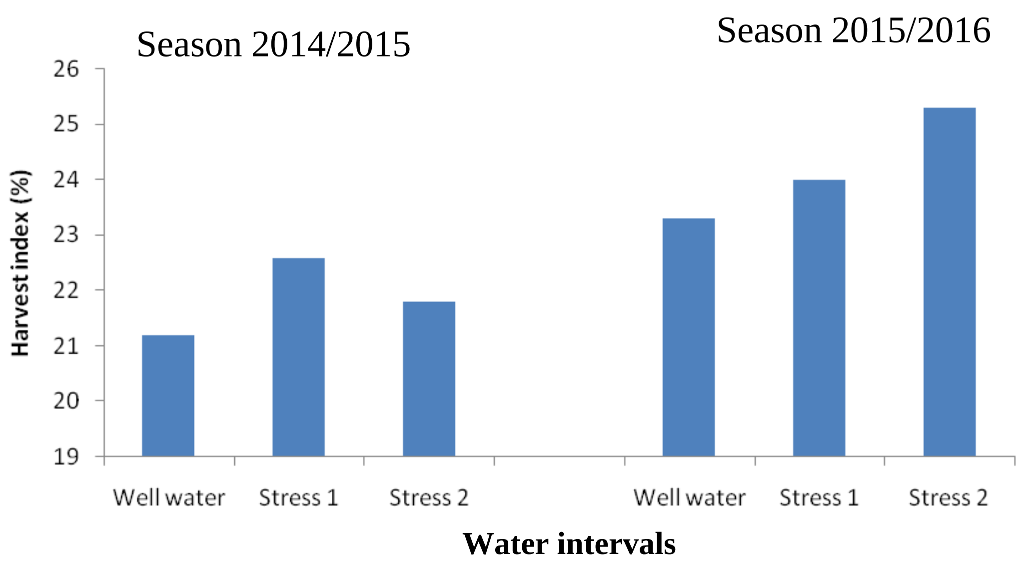

Fig.20 Main effects of water intervals on Harvest index

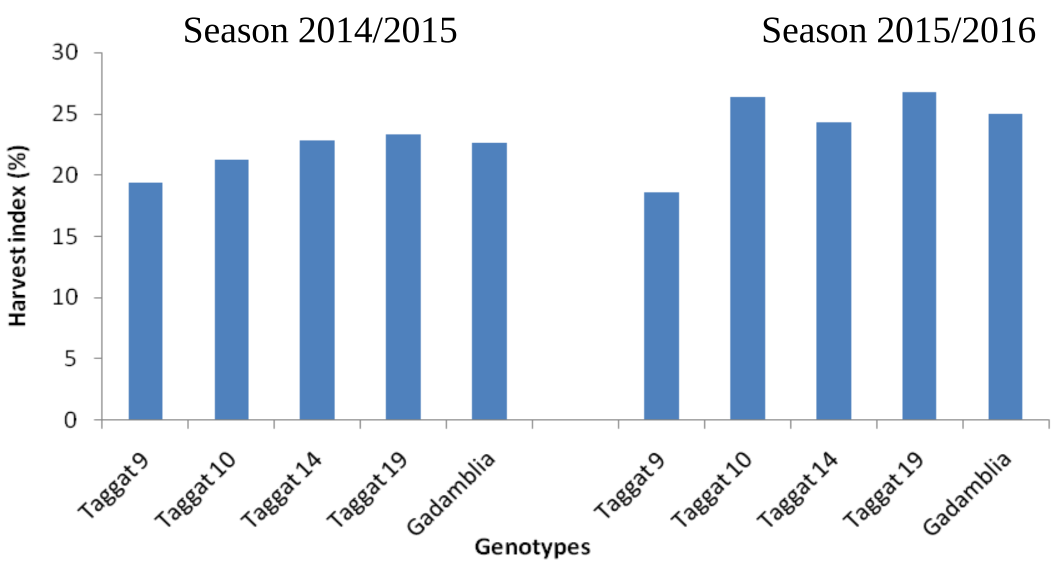

Fig.21 Main effects of sorghum genotypes on harvest index (%)

4.1.14 Seed index (%)

Analysis of variance (Appendix 1) showed significant effects among each of water intervals, genotypes and their interactions in season one. Table 14 showed that well-watered plants and plants in stress **II** recorded the highest seed index 0.6%, the lowest estimate (0.5) was recorded by plants in stress **I** (Fig.22). With regard to the genotypes, the highest estimate for this trait was recorded by Gadambalea (0.7%). On the other hand, the lowest estimate (0.5%) was given by Taggat 9 (Fig.23). The highest estimate of the interaction was recorded by Gadambalea in stress **II** (0.8%), while the lowest one was recorded by Taggat 14 in well-watered treatment (0.4%).

4.1.15 Drought tolerance index

Appendix 1 disclosed significant effects in drought tolerance index among the two water stresses, genotypes and their interactions in both seasons. Table15 showed that the highest estimates recorded by plants in stress **II** in the two seasons (1.1 and 0.97, respectively) compared with plants in stress **I** (0.9) Fig.24. Taggat 10 and 14 genotypes recorded the highest drought tolerance index in season one (1.2), while Taggat 19 exhibited the highest one in season two (0.96). The lowest estimates were recorded by Gadambalea and Taggat 9 (between 0.8 and 0.9) in both seasons (Fig.25). The interaction of Taggat 10 and 14 under stress **I** in both seasons recorded the highest estimates (1.4 and 1.5 in season one and 0.94 and 0.99 in season two, respectively). In contrast, the lowest estimates for the interaction were recorded by Gadambalea in stress **II** in season one (0.7) and Tagat 14 under stress **II** in season two (0.68).

Table 14: Effect of three water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on seed index (%) in field experiment conducted during 2014/015 - 2015/016 seasons in Elobeid.

	Season 2014/2015				Season 2015/2016			
Treatments	Water intervals				Water intervals			
Genotypes	IR_0	IR_1	IR_2	Mean	IR_0	IR_1	IR_2	Mean
Taggat 9	0.6^{cd}	0.4^{k}	0.5^{i}	$0.5^{\mathbf{d}}$	0.6	0.6	0.6	0.6
Taggat 10	0.6^{cd}	0.5^{h}	0.6^{f}	$0.6^{\mathbf{bc}}$	0.5	0.5	0.5	0.5
Taggat 14	0.4^{j}	0.6^{e}	0.7^{c}	$0.6^{\mathbf{c}}$	0.5	0.7	0.7	0.6
Taggat 19	0.5^{g}	0.5^{g}	0.6^{cd}	$0.6^{\mathbf{b}}$	0.6	0.5	0.7	0.6
Gadambalea	0.6^{d}	0.7^{b}	0.8^{a}	$0.7^{\mathbf{a}}$	0.6	0.6	0.7	0.6
Mean	0.6^{a}	0.5^{b}	0.6^{a}	……	0.6	0.6	0.6	……
Grand mean				**0.6**				**0.6**
SE±	SE w = 0.002, SE g = 0.003, SE w × g = 0.005						SE w = 0.01, SE	

IR_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.

SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.

*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means.

Table 15: Effect of tow water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on drought tolerance index in field experiment conducted during 2014/015 -2015/016 seasons in Elobeid.

	Season 2014/2015			Season 2015/2016		
Treatments	Water intervals			Water intervals		
Genotypes	IR_1	IR_2	Mean	IR_1	IR_2	Mean
Taggat 9	0.8^{cd}	0.9^{b}	$0.8^{\mathbf{c}}$	0.68^{c}	0.99^{a}	0.84^{c}
Taggat 10	1.0^{b}	1.4^{a}	$1.2^{\mathbf{a}}$	0.91^{a}	0.94^{a}	$0.92^{\mathbf{ab}}$
Taggat 14	1.0^{b}	1.5^{a}	$1.2^{\mathbf{a}}$	0.93^{a}	1.00^{a}	$0.96^{\mathbf{a}}$
Taggat 19	0.9^{b}	0.9^{b}	0.9^{b}	0.92^{a}	0.96^{a}	$0.94^{\mathbf{ab}}$
Gadambalea	0.7^{d}	0.9^{b}	$0.8^{\mathbf{c}}$	0.80^{b}	0.94^{a}	0.87^{bc}
Mean	0.9^{b}	1.1^{a}	……..	0.85^{b}	0.97^{a}	……..
Grand mean			**1.0**			**0.91**
SE±	SE w = 0.01, SE g = 0.02, SE w × g = 0.03			SE w = 0.01, SE g =		

IR_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.

SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.

*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means.

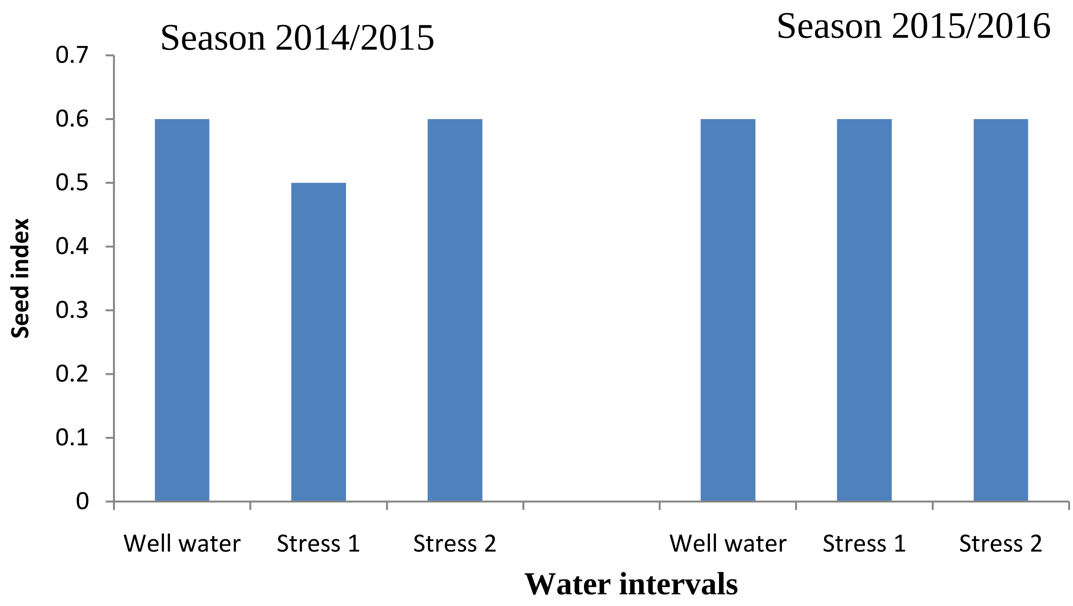

Fig.22 Main effects of water intervals on seed index

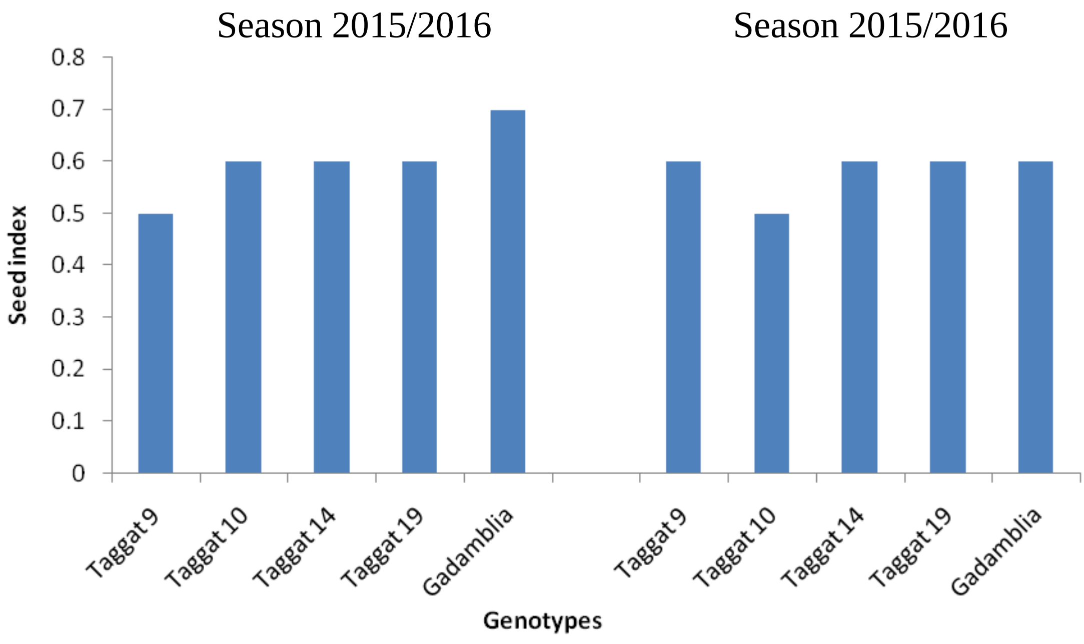

Fig.23 Main effects of sorghum genotypes on seed index

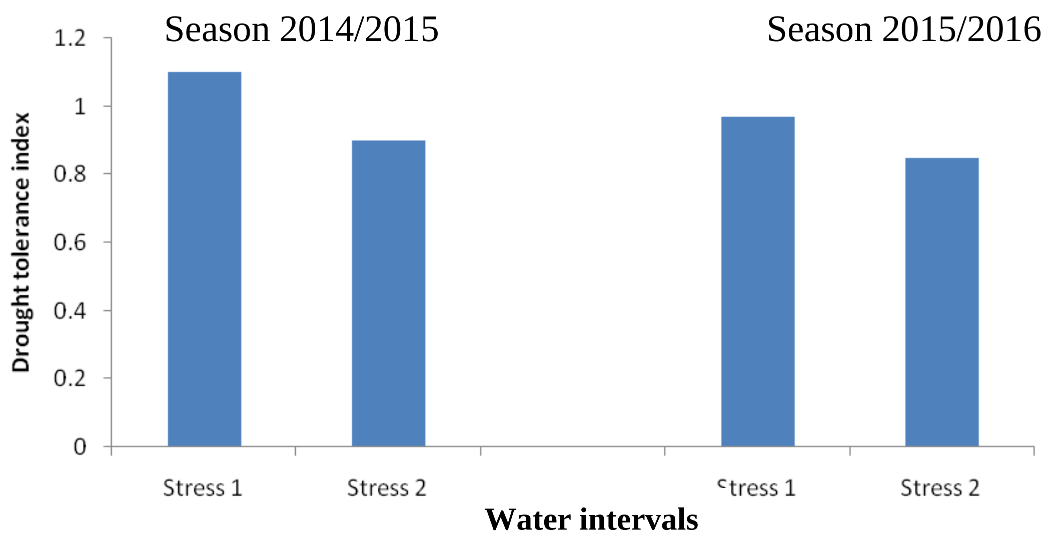

Fig.24 Main effects of water intervals on Drought tolerance index

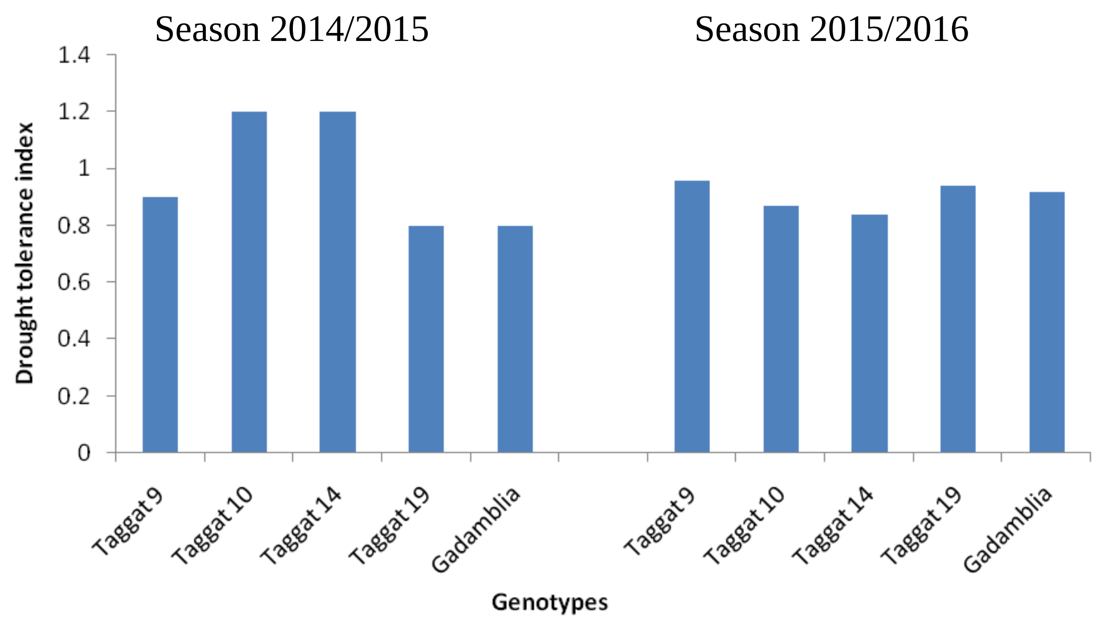

Fig.25 Main effects of sorghum genotypes on drought tolerance index

4.1.16 Soil moisture content (%) at pre and post watering

Analysis of variance (Appendix 2) showed that water intervals and soil depths had significant effects on moisture content percent at pre-watering only in stress **I** and **II** (Table 16 and 17). With regard to water treatments, the highest estimate for this trait was recorded by well-watered treatment (6.887 and 7.090, at the two types of stress, respectively). The depth 30 - 45 cm reported the highest moisture content (4.79 and 4.74 at stress **I** and **II** periods, respectively). In contrast, the lowest estimate was reported by soil depth 0 – 15 (4.18 and 4.48 at stress **I** and **II** periods, respectively).

4.1.17 Consumed moisture in the soil

Analysis of variance (Appendix 2) disclosed significant effects for consumed moisture in the soil among water intervals in the two stressed periods only. Data presented on Table 18 showed that the highest estimate of this trait recorded by the stress in the two periods (4.81 and 4.55 in stress **I** and **II**, respectively) compared with well-watered treatment (0.35 and 0.34 in stress **I** and **II**, respectively).

4.2 Laboratory Experiment:

Two laboratory experiments were conducted for two seasons (2014/2015 – 2015/ 2016). Data from these experiments were collected during seed filling stages of sorghum genotypes which were sown in the field under different water intervals. The parameters were obtained at soft and hard dough stages and at physiological maturity stage. The collected data were subjected to statistical analyses. Results are shown in 15 tables (from table 19 up to table 27). Results of each estimated parameter in the first and second seasons were illustrated in one table. Effects of each of the genotypes, water regimes and their interactions were significant on seed quality for most of the studied traits in both seasons (Appendices 3 - 5).

Table 16: Effect of two water intervals and three soil depths on soil moisture content (%) at pre and

post-watering in stress I period in a field experiment (2014/2015 season) in Elobeid.

	Moisture (%) at pre-watering				Moisture (%) at post-watering			
	Soil depths (cm)				Soil depths(cm)			
Treatments	0 — 15	15 — 30	30 — 45	Mean	0 — 15	15 — 30	30 — 45	Mean
Well-water	6.590	6.783	7.288	6.887	6.383	6.980	7.317	6.893
Stress I	2.035	2.173	2.293	2.079	6.162	6.472	7.158	6.597
Mean	4.181	4.478	4.790	—	6.272	6.726	7.238	—
Grand mean				**4.483**				**6.745**

Table17: Effect of two water intervals and three soil depths on soil moisture content (%) at pre and

post-watering in stress II period in a field experiment (2015/2016 season) in Elobeid.

	Moisture (%) at pre-watering				Moisture (%) at post-watering			
	Soil depths (cm)				Soil depths(cm)			

reatments	0 — 15	15 — 30	30 — 45	Mean	0 — 15	15 — 30	30 — 45	Mean
'ell-water	6.857	7.045	7.368	7.090	7.058	7.055	7.050	7.054
ress II	2.095	2.035	2.118	2.083	6.755	7.050	7.163	6.989
lean	4.476	4.540	4.743	—	6.906	7.053	7.106	—
rand mean				**4.586**				**7.022**

Table18: Effect of two water intervals and three soil depths on consumed moisture in the soil in stress I and II periods at three soil depths in a field experiment (2014/2015 season) in Elobeid.

	Consume moisture in stress **I**				Consume moisture in stress **II**			
	Soil depths (cm)				Soil depths (cm)			
eatments	0 — 15	15 — 30	30 — 45	Mean	0 — 15	15 — 30	30 — 45	Mean
ell-water	0.288	0.370	0.393	0.350	0.335	0.318	0.353	0.335
ess	4.498	4.900	5.045	4.814	4.390	4.408	4.865	4.554
ean	2.393	2.635	2.719		2.363	2.363	2.609	
and an				**2.582**				**2.445**

4.2.1 Standard germination test (%) at soft dough stage

Analysis of variance for standard germination percent at soft dough stage (Appendix 3) showed that water intervals, genotypes and their interactions had no significant effects on mean germination percent in season one and two (Table 19).

4.2.2 Standard germination test (%) at hard dough stage

Appendix 3 indicated that water intervals, genotypes and their interactions had no significant effects on standard germination percent at hard dough stage in both seasons (Table 20).

4.2.3 Standard germination test (%) at physiological maturity stage

Genotypes and water intervals disclosed significant effects on standard germination percent at physiological maturity stage in season one (Appendix 3). Table 21 showed that well-watered and stress**I** plants scored the highest estimates (100%) compared with stress **II** plants (98%). Taggat 9, 10, 19 and Gadambalea genotypes recorded the highest estimates (100%). On the other hand, Taggat 14 recorded the lowest one (97%).

4.2.4 Seedling length (cm) at soft dough stage

Analysis of variance (Appendix 4) disclosed significant effects in both seasons among each of water intervals and genotypes. Data presented on Table 22 indicated that the highest seedling length at soft dough stage was scored by well-watered plants (between 14 and 18 cm) in the two seasons. On the other hand, the lowest estimates (between 12 and 16 cm) were recorded by plants in stress **II** in both seasons. Taggat 10 recorded the highest estimates (between 16 and 20 cm in season one and two). In contrast, the lowest estimates (between 12 and 14 cm) were recorded by Gadambalea in the two seasons. Regarding the interactions, the highest estimates were given by Taggat 10 in well-watered treatment (18.77 cm), while the lowest ones were given by Tagat 19 in well-water and Gadambalea in stress **II** (9.51 and 10.16 cm, respectively).

Table 19: Effect of three water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on standard germination test (%) at soft dough stage in a laboratory experiment conducted during 2014/015-2015/016 seasons in Elobeid.

	Season 2014/2015				Season 2015/2016			
Treatments	Water intervals				Water intervals			
Genotypes	IR_0	IR_1	IR_2	Mean	IR_0	IR_1	IR_2	Mean
Taggat 9	90.0	90.0	90.0	90.0	88.0	88.0	80.0	85.0
Taggat 10	90.0	90.0	70.0	83.0	93.0	93.0	85.0	90.0
Taggat 14	90.0	90.0	90.0	90.0	93.0	85.0	82.0	87.0
Taggat 19	90.0	70.0	80.0	80.0	88.0	85.0	87.0	87.0
Gadambalea	80.0	90.0	80.0	83.0	83.0	88.0	82.0	84.0
Mean	88.0	86.0	82.0	……..	89.0	88.0	83.0	……..
Grand mean				**87.00**				**86.5**
SE±	SE w = 0.21, SE g = 0.28, SE w × g = 0.48				SE w = 2.56, SE g =			

IR_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.
SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.
*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means.

Table 20: Effect of three water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on standard germination test (%) at hard dough stage in a laboratory experiment conducted during 2014/015-2015/016 seasons in Elobeid.

	Season 2014/2015				Season 2015/2016			
Treatments	Water intervals				Water intervals			
Genotypes	IR_0	IR_1	IR_2	Mean	IR_0	IR_1	IR_2	Mean

Taggat 9	90.0	90.0	90.0	90.0	93.0	95.0	93.0	93.0
Taggat 10	100.0	100.0	90.0	97.0	95.0	98.0	98.0	97.0
Taggat 14	90.0	100.0	100.0	97.0	98.0	98.0	93.0	96.0
Taggat 19	100.0	100.0	100.0	100.0	98.0	100.0	95.0	98.0
Gadambalea	90.0	90.0	90.0	90.0	90.0	100.0	93.0	94.0
Mean	94.0	96.0	94.0	……..	95.0	98.0	94.0	……..
Grand mean				**95.67**				**95.50**
SE±	SE w = 0.12, SE g = 0.16, SE w × g = 0.27					SE w = 1.71, SE g		

IR_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.

SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.

*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means.

Table 21: Effect of three water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on
standard germination test (%) at physiological maturity in a laboratory experiment conducted during
2014/015 -2015/016 seasons in Elobeid.

	Season 2014/2015				Season 2015/2016			
Treatments	Water intervals				Water intervals			
Genotypes	IR_0	IR_1	IR_2	Mean	IR_0	IR_1	IR_2	Mean
Taggat 9	100.0	100.0	100.0	100.0**a**	95.0	100.0	100.0	98.0
Taggat 10	100.0	100.0	100.0	100.0**a**	100.0	100.0	100.0	100.0
Taggat 14	100.0	100.0	90.0	97.0**b**	100.0	100.0	100.0	100.0
Taggat 19	100.0	100.0	100.0	100.0**a**	100.0	97.0	100.0	99.0
Gadambalea	100.0	100.0	100.0	100.0**a**	100.0	100.0	92.0	97.0
Mean	100.0a	100.0a	98.0*b*	……..	99.0	100.0	98.0	……..
Grand mean				**99.0**				**99.0**
SE±	SE w = 0.07, SE g = 0.08, SE w × g = 0.15				SE w = 0.73, SE g			

IR_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.
SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.
*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means.

Table 22: Effect of three water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on seedling length (cm) at soft dough stage in a laboratory experiment conducted during 2014/015 -2015/016 seasons in Elobeid.

	Season 2014/2015				Season 2015/2016			
Treatments	Water intervals				Water intervals			
Genotypes	IR_0	IR_1	IR_2	Mean	IR_0	IR_1	IR_2	Mean
Taggat 9	13.82^{e}	13.70^{e}	12.96^{e}	13.49$^{\mathbf{c}}$	16.15	15.63	14.48	15.42$^{\mathbf{c}}$
Taggat 10	18.77^{a}	17.77^{a}	14.32^{d}	16.95	20.86	18.30	17.83	19.09
Taggat 14	16.86^{b}	15.60^{c}	14.38^{d}	15.61	19.27	15.60	16.57	17.15
Taggat 19	9.51^{f}	13.55^{e}	10.62^{c}	11.23	19.23	17.23	16.80	17.75
Gadambale	15.53^{c}	13.25^{e}	10.16^{f}	12.98$^{\mathbf{c}}$	14.08	12.60	13.13	13.27
Mean	14.90^{a}	14.77^{a}	12.49^{b}	……..	17.92	15.87	15.76	……..
Grand mean				**14.05**				**16.52**
SE±	SE w = 0.21, SE g = 0.28, SE w × g = 0.48				SE w = 0.51, SE g =			

IR_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.

SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.

*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means.

4.2.5 Seedling length (cm) at hard dough stage

Seedling length at hard dough stage analysis (Appendix 4) showed significant effects among each of the water intervals and genotypes in the two seasons and their interactions in season one. Table 23 denotes that the highest estimates were achieved by well-watered plants in the two seasons (18.47 and 18.14 cm, respectively), and stress **I** plants in season two (18.45 cm).On the other hand, stress **II** plants recorded the lowest length in the two seasons (16.24 and 16.85 cm respectively). Taggat 10 produced the longest seedlings in both seasons (23.07 and 21.77 cm, respectively). On the other hand, the lowest estimates were recorded by Gadambalea (12.98 cm in season one) and Taggat 9 (15.08 cm in season two). The Interaction of Taggat 10 in the three water intervals and Taggat 14 in well-watered (22.54 cm) gave the highest seedling length (between 22 and 23 cm), while the lowest estimates were recorded by Gadambalea in stress **II** (10.16 cm).

4.2.6 Seedling length (cm) at physiological maturity stage

Analysis of variance showed significant effects among the genotypes only in both seasons and among the interaction between water intervals and genotypes in season one (Appendix 4). Table 24 revealed that the highest estimates were recorded by Taggat 10 in season one (25.26 cm) and Taggat 14 in season two (22.30 cm). On the other hand, the lowest estimates were recorded by Taggat 9 in season one and Gadambalea in season two (17.26 and 18.23 cm, respectively). The interaction of Taggat 10 in well-water scored the highest seedling length at physiological maturity stage (26.79 cm), while the lowest estimates recorded by Taggat 9 in stress **II** (14.01 cm).

Table 23: Effect of three water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on seedling length (cm) at hard dough stage in laboratory experiment conducted during 2014 /015 -2015/ 016 seasons in Elobeid.

	Season 2014/2015				Season 2015/2016			
Treatments	Water intervals				Water intervals			
Genotypes	IR_0	IR_1	IR_2	Mean	IR_0	IR_1	IR_2	Mean
Taggat 9	16.02^{d}	15.03^{de}	15.24^{d}	15.43$^{\mathbf{c}}$	15.60	15.58	14.07	15.08$^{\mathbf{d}}$
Taggat 10	22.91^{a}	23.26^{a}	23.04^{a}	23.07$^{\mathbf{a}}$	22.17	22.05	21.10	21.77$^{\mathbf{a}}$
Taggat 14	22.54^{a}	18.67^{b}	19.08^{b}	20.09$^{\mathbf{b}}$	20.94	20.09	18.82	19.95$^{\mathbf{b}}$
Taggat 19	17.37^{c}	14.08^{cf}	13.66^{f}	15.04$^{\mathbf{c}}$	16.95	17.03	17.12	17.03$^{\mathbf{c}}$
Gadambalea	15.53^{d}	13.25^{f}	10.16^{g}	12.98$^{\mathbf{d}}$	16.71	17.51	13.14	15.79$^{\mathbf{cd}}$
Mean	18.87^{a}	16.86^{b}	16.24^{c}	……..	18.47^{a}	18.45^{a}	16.85^{b}	……..
Grand mean				**17.32**				**17.92**
SE±	SE w = 0.16, SE g = 0.20, SE w × g = 0.35				SE w = 0.36, SE g = 0.43, SE w × g = 0.96			

IR_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.

SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.

*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means.

Table 24: Effect of three water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on seedling length (cm) at physiological maturity stage in laboratory experiment conducted during 2014/015 -2015/016 seasons in Elobeid.

	Season 2014/2015				Season 2015/2016			
Treatments	Water intervals				Water intervals			
Genotypes	IR_0	IR_1	IR_2	Mean	IR_0	IR_1	IR_2	Mean
Taggat 9	18.75^{f}	19.02^{f}	14.01^{g}	$17.26^{\mathbf{e}}$	18.8	20.3	18.4	$19.23^{\mathbf{c}}$
Taggat 10	26.79^{a}	23.89^{bc}	25.11^{a}	$25.26^{\mathbf{a}}$	21.8	20.1	19.7	$20.58^{\mathbf{b}}$
Taggat 14	24.07^{b}	22.49^{cde}	24.68^{b}	23.75	21.7	22.2	22.9	$22.30^{\mathbf{a}}$
Taggat 19	21.99^{d}	22.38^{cde}	20.94^{e}	$21.77^{\mathbf{c}}$	22.2	22.9	19.6	$21.61^{\mathbf{b}}$
Gadambale	18.37^{f}	18.68^{f}	19.04^{f}	18.69	19.9	18.3	17.9	$18.73^{\mathbf{d}}$
Mean	21.99	21.21	20.76	……..	20.9	20.7	19.7	……..
Grand mean				**21.35**				**20.49**
SE±	SE w = 0.28, SE g = 0.36, SE w × g = 0.63				SE w = 0.34, SE g =			

R_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.

SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.

*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means.

4.2.13 Seedling relative moisture content at soft dough stage

Analysis of variance for seedling relative moisture content at soft dough stage (Appendix 5) showed significant differences among genotypes and interaction in both seasons, and among water intervals in season one only. Table 25 showed that, well-watered plants gave the highest estimates (2.06), while plants in stress **II** recorded the lowest one (1.90). Regarding genotypes, the maximum estimate (2.45 and 2.36) was recorded by Taggat 10 in both seasons. On contrarily the lowest value reported by Gadambalea and Taggat 9 (1.45 and 1.36 in season one and two, respectively). The interaction of Taggat 10 in each water intervals recorded the highest estimates in both seasons (between 2.32 and 2.46) and Taggat 19 in well-water and in stress **I** in season two (2.17 and 2.33). However the lowest value was given by Tagat 9 in stress **I** in season one (1.27) and in stress **II** in season two (1.25).

4.2.14 Seedling relative moisture content at hard dough stage

Table 26 disclosed the means of seedling relative moisture content at hard dough stage. Statistical analysis showed significant effects among each of the genotypes and the interactions in both seasons, and among water intervals in season one (Appendix 5). Well-watered plants in season one scored the highest estimates (2.09), while plants in stress **II** recorded the lowest one (1.94). Regarding to the genotypes effects, Taggat 10 in season one and 14 in season two recorded the highest estimates (2.43 and 2.75, respectively). In contrast, the lowest estimates recorded by Gadambalea in season one and two (1.50 and 1.22 respectively). In season one, the interaction of Taggat 10 in well-watered plants and in stress **I** recorded the highest estimates (2.46 and 2.47 respectively), while in season two, Taggat 14 in stress **I** scoreed the highest one (3.10). In contrast, Taggat 9 in stress **II** in season one and Gadambalea in stress II also in season two scored the lowest ones (1.41 and 1.17, respectively).

Table 25: Effect of three water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on seedling relative moisture content at soft dough stage in a laboratory experiment conducted during 2014/015 -2015/016 seasons in Elobeid.

	Season 2014/2015				Season 2015/2016			
Treatments	Water intervals				Water intervals			
Genotypes	IR_0	IR_1	IR_2	Mean	IR_0	IR_1	IR_2	Mean
Taggat 9	1.92^{d}	1.72^{e}	1.27^{g}	$1.63^{\mathbf{d}}$	1.34^{efg}	1.49^{efg}	1.25^{g}	$1.36^{\mathbf{d}}$
Taggat 10	2.46^{a}	2.44^{a}	2.45^{a}	$2.45^{\mathbf{a}}$	2.36^{a}	2.40^{a}	2.32^{a}	$2.36^{\mathbf{a}}$
Taggat 14	2.16^{bc}	2.18^{bc}	1.97^{d}	$2.10^{\mathbf{c}}$	2.07^{abc}	1.80^{cde}	2.13^{ab}	$2.09^{\mathbf{b}}$
Taggat 19	2.33^{ab}	2.07^{cd}	2.34^{ab}	$2.25^{\mathbf{b}}$	2.17^{a}	2.33^{a}	1.86^{bcd}	$2.12^{\mathbf{b}}$
Gadambalea	1.42^{fg}	1.47^{f}	1.47^{f}	$1.45^{\mathbf{e}}$	1.38^{fg}	1.52^{efg}	1.66^{def}	$1.52^{\mathbf{c}}$
Mean	2.06^{a}	1.97^{b}	$1.90^{\mathbf{c}}$	……..	1.87	1.91	1.84	……..
Grand mean				**1.98**				**1.87**
SE±	SE w = 0.08, SE g = 0.10, SE w × g = 0.17				SE w = 0.04, SE g = 0.06, SE w × g = 0.09			

R_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.

SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.

*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means.

Table 26: Effect of three water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on seedling relative moisture content at hard dough stage in a laboratory experiment conducted during 2014/015 -2015/016 seasons in Elobeid..

	Season 2014/2015				Season 2015/2016			
Treatments	Water intervals				Water intervals			
Genotypes	IR_0	IR_1	IR_2	Mean	IR_0	IR_1	IR_2	Mean
Taggat 9	1.94^{e}	1.72^{f}	1.41^{h}	$1.69^{\mathbf{d}}$	1.72^{cd}	1.44^{de}	1.39^{de}	$1.52^{\mathbf{c}}$
Taggat 10	2.46^{a}	2.47^{a}	2.36^{b}	$2.43^{\mathbf{a}}$	2.38^{b}	2.39^{b}	2.37^{b}	$2.38^{\mathbf{b}}$
Taggat 14	2.22^{c}	2.17^{c}	2.02^{de}	$2.13^{\mathbf{c}}$	2.42^{b}	3.10^{a}	2.72^{b}	$2.75^{\mathbf{a}}$
Taggat 19	2.32^{b}	2.07^{d}	2.39^{ab}	$2.26^{\mathbf{b}}$	2.37^{b}	1.92^{c}	2.55^{b}	$2.28^{\mathbf{b}}$
Gadambalea	1.50^{gh}	1.51^{g}	1.50^{gh}	$1.50^{\mathbf{e}}$	1.12^{e}	1.37^{de}	1.17^{e}	$1.22^{\mathbf{d}}$
Mean	2.09^{a}	1.99^{b}	1.94^{c}	……..	2.00	2.04	2.04	……..
Grand mean				**2.003**				**2.03**
SE±	SE w = 0.09, SE g = 0.12, SE w × g = 0.21				SE w = 0.02, SE g =			

R_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.

SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.

*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means.

4.2.15 Seedling relative moisture content at physiological maturity stage

Analysis of variance for seedling relative moisture content at physiological maturity stage (Appendix 5) showed significant effects among each of the water intervals, genotypes and their interactions in both seasons. Table 27 showed that well watered plants and plants in stress **I** exhibited the highest estimates in season one (1.97 and 1.95, respectively) and well-watered plants in season two (1.10). On the other hand, plants in stress **II** exhibited the lowest one in both seasons (1.75 and 1.50, respectively). Regarding the genotypes, the highest estimate was recorded by Taggat 10 in season one (2.20) and Taggat 14 in season two (2.18). In contrast, the lowest estimate was recorded by Taggat 9 and Gadambalea in both seasons (1.55 and 1.49 in season one, 1.39 and 1.140 in season two, respectively). The highest estimates of interaction were reported by Taggat 10 in stress I in season one and two (2.37 and 2.28, respectively). Taggat 19 in stress **I** in season one and in well-water in season two recorded also the highest estimates (2.36 and 2.25, respectively). In contrast, the lowest values in season one were reported by Taggat 9 in stress **I** (1.47) and in season two by the same genotype in stress **II** (1.17).

Table 27: Effect of three water intervals on five sorghum genotypes [*Sorghum bicolor* (L).Moench] on
seedling relative moisture content at physiological stage in a laboratory experiment conducted in 2014/015
-2015/016 seasons in Elobeid.

	Season 2014/2015				Season 2015/2016			
Treatments	Water intervals				Water intervals			
Genotypes	IR_0	IR_1	IR_2	Mean	IR_0	IR_1	IR_2	Mean
Taggat 9	$1.59d^{e}$	1.47^{e}	1.59^{de}	$1.55^{\mathbf{c}}$	1.32^{de}	1.68^{c}	1.17^{e}	$1.39^{\mathbf{d}}$
Taggat 10	2.50^{a}	2.37^{a}	1.73^{d}	$2.20^{\mathbf{a}}$	1.29^{de}	2.28^{a}	1.35^{de}	$1.64^{\mathbf{c}}$
Taggat 14	2.18^{b}	2.07^{bc}	2.05^{bc}	$2.10^{\mathbf{b}}$	2.21^{b}	2.17^{ab}	2.17^{ab}	$2.18^{\mathbf{a}}$
Taggat 19	2.11^{b}	2.36^{a}	1.91^{c}	$2.13^{\mathbf{ab}}$	2.25^{a}	1.95^{b}	1.27^{de}	$1.82^{\mathbf{b}}$
Gadambalea	1.48^{e}	1.50^{e}	1.48^{e}	$1.49^{\mathbf{c}}$	1.26^{de}	1.42^{de}	1.53^{cd}	$1.40^{\mathbf{d}}$
Mean	1.97^{a}	1.95^{a}	1.75^{b}	……..	1.67^{b}	1.90^{a}	1.50^{c}	……..
Grand mean				**1.90**				**1.69**
SE±	SE w = 0.04, SE g = 0.05, SE w × g = 0.09				SE w = 0.02, SE g			

R_0, IR_1 and IR_2 denote full irrigation, stressed 1 and stressed 2 respectively.
SE w, SE g and SE w × g denote standard error of water interval, genotype and their interaction, respectively.
*Values having the same letter are not significant different at 5% (using Duncan Multiple Range Test) italic letters denote water interval means, bold letters denote genotype means and normal letters denote the interaction means.

CHAPTER FIVE

DISCUSSION

Generally, most of the traits measured in this study in both seasons were affected by water stress. Prominently, withholding irrigation at eight-leaf stage significantly reduced most of morphological, yield and its attributes. Studied genotypes also differed significantly in morphological, yield and yield components traits and showed different responses at the two stresses.

5. 1. Field experiment

5. 1. 1 Differences between seasons

The weather data during the two field experiments (2014/2015 and 2015/2016), showed that the two seasons differed greatly in their environmental conditions (Appendix 6). Season two (2015/2016) recorded high amount of rainfall (418.10 mm) and even distribution of rainfall. This is reflected in good performance in most of the studied traits, on the other hand, a wide variability in the studied traits among the genotypes in season one which could be a result of the less amount of rainfall in that season (339.10 mm). The less amount of rainfall and its distribution caused a variation in studied characters. With respect to genotypes, their significant effect in most of the studied traits in both seasons could be attributed to variability among the genotypes or to the differences in environmental conditions.

5. 1. 2 Morphological traits

The plant height significantly increased by withholding irrigation at three leaves stage and decreased by withholding irrigation at eight-leaf stage. Extensive and wide root system might be encouraged by early withholding of water (at three-leaf stage) and consequently reflected in high growth rate of plant height. Moreover, the less sensitivity of this stage (the three-leaf stage) to water stress could be a reason behind this result. Similar results were reported by Boyer (1988) who showed that increasing water stress resulted in decrease in plant height. In contrast, Nouri (2005) reported that stressed plants at the end of the season were significantly taller compared to the well-watered plants. Regarding to the genotypes, the genetic variability among the tested genotypes might explain that Taggat 14 recorded the highest estimates in plant height, and Gadambalia recorded the lowest ones in the both seasons. This result was in line with Nouri (2005) and Sher *et.al* (2013) who reported that plant height significantly varied among cultivars and moisture levels in the three growth stages. Similar findings were also reported by Suliman and Abdelbagi, (2016) and Mohamed (2011) when they studied the genetic variation of sorghum genotypes collection from Sudan.

In both seasons, no significant effects were reported among water intervals on number of leaves per plant. Supporting evidence was reported by Nouri (2005) and Kabbashi (1991) who stated that the number of leaves per plant was not affected by water stress. On the contrary, Rohbakhsh (2013) reported that the leaf number and tiller number of sorghum plants decreased dramatically with the increasing of water stress levels. With regard to the genotypes, the significant effect of the number of leaves per plant could be attributed to the different genetic materials.

Generally, the effect of water stress on phenology of sorghum depends upon the severity of the stress itself and on the stage of development of the crop at the time of stress. With respect to days to 50% flowering, water stress had no significant effect on days to 50% flowering. Similar results were reported by Abdelrahman (1985) and Ahmed (1989). In contrast, Nouri (2005) reported that stressed plants significantly took fewer days to reach 50% flowering compared to the well-watered plants. Regarding to genotypes, Gadambalia and Taggat 9 were the earliest flowering genotypes in the two seasons. Therefore, they were early flowering and suitable for cultivation in areas with low rain fall. Similar results were reported by Kane and Grabau (1992). On the other hand, Taggat 10 was the latest flowering genotype in the corresponding seasons. The late flowering genotypes require long rainy season to produce yield. Supported evidences were reported by Edwards and Purcell, (2005) who reported that long-cycle cultivars may deplete more water before the critical periods.

In the present study, the earliest matured plants in the two seasons were reported in well watering, In contrast, the late matured plants were reported in withholding irrigation at eight-leaf stage. This result contrasted with that obtained by Nouri (2005) who showed that stressed plants took significantly less days to reach milking and maturity stages compared to the well-watered plants. Regarding the genotypes, the earliest one in the two seasons was Gadamballea while the late one was Taggat 10. Thus, Gadamballea could be classified as drought escaper. Similar results were shown by Miller *et.al.*, (1996) and Ahmed (2009). The late maturing genotypes (as Taggat 10) need a long rainy season. Therefore, they are not suitable for cultivation in areas with low rain fall. This result agreed with FAO findings, (2002) which suggested that achieving high yield production in medium to late maturing sorghum cultivar requires approximately 450 to 650 mm of water during a growing season.

5.1.3 Yield and yields component:

Sorghum grain yield is dependent on soil water at planting and in-season precipitation. The relationship between grain yield and water is complex because grain yield and yield components are more sensitive to water deficits at certain growth stages. In the present study, watering regime and genotypes had no significant effects on mean number of heads per m^2. The consistent number of plants per meter square could be a reason to explain this result. In addition, the less responsibility of selected genotypes to produce more tillers might support this hypothesis. This result contrasted with that obtained by Blum *et, al*., (1989) who reported that panicles per m^2 and grain weight were reduced by water stress.

With respect to head length, well-watered plants and stressed plants at three leaves stage scored the tallest head length in both seasons. This period of stress might stimulate stressed plants to hasten the development of their root system and this consequently accelerates head development that was reflected in the tallest heads. The results agreed with the findings that were obtained by Younesi and Moradi, (2009). In contrast, Lahiri and Kumar, (1966) stated that stress occurring after crop establishment within the seedling phase generally has very little effect on grain yields either in millet or in sorghum. Regarding the genotypes, the significant effect of the studied genotypes could be attributed to their different genetic sources.

The significant higher head weight, in well watered and stressed plants at the three-leaf stage compared with stressed plant at the eight-leaf stage in both seasons could also be referred to the good development of their root system. Decreased head weight of plants under withholding irrigation at eight-leaf stage could be due to its effect on panicle size and potential grain number. Similar results were reported by Bakhiet (1990) and Ahmed (1989) who found that water stress reduced the mean grain yield per plant and panicle weight due to its effect on flowering and grain filling. Regarding the genotypes, significant differences in head weight were reported among the studied genotypes, the heaviest head weights genotypes in the two seasons Taggat 10 and 14 out-yielded. On other hand genotype Gadambalea scored the lowest head weight in the same seasons. The existence of diverse genetic variability among sorghum genotypes might explain the variation in head weight.

The significant effect among water intervals in number of grains per head explains the importance of mild stress in encouraging plants to efficient water uptake. Henceforth, stressed plants at three-leaf stage recorded greater number of grains per head in the two seasons. However, well-watered plants in season one and stressed plants at eight-leaf stage in season two scored fewer grains per head. Fewer grains in well-watered plants could be attributed to long vegetative period than reproductive growth period, while stressed plants at eight-leaf stage could be attributed to their effect on flowering by increasing the degree of floral abortion. This result agreed with that reported by Nouri (2005), and Younesi and Moradi, (2009). Difference in flowering time among the genotypes might affect Taggat 14 and 19 to score the high estimates in number of grains per head and Gadambalea and Taggat 9 to score the low estimates. Supporting evidence was reported by

Blum *et.al.*,(1989) who showed that the genotypes of longer growth duration produced more stover and total biomass with a lesser amount of grains per panicle and per unit area, as compared with genotypes of shorter growth duration.

The significantly heaviest 100 grain weight in well watered plants and the highest one in the stressed plants at the eight-leaf stage could be attributed to the strong relation between seed size and the duration of seed filling period. Moreover, photosynthesis most probably is reduced also by stress. This result is similar to that reported by Bakhiet (1990), Ahmed (1989) and Nouri, (2005). Regarding the genotypes, the heaviest seed weight of Tagat 19, Taggat 10 and Tagat 14 might be denoted to high capability of these genotypes to prolong their grain filling periods in spite of moisture stress. This result agreed with Samarah *et.al.*,(2009) who found that grain weight in cereals was reduced by drought stress, which could be attributed to shorter grain filling duration and lower accumulation of dry matter.

With respect to the grain yield per plant, the significantly lowest grain yield per plant in the two seasons was shown in the stressed plant at the eight-leaf stage. This may be attributed to the negative effect of water stress on seed mass during seed filling duration or to the number of seeds per head. These results were consistent with the study of Nouri, (2005), Bakhiet (1990) and Ahmed (1989) who showed that water stress reduced the mean grain yield per plant. With regard to the genotypes, Taggat 10 scored the highest estimates of grain yield per plant in the two seasons and Taggat 14 and 19 in season one only could denote good adaptability of the first genotype and the different responses of the second and third genotypes to the variation in rainfall between the two seasons. On the other hand, the lowest grain yields per plant that were shown by Taggat 9 in the two seasons could be attributed to the genetic factors of this genotype.

In this study water stress had significant effect on grain yield/m^2, stressed plants at three-leaf stage in season one and well-watered plants in season two scored the highest estimates, while stressed plants at eight-leaf stage recorded the lowest. High yield of stressed plants at three leaf-stage and well watered plants could reflect the less sensetivty of the stressed plants at that stage compared with its effect at eight-leaf stage on yield components. This result was similar to that obtained by Garcia, (2003) and Samarah, (2004) who reported that declines in total grain yield under the drought stress. Regarding the genotypes, efficient metabolite conversion and good water uptake and transirate of Taggat 10 may be the cause that made Taggat 10 to score in the two seasons. This result contradicted that obtained by Blum *et.al*., (1989) who showed that under water stress, the genotypes of longer growth duration produced lesser amount of grain per panicle and per unit area, as compared with genotypes of shorter growth duration.

The significant increase in grain yield (ton/ha) in stressed plants at the three-leaf stage in season one compared with the decreased yield in stressed plants at eight-leaf stage, might be due to positive effect of the first treatment that stimulate full development of root system and consequently efficient water uptake and nutrient. Supporting evidence was reported by Mutava, (2009), Younesi and Moradi, (2009) who stated that withholding irrigation at eight-leaf stage decreased grain yield. Potentiality of individual genotypes could explain the high grain yield (ton/ha) that were reported by Taggat 10 and Taggat 14 and the low yield of Gadambalea in the two seasons. The different ranking of these two genotypes in achieving the highest grain yield per hectare between the two yields could be attributed to the differences in rainfall amount and distribution during the two seasons.

The significant increase of harvest index in stressed plants compared with plants under full-irrigation, might be due either to early flowering signal to flower produced by stressed plants or high efficiency of stressed plants to translocate most of the photosynthesis to the developing grains. A different observation was reported by Blum *et.al*.,(1989), Samarah *et al.,* (2009) and Ekanayake *et.al*., (1989). Different environments for evaluation might be behind this result. With regard to the genotypes, the highest harvest index that was produced by Taggat 19 in both seasons, Taggat 14 and Gadambalea in season one and the lowest harvest index that was produced by Taggat 9 might denote to the prominent effect of genetic factors of these genotypes and the significant effect on their interactions with the environment. Similar results were obtained by Blum *et.al*.,(1989) who reported that harvest index varied extensively among the genotypes.

With respect to seed index, early flowering and or efficient translocation of metabolites might be a reason of well watered and stressed plants at the three-leaf stage to score the high estimates. With regard to the genotypes, the genetic factors could be accused behind Gadambalea and Taggat 9 to score the highest and the lowest estimates. In the present study, the significantly high drought tolerance index in stressed plants at the three leaf stage compared with the eight-leaf stage denotes the positive effect of moisture stress on the plants at this period of time. With respect to genotypes, the genotypes that showed the highest drought index (Taggat 10 and 14) their yield could increase or not reduced, while the genotypes that showed the lowest estimates (Gadambalea in season one and Taggat 19 in season two) their yields could be highly reduced. Therefore, they were not stable for growing in areas with low rain fall. This result was in line with Elmunsor *et.al* (2014) who reported that there was a wide range of genetic variability detected among the grain sorghum genotypes for drought tolerance.

The highest moisture content in lower layers of soil (30- 45 cm depth) compared with the upper layers in well water interval could explain the continued uptake of water by extensive root system in the upper layers. The lowest water content in upper layer (0 – 15 cm) of stressed plants denotes depletion of available moisture in this zone by extensive root system of stressed plants. Consumed moisture in the soil significantly affected by water regime. The highest estimate of this trait was recorded by the stress in the two periods compared with well-watering. The high value of consumed moisture achieved in stress at three-leaf stage. This might be due to the best development of root system that was capable to take much water. Similar results were obtained by Assefa, (2010) who stated that the water depletion zone for sorghum will vary with growing stage.

5. 2 Laboratory Experiment

Generally, seed quality determined at three filling stage was affected by water interval and genotypes for most of the studied traits in both seasons. With respect to standard germination percent, the significant effect was observed at physiological maturity stage only. Well-watered and stressed plants at the three-leaf stage scored the highest estimate compared with stressed plants at eight-leaf stage. This was because, water limitation might lower the level of seed mass due to its effect on amount of starch produced. The results agree with Drummond *et.al*.,(1983) who reported that standard germination, was lower for seeds harvested from plants under drought than seeds harvested from irrigated plants. Regarding genotypes, the differences on germination percent could be due to its response to water intervals during the growing season. With regard to seedling length, the significant effects among water regime and genotypes were observed in this study. Well-watered plants recorded longest estimate at soft and hard dough stage, while the lowest estimate were recorded by withholding irrigation at eight-leaf stage. This finding was similar to that obtained by Achakzai, (2009) who found that Seedling shoot length, seedling root fresh weight and seedling shoot fresh weight recorded higher value by increasing water potential levels. Regarding genotypes, the significant difference among the five studied sorghum genotypes in their means of seedling lengths could be reflected to their resistance to moisture stress.With respect to seedling relative moisture content, well-watered plants exhibited the highest estimates, while the lowest estimate was recorded by withholding irrigation at eight-leaf stage. This might be due to different requirements of plants to moisture at different growth stages, hence, plants at eight-leaf stage needed high moisture content compared with plants at three-leaf stage. Similar results were reported by FAO, (2002). Regarding genotypes, the differences between genotypes in relative seedling moisture content could be attributed to requirements of each genotype to moisture content and soil moisture status or depending on growth duration of genotype.

CONCULSIONS

The results indicated that water intervals had significant effect on most the measured parameters under field and laboratory conditions. In this respect, withholding irrigation at eight-leaf stage consistently resulted in reducing growth, yield, and yield components and seed quality.The highest grain yield among the three water intervals were reported by well-watered treatment and stresses at three-leaf stage, while the highest grain yield among the five tested genotypes were recorded by Taggat 10 and Taggat 14 (between 3.9 and 4.9 ton/ha, respectively).

The studied genotypes varied in their characters, from early to late maturing, dwarf to tall, loose to compacted heads, white and red seeded. From this study Gadambalia and Taggat 9 genotypes could be classified as drought escapers and early maturing genotypes, while Taggat 10 and 14 were classified as drought tolerant and moderately late maturing genotypes.

Most of the studied seed qualities were affected by water intervals and seed filling period, seed quality estimated by standard germination and seed vigor showed low estimates for seeds harvested from plants that grew under drought compared with those harvested from irrigated treatments. Moreover, the highest estimates in the five tested genotypes were obtained in the harvested seed at physiological maturity stage.

Based on drought tolerance index, there was a wide range of genetic variability among the five tested genotypes for this trait. Genotypes Taggat 10 and Taggat 14 recorded the highest estimates while Gadambalea and Taggat 19 recorded the lowest drought tolerance index.

RECOMMENDATIONS

The following recommendations were obtained from the present study:

- Genotypes Taggat 10 and Taggat 14 could be suitable for cultivation in this area.
- The five tested genotypes could be used for screening for drought tolerance among local land races of sorghum in North Kordofan State.
- Genotypes Taggat 9 and Gadambalea could be suitable for the farmers of the area and could be classified as drought escapers.
- Breeding programs may be exploited for further selection of oppropriater cultivars.
- Taggat 10 and 14 genotypes could be used for production of good quality seeds.
- Suitable genotypes for areas of short season rainfall would be Gadambelia and Taggat 9, while the suitable genotypes for areas of moderately longer season rainfall would be Taggat 10 and Taggat 14.
- A more exploring study with different water regimes at different growth stages among different sorghum genotypes is recommended.

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APPENDICES

Appendix 1. Mean squares of some trails on five sorghum genotypes (Sorghum bicolor L.Moench) cultivated under three water intervals conducted during (2014/ 015 – 2015 / 016) seasons in Elobeid.

		Season (2014/ 2015)			Season (2015/ 2016)		
ce of tion	D.F	Plant height (cm)	No. of leaves/ plant	50% flowering	Plant height (cm)	No. of Leaves/ plant	50% flower
cations	3	4.651	0.594	1.528	34.816	0.178	0.461
r intervals	2	2916.688**	0.267	19.467**	403.512*	1.050	0.417
a	6	2.243	0.711	1.844	39.437	0.428	1.928
type	4	2878.355**	8.917**	155.233*	4683.280**	4.600**	456.85
b	12	3.866	0.539	0.667	50.053	0.344	3.392
× G	8	715.677**	1.017**	29.883**	121.515*	0.300	0.333
c	24	2.534	0.571	2.567	49.981	0.594	0.983
,		1.21	6.53	2.43	5.09	6.76	1.47

Error a = water intervals. Error b = genotypes. Error c= interaction.
C.V denotes coefficient of variation.
*and **denotes levels of significance at 5% and 1% levels, respectively.

Continued Appendix1:

		Season (2014/ 2015)			Season (2015/ 2016)		
ce of tion	D.F	95% physiological maturity	No. of Heads/ m^2	Head length (cm)	95% physiological maturity	No. of Heads/ m^2	Head (cm)
ications	3	10.178	0.048	2.139	9.706	0.134	1.457
er intervals	2	168.067**	2.966**	87.715**	57.050*	0.459*	12.93
r a	6	3.444	0.109	2.904	1.806	0.059	1.614

otype	4	234.358**	1.947*	320.456**	204.308**	0.758**	316.8
r b	12	4.303	0.73	1.415	1.719	0.113	2.173
× G	8	56.608**	0.216*	4.013	12.696**	0.155*	2.003
r c	24	3.569	0.128	1.280	1.257	0.059	1.953
6		1.98	6.63	4.80	1.17	4.07	5.94

Continued Appendix1:

		Season (2014/ 2015)			Season(2015/ 2016)		
rce of ation	D.F	Head weight (g)	No. of grains per head	100 grain weight (g)	Head weight (g)	No. of grains per head	100 weig
lications	3	0.488	261.172	0.034	6.093	2988.513	0.00
er intervals	2	3251.077**	591652.067**	0.431**	153.404**	72716.152**	1.25
or a	6	2.716	360.556	0.016	2.325	1236.747	0.01
otype	4	6359.428**	498013.442**	4.833**	14764.583**	225766.192**	11.0
or b	12	3.108	174.908	0.017	7.921	2705.328	0.01
× G	8	827.865**	194954.504**	0.231**	32.028**	13695.661*	0.14
or c	24	3.233	239.521	0.021	6.135	4775.990	0.02
%		2.55	1.12	4.82	3.17	5.20	4.16

Continued Appendix1:

		Season (2014/ 2015)			Season (2015/ 2016)		
rce of ation	D.F	Grain yield plant (g)	Grain yield / m^2	Grain yield ton / ha	Grain yield / plant (g)	Grain yield / m^2	Grai ton /
lications	3	2.544	392.103	0.005	7.619	474.395	0.04
er intervals	2	576.678**	44559.369**	4.911**	512.179**	32123.513**	3.23
r a	6	7.190	504.911	0.026	4.418	247.149	0.02
otype	4	1917.107**	107334.768**	10.893**	3225.017**	204589.501**	20.4
r b	12	6.689	380.224	0.030	4.073	255.628	0.02
× G	8	177.288**	12543.010**	0.970**	72.316**	4642.893**	0.46
r c	24	4.831	398.236	0.053	5.453	359.440	0.03
%		5.55	6.36	7.39	4.96	5.04	5.04

Continued Appendix1:

		Season (2014/ 2015)			Season (2015/ 2016)		
rce of ation	D.F	Harvest index (%)	Seed index	Drought tolerance index	Harvest index (%)	Seed index	Drought tolerance
plications	3	0.589	0.001	0.009	1.524	0.001	0.005
ter intervals	2	10.210**	0.033**	0.708**	22.142*	0.033**	0.151**
or a	6	0.445	0.001	0.001	1.854	0.002	0.002
notype	4	30.643**	0.063**	0.333**	131.213**	0.041**	0.022
or b	12	0.920	0.001	0.003	1.561	0.001	0.011
× G	8	27.114**	0.040**	0.093**	37.523**	0.012**	0.026*

or c	24	1.139	0.0001	0.003	3.114	0.001	0.005
%		4.88	3.01	5.02	7.32	4.85	7.77

Appendix 2. Mean squares of moisture content and consumed moisture in the soil at two stress period
in three soil depths in (2014/2015) season in Elobeid.

		Moisture content (%) in stress **I**		Moisture content (%) in stress **II**		Consumed moisture Content	
ource of ariation	D. F	Pre- watering	Post- watering	Pre- watering	Post- watering	Moisture (%) in stress **I**	Moisture (% in stress **II**
eplications	3	0.033	0.023	0.010	0.055	0.030	0.039
ater intervals	1	138.672**	0.525	150.450**	0.025	119.573**	106.808**
rror a	3	0.041	0.084	0.054	0.125	0.034	0.052
oil depths	2	0.741*	1.865	0.155*	0.086	0.230	0.162
rror b	6	0.073	0.056	0.034	0.114	0.055	0.043
R × D	2	0.074	0.069	0.119	0.092	0.104	0.130
rror c	6	0.086	0.086	0.056	0.047	0.058	0.043
V%		6.55	4.33	5.15	3.08	9.29	8.49

Error a = water intervals. Error b = depths. Error c= interaction.
C.V denotes coefficient of variation.
*and **denotes levels of significance at 5% and 1% levels, respectively.

Appendix 3: Mean squares of germination test (%) at three stages of grain maturity of five sorghum genotypes (*Sorghum bicolor* L.Moench) cultivated under three water intervals during (2014/ 015 – 2015 / 016) seasons in Elobeid.

		Season (2014/ 2015)			Season 2015/ 2016)		
rce of ation	D. F	Germination at H_1 stage	Germination at H_2stage	Germination at H_3 stage	Germination at H_1 stage	Germination at H_2stage	Germin at H_3 sta
plications	3	2.150	0.200	0.022	366.111	86.111	2.222
ter intervals	2	1.017	0.067	0.350*	140.00	1.5981	35.00
or a	6	2.217	0.267	0,039	131.111	59.444	10.556
notype	4	3.017	0.475	0.392*	60.00	1.2286	14.167
or b	12	2.094	0.186	0.092	113.333	29.167	17.500
× G	8	1.954	0.150	0.204	40.00	22.083	20.417
or c	24	0.932	0.294	0.088	136.667	50.417	15.417
%		11.12	5.67	2.99	13.51	7.44	3.97

H_1,H_2 and H_3 denotes soft dough stage, hard dough stage and physiological maturity stage respectively.

Error a = water intervals. Error b = genotypes. Error c= interaction.

C.V denotes coefficient of variation.

*and **denotes levels of significance at 5% and 1% levels, respectively.

Appendix 4: Mean squares of seedling length (cm) at three stages of grain maturity of five sorghum genotypes (*Sorghum bicolor* L.Moench) cultivated under three water intervals during (2014/015 – 2015/ 016) seasons in Elobeid.

		Season (2014/ 2015)			Season (2015/ 2016)		
ource of ariation	D.F	Seedling length(cm) at H_1 stage	Seedling length(cm) at H_2 stage	Seedling length(cm) at H_3 stage	Seedling length(cm) at H_1 stage	Seedling length(m) at H_2 stage	Seedling length(cm at H_3 stag
eplications	3	2.035	1.343	3.751	0.358	0.338	1.663
/ater intervals	2	36.771**	38.081**	7.733	29.557*	17.347*	8.468
rror a	6	0.829	1.770	3.295	5.286	2.578	2.361
enotype	4	60.885**	205.241**	135.023**	59.481**	97.037**	27.793**
rror b	12	1.689	1.548	3.200	2.799	2.169	3.259
/R × G	8	9.637**	6.699**	10.068**	1.870	3.323	4.656

rror c	24	0.923	0.493	1.604	2.160	3.655	3.727
V%		6.83	4.05	5.93	8.90	10.67	9.42

H_1,H_2 and H_3 denotes soft dough stage, hard dough stage and physiological maturity stage respectively.

Error a = water intervals. Error b = genotypes. Error c= interaction.

C.V denotes coefficient of variation.

*and **denotes levels of significance at 5% and 1% levels, respectively.

Appendix 5: Mean squares of seedling relative moisture content at three stages of grain maturity of five sorghum genotypes (*Sorghum bicolor* L.Moench) cultivated under three water intervals in (2014/ 015 – 2015 / 016) seasons in Elobeid.

		Season (2014/ 2015)			Season (2015/ 2016)		
f	D.F	(S.R.M.C) at H_1 stage	S.R.M.C at H_2 stage	S.R.M.C at H_3 stage	S.R.M.C at H_1 stage	S.R.M.C at H_2 stage	S. H
ons	3	0.001	0.001	0.001	0.059	0.017	0.
ervals	2	0.126	0.118	0.295	0.020	0.011	0.
	6	0.003	0.004	0.004	0.040	0.007	0.
e	4	2.105	1.839	1.417	2.105**	4.839**	1.
	12	0.008	0.004	0.009	0.036	0.023	0.
	8	0.118	0.084	0.156	0.120*	0.269**	0.
	24	0.007	0.003	0.005	0.033	0.035	0.
		4.20	2.91	3.64	9.75	9.23	8.

(S.R.M.C) denotes seedling relative moisture content.

H1,H_2 and H_3 denotes soft dough stage, hard dough stage and physiological maturity stage respectively.

Error a = water intervals. Error b = genotypes. Error c= interaction.

C.V denotes coefficient of variation.

*and **denotes levels of significance at 5% and 1% levels, respectively.

Appendix 6. Mean monthly weather data for Elobied in (2014-2015/ 2015-2016) cropping seasons.

onth	Season 2014/ 2015				Season 2015/ 2016			
	Rainfall (mm)	**Temperature** C°		**Relative Humidity** %	**Rainfall** (mm)	**Temperature** C°		**Relative Humidity**
		Max	**Min**			**Max**	**Min**	
n.	—	30.9	15.1	25	—	29.2	13.4	24
b.	—	34.0	19.0	22	—	35.5	18.8	22
arch	2.4	36.9	22.5	25	—	37.5	22.6	26
oril	8.9	39.3	25.5	20	Light-rain	36.8	21.5	30
ay	Light-rain	39.3	25.8	35	46.0	39.9	25.6	55
ne	68.3	38.4	25.2	56	30.8	38.2	25.1	60
ly	119.0	33.0	22.7	80	111.9	36.3	24.2	75
ug.	63.7	31.5	22.1	75	89.8	33.2	22.6	76
pt.	41.6	34.2	21.8	70	109.1	34.9	23.6	70
ct.	35.2	36.2	22.6	55	29.5	36.6	24.4	50
ov.	—	33.9	19.4	33	—	33.4	19.1	29
ec.	—	32.1	16.9	30	—	27.2	13.5	26
otal	**339.10**				**418.10**			
verage	28.26	34.98	21.55	43.83	34.76	34.89	21.2	45.25

Source: Metrological Station (Faculty of Natural Resources & Environmental Studies, University of Kordofan, 2016).

Taggat 19

Taggat 10

Gadambalea

Taggat 14

Taggat 9

Plate 1: heads of the five tested genotypes.

Plate 2: General view of sorghum plants in the field experiment

Plate 3: Data collection at 50% flowering.