EFFECTS OF SAFFLOWER (CARTHAMUS TINCTORIUS L.) GENOTYPES ON GROWTH, DEVELOPMENT, YIELD AND YIELD COMPONENTS, AND OIL CONTENT AND YIELD

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A dissertation presented to the Department of Crop Science and Production in partial fulfillment of the requirements for the degree of Masters of Science (MSc) in Crop Science; Horticulture stream in Botswana University of Agriculture and Natural Resources

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STATEMENT OF ORIGINALITY

The work contained in this dissertation was completed by the author at the Botswana University of Agriculture and Natural Resources between May 2015 and June 2016. It is original except where references are made and it will not be submitted for the award of any other degree or diploma of any other university.

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To my institution and my Supervisors

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ABSTRACT

Safflower (*CarthamustinctoriusL.*) is a multipurpose oil seed crop that is drought, heat, cold and saline tolerant, but minor and neglected despite its many uses. However, recently there is renewed interest in safflower due to its drought tolerance and the suitability of its oil for nutritional or industrial purposes. Under semi-arid conditions of Botswana, farmers have difficulty in increasing crop productivity and diversity in crop rotations due to unfavourable conditions imposed by high and cold temperatures, inadequate rainfall and very high evapotranspiration rate and saline soils in some parts of the country. In such conditions, safflower appears a promising alternative crop. Therefore, the objective of this study was to evaluate the adaptability of safflower genotypes to the semi-arid conditions of Botswana. Nine safflower genotypes were evaluated during the rainy seasons of May to October 2015 and January to April 2016 in a completely randomized block design with three replications in the Botswana University of Agriculture and Natural Resources, Notwane Farm under sandy loam soils. The results of the study showed that safflower genotypes significantly ($P < 0.05$) differed in agro-morphological traits, growth habit, maturity date, seed yield and yield components, oil content and oil yield. The seed yield, oil yield and oil content significantly ($P < 0.05$) varied between 888-3113 kg/ha, 226-1313 kg/ha and 26-42% in winter, respectively, depending on genotype. In summer the seed yield ranged from 1421 to 2140 kg/ha. The safflower genotype PI537598-SINA-USA out performed all the other safflower genotypes including the local genotype Kiama Composite. This research showed that safflower has a big potential as an oilseed crop in semi-arid Botswana.

Keywords: Adaptation, *Carthamustinctorinus,* oil yield and content, seed yield and yield components.

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FAO	Food Agricultural Organization
USA	United States of America
TMR	Total Mixed Ration
DIF	Difference Between night and day temperatures
LAI	Leaf Area Index
HI	Harvest Index
LAD	Leaf Area Duration
HCl	Hydrochloric acid
ANOVA	Analysis Of Variance
LSD	Least Significant Difference
DAE	Days After Emergence

CHAPTER 1

1.0 INTRODUCTION

1.1 Botany of safflower

Safflower belongs to the family Compositae or Asteraceae, genus *Carthamus*. The cultivated *Carthamus tinctorius* L has a chromosome number of 2n = 24 (Knowles, 1989; López, 1989; Zehra, 2005). It is a thistle-like herbaceous annual usually with long sharp spines on the leaves (Weiss, 1983; Dajue and Mündell, 1996). It has a strong central branch system, a varying number of branches and a tap root system. Plant height varies from 30-210 cm depending on cultivar and environmental conditions during growth and some cultivars are spiny while others are not (Li and Mündell, 1996, Emongor, 2010). Each branch will usually have one to five flower heads containing 5-20 seeds per head (Bergman and Kandel, 2013). The tap root is characterized as being strong, growing to 3 m deep allowing it to thrive under dry climates (Weiss, 2000; Emongor, 2010). Flower colours vary between cultivars and usually yellow or orange colours are mostly seen while other cultivars have white and red flowers (Emongor, 2010; Bergman and Kandel, 2013).

1.2 Origin and distribution of safflower

Safflower is probably native of an area bounded by the eastern Mediterranean and the Persian Gulf. Production is approximately restricted to the region within the latitudes 20°S and 40°N. It is usually grown below 900 m in elevation but not suited for the low hot tropics. In Ethiopia, it is grown up to 1400 m and in Kenya up to 1800 m in elevation (Smith, 1996).Safflower is a warm temperature crop, originated from Southern Asia, and it is cultivated all over the world (Knowles, 1969). Safflower is one of humanity's oldest crops, with its use in China reported over 2,200 years ago. Safflower seeds are reported in Egyptian tombs over 4,000 years ago (Gyulai, 1996).The world seed production of safflower was estimated at 910,545 tons between 1995 and 2000 (FAO, 2011; Esendal, 2001). India, USA, Mexico and China are the major producers of safflower (Rowland, 1993). Presently, India is the largest producer of safflower in the world, followed by the USA, Mexico and China (Esendal, 2001; FAO, 2008). In the whole world, India is the largest producer of safflower and it accounts for 46% of the world production (421,000 tons) and itis used mainly for oil production (Rowland, 1993, Esendal, 2001). Mexico is the second largest producer of safflower, mainly producing it for oil production for domestic consumption and export (Bassil and Kaffka *et al.*, 2001; Esendal, 2001). According to FAO (2011), safflower is produced in large areas in India (718,167 ha), Mexico (391,145 ha), Ethiopia (71,939 ha), and USA (175,000 ha, mainly in California, Nebraska, Arizona and Montana). Other producing countries in decreasing order are Australia (35 000 ha), Argentina (30 000 ha), Uzbeistan (13,000 ha), and China (35,000-50,000 ha) just to name a few. In Africa, Ethiopia (71,939 ha) is the virtual producer with production estimated at 34 000 tons per annum (Rowland, 1993). Amount of land under safflower production varies widely from country to country. Seed yields increased considerably from the 1950s until the 1970s, but have remained relatively constant since that time (Bassil and Kaffka *et al.*, 2001).

1.3 Uses of safflower

Safflower is a multipurpose oilseed crop grown mainly as cut flowers, vegetables and for its high quality oil. The uses of safflower have been recorded in China approximately 2,200 years ago (Dajue and Mündel, 1996). Traditionally, safflower was grown for its seeds, for colouring and flavouring foods, as medicines and for making red and yellow dyes, especially before cheaper aniline dyes became available (Weiss, 1983). In Egypt, dye from safflower was used to colour cotton and silk as well as ceremonial ointment used in religious ceremonies and to anoint mummies prior to binding. Safflower seeds and packets and garlands of florets have been found with 4000-year-old mummies (Weiss, 1983).

1.3.1 Food uses

Food producers and industries use safflower oil. Safflower oil is often considered a healthier option than using sunflower oil (Dajue and Mündel, 1996). The oil consists of two types: that which is high in monounsaturated fatty acid (oleic acid) and that which is high in polyunsaturated fatty acid (linoleic acid). At the moment the predominant oil market is for the varieties that produce seeds higher in oleic acid and very low in saturated fatty acids (Camas and Esendal, 2006; Jalilian *et al.*, 2009).

For the last 50 years or so, the plant has been cultivated mainly for the vegetable oil that is extracted from its seeds. The tests in India have shown that seed production from ratoon crop is also possible. Safflower oil is heat-stable, therefore, it is used as cooking oil to fry such foods as french fries and other snack foods. The oil is also used in food coatings, infant food formulations, in salad dressing and for the production of margarine. The flowers are occasionally used in cooking as a cheaper substitute for saffron (Bergland *et al.*, 2007). Safflower oil is also used as condiment oil, along with sesame, red pepper and perillar oils in Korea. These condiments are prepared traditionally by extracting the roasted seeds with a mechanical press or expeller after roasting seeds at appropriate temperatures (Kim and Lee 1998). Seed oil content is between 35 and 50% (Camas *et al*,. 2007).

Safflower leaves are eaten as vegetables (Weiss, 1983). Safflower petals are used for colouring foods. Rice, soup, sauces, bread and pickles take on a yellow to bright-orange colour from the florets. Health concerns regarding synthetic food colourants may increase the demand of safflower-derived food colourant. China produces carthamin dye for use in food. Safflower yellow (carthamidine) and red (carthamin) pigments are safe and natural pigments which can be used for colouring food and cosmetics (Kulkarni *et al.*, 1997; Zhaomu and Lijie, 2010). Safflower petals are also used as a pleasant-tasting herbal tea. In Iran, a paste of safflower seeds is used to hasten cheese curd formation (Knowles, 1969). Roasted seeds, generally mixed with chickpeas, barley or wheat, are eaten as a snack food in Ethiopia and Sudan while the Egyptians ground the kernels and mix them with sesame (Knowles, 1969).

1.3.2 Fodder

Safflower can be grazed or made into hay or silage (Bar-Tal *et al.*, 2008). The forage is reported to be palatable and its feed value and yields are similar to or better than oats or lucerne (Smith, 1996; Wichman, 1996). The *in vivo* digestibility and the intake of green safflower fodder are reported to be similar to those of a vetch-oat mixture (Vonghai*et al.*, 1992). Grazed safflower has been reported to support satisfactory growth rates in Australian steers (French *et al.*, 1988) and improve fertility in Canadian ewes (Stanford *et al.*, 2001). Safflower also makes an acceptable livestock forage if cut at or just after bloom stage (Bergland*et al.*, 2007). Safflower hay, given adlibtum, has been successfully used as a sole feed for late-pregnancy dairy cows (Landau *et al.*, 2004). Safflower cropped at the budding stage can be ensiled (Weinberg *et al.*, 2002) and safflower silage was substituted for cereal silage in the diet of high-yielding dairy cows (Landau *et al.*, 2004) and dairy sheep (Landau *et al.*, 2005) without affecting their dairy performance. Safflower meal contains about 24 % protein and is considerably high in fiber. It can also be taken as a nutritional supplement. Therefore, it is used as a protein supplement in livestock and poultry feeds. Safflower silage has the potential for widespread adoption as a feed in many countries especially in the semi-arid arid countries since safflower is drought tolerant. Special characteristics such as protein degradability are taken into account to optimize its inclusion in total mixed ration (TMR) (Landau *et al.*, 2004).

1.3.3 Medicinal uses

Safflower petals are known to have many medicinal properties for curing several chronic diseases such as hypertension, type 2-diabetes, coronary artery disease, thrombus formation and infertility (Wang and Yili, 1985; Wang and Li, 1985). Safflower petalsare also widely used in Chinese herbal preparations (Knowles, 1969; Wang and Yili, 1985). The petals are an important source of traditional medicine (More *et al.*, 2005), it has a wide spectrum of pharmacological activity effective against a variety of disorders like gynecological diseases, osteoporosis, hyper-lipidaemia and inflammation (Zhou *et al.*, 2014). It has also been explored for excitotic neuronal death (Yang *et al.*, 2010), reducing the size of cerebral infarct and edema (Ye and Gao 2008).Yields of fresh petals may range from 0.1-0.7 t/ha, giving up to 150 kg/ha of dry drug (FAO, 2008). Safflower petals have been used to induce labour and are reported to be more effective than western medicine (Liu, 1985). When boiled in wine along with other flower decoctions is recommended to encounter retained afterbirth and retained stillbirth (Wang and Yili, 1985). Women in Afghanistan and India use a tea made from safflower foliage to prevent abortion and infertility (Weiss, 1983).

1.3.4 Other uses

1.3.4.1 Colourant

Safflower has originally been grown for centuries in India for the orange-red dye (carthamin) extracted from its brilliantly coloured flowers (Dajue and Mündel, 1996).A scarlet red dye, insoluble in water, can be obtained from the dried florets and used for dying clothes, cakes, biscuits, and rouge (Mündel et al., 1985; Esendal 2001; FAO, 2011).Safflower yellow or red pigments are safe for cosmetics colourings such as hair cream, shampoo, face cream, perfume or body lotions (Shouchun*et al.*, 1993).

1.3.4.2 Phytoremediation

Safflower is known to be adapted to a wide range of soils including saline soils (Er*et al.*, 1999), and this adaptability has led to a further evaluation of safflower plants for phytoremediation of contaminated soils. The study by Angelova *et al.* (2015) indicated that it can be successfully used in the phytoremediation of heavy metals.

1.3.4.3 Paint

High linoleic acid safflower oil has an important use in the paint industry. Before 1960's in the USA, the oil was used mainly as a base for superior quality paints. Safflower oil is used as a drying agent in paints and varnishes because of its non-yellowing characteristic (Bergland *et al.*, 2007).

1.4 Justification of the study

Agricultural production in Botswana both in livestock and crop sub-sectors is on a downward trend according to the 2013 annual agricultural survey results. Production of cereals is a common cropping system for both commercial and traditional farmers in Botswana. The country is semi-arid in which the rains are erratic and unreliable hence there are frequent recurring droughts (Emongor, 2009). Sorghum continues to be the major cereal crop and an important source of food for people in drought prone areas and fodder for livestock. Sorghum production is however, reported to have fallen steeply together with maize, millet, groundnuts, and sunflower (Statistics Botswana, 2013). Beans/pulses have so far been the only crops showing exceptional performance by increasing production (Statistics Botswana,2013). Therefore, alternative crops are sought that would be suitable for crop rotation in this semi- arid region.

Botswana's location in the sub-tropical high pressure belt of southern hemisphere in the interior of Southern Africa and away from oceanic influence makes it experience low rainfall and high temperatures in summer. There is high inter-annual variability of rainfall and drought is a recurring element of Botswana's climate (Emongor, 2009). Drought adversely affects the already fragile food and agricultural situation in the country and seriously impairs the rural economy and socio-cultural structures. Due to the erratic, unreliable, and poorly distributed rainfall, plus high temperatures, water becomes the most limiting factor to agricultural production in Botswana (Emongor, 2009). In Botswana, the annual precipitation and evapotranspiration ranges between 200-650 mm and 1800-3000 mm, respectively, depending on season (Emongor *et al.*, 2008). Therefore, growing a drought and winter tolerant crop such as safflower will improve food security, reduce reliance on food imports and improve income levels of farmers in Botswana, hence the importance of this project.

Global warming is likely to increase the incidence of drought in many African countries including Botswana. An extensive study based on simulation model for yield under changed global scenario in 18 countries, showed that crop production would decline by 9-10% in the tropics, while yields in higher latitudes may tend to increase (Zaidi, 2006). Decline in yield will result largely from temperature-induced acceleration of crop growth and development, hastened crop maturity and reduced soil moisture. Production decline are predicted to be more severe in sub-Saharan Africa (Zaidi, 2006). Evidence suggests that shortage of cultivatable land and water scarcity will be prevalent in the tropics during the next decade. Therefore, growing a multipurpose and drought tolerant crop such as safflower is hoped to mitigate the effects of climate change in Botswana.

Despite the many uses and drought tolerant properties of safflower, it has remained a neglected, underutilized and minor crop in Africa, except in Ethiopia because of lack of information on its crop management and product development from it (Singh and Nimbkar, 2006; Dajue and Mündel, 1996). The motivation for this project is two-fold: firstly to introduce safflower as an oil (cooking oil) and multipurpose crop that is drought, heat and winter tolerant (Dajue and Mündel, 1996) to the farming community of Botswana that is plaqued with drought, and conserve safflower germplasms; and secondly, to grow safflower which is drought tolerant in the semi-arid and arid country of Botswana, to help alleviate food insecurity, improve the income levels and social welfare of Batswana in a country pledged with recurrent droughts, and mitigate the effects of climate change.

1.5 The Objective of the study

The overall goal of this study is to evaluate the adaptability of safflower germplasm in Botswana using agro-morphological traits and biochemical traits in seed with the aim of mitigating the effects of drought and climate change, improve food security, increase income and social welfare of farmers in Botswana, and to reduce reliance on food importation.

The specific objectives of this study were to evaluate:

1) safflowergenotypes on growth, development,seed yield, yield components, oil content and yield; and
2) safflower genotypes suitable for summer, winter and/or both seasons.

1.6 Hypothesis

The following hypothesis was tested:

Ho: Safflower germplasm are not different ingrowth, developmental pattern, seed yield, seed yield components, and oil content and yieldgrown in winter and summer.

Ha: Safflower germplasm are differentin growth, development,seed yield and yield components, and oil contentand yield grownin summer and winter seasons.

CHAPTER 2

2.0 LITERATURE REVIEW

This review has been based on general overview of safflower status in the world and agronomic requirements. The main emphasis was in determining the impact of genotypes (cultivars) on general growth and yielding habit of safflower plant. It addresses how the different safflower genotypes affects yield, yield components and oil content.

2.1 Status of safflower in the world

Research on safflower and other oil crops has been conducted in different areas and the results generally show that phenological and physiological performance of each cultivar varies with different environmental and agronomic conditions, which contributes to variations on crop yields. Emongor and Oagile (2017), explained how these components influence the source-sink relationship of safflower plant. The source-sink interaction is critical for physiological processes within the plant which contributes to the potential economic production of a plant.

Safflower is described by many authors as one of the oldest crops with many uses though it remained underutilized and minor crop mainly due to lack of information on its crop management and product development (Singh *et al.*, 2001; Emongor, 2010).Reports in some regions state that the spiny characteristic of safflower is the primary factor leading to its negligence and underutilization (Singh *et al.*, 2001). Safflower has recently been receiving a lot of publicity because of the preference of consumers for healthy oil with less amounts of saturated fats, for which safflower is well known. Ithas hailed as one of the most important source of vegetable oils. The seeds contain 35-50% oil, 15-24% protein and 35-45% hull fraction (Rahamatalla *et al.*, 2001; Moatshe *et al.*, 2016).

Interest in cultivation of safflower has increased because of increased demand for vegetable oil for biodiesel and edible oil (Mailer *et al.*, 2008). There is a huge shortfall in oilseed production in countries having a sizable area with scanty rainfall, to which safflower is most suited, the preference of consumers for healthy oil with less amounts of saturated fats, for which safflower is well known, and the medicinal uses of flowers in China and extraction of edible dyes from flowers have become more widely known (Singh and Nimbkar, 2006; Emongor, 2010). Interest in cultivating safflower as source of edible oil has further been stimulated since the identification of safflower oil as a rich source of polyunsaturated essential fatty acid linoleic acid (70-87%) and monounsaturated fatty acid oleic acid (11-80%) (Murthy and Anjani, 2008). Linoleic acid has been shown to offer nutritional and therapeutic benefits such as prevention of coronary heart disease, arteriosclerosis, high blood pressure and hyper lipaemia (Wang and Li, 1985;). The seeds of safflower are also a rich source of minerals (Zn, Cu, Mn and Fe), vitamins (thiamine and β-carotene) and tocopherols α, β and γ (Velasco *et al.*, 2005).

Vegetable oil is one of the fundamental components in foods and has important functions regarding human health and its nutritional physiology. The demand for vegetable oils for food purposes has entailed a considerable expansion of oilseed crops all over the world (Corleto *et al.*, 1997; Camas *et al.*, 2007). Currently, consumers have demand for healthier oils, naturally low in saturated fat such as olive, safflower, canola, and sunflower oils. Safflower has received a lot of publicity recently, not because of its colourful petals, but because it is hailed as one of the most important sources of vegetable oils (Wang and Li, 1985; Cosge *et al.*, 2007; Murthy and Anjani, 2008). Safflower has also attracted significant interest as an alternative oil seed due to its high adaptability for dry climatic conditions with little precipitation. Safflower is a drought tolerant crop that is capable of obtaining moisture from levels not available to the majority of crops due to its deep tap root that can grow to 2-3 m (Weiss, 2000; Emongor, 2010, Kedikanestwe, 2012; Emongor *et al.*, 2013).Safflower is a drought, heat, cold and saline tolerant crop (Bassil and Kaffka, 2002; Khalili *et al.*, 2014; Emongor *et al.*, 2015). It is the most drought tolerant oilseed crop and can produce good seed yield in semi-arid regions, while its salt tolerance is a valuable asset as the area affected by some degree of salinity increases world-wide (Weiss, 2000).

2.2 Ecological requirements of safflower

Safflower production is restricted to the region between the latitudes 45 °S (Argentina and Australia) and 60 °N (Russia) (Esendal, 2001). It is usually grown in altitudes below 900 m above sea level, but in the tropics it can be grown in altitudes of 1400-2000 m above sea level (Ethiopia, Kenya) (Dajue and Mündel, 1996; Emongor, 2010). Climate plays a significant influence on the growth and development of safflower. Safflower can grow in cool and temperate climate zones of the world. Germination takes 3-8 days depending on temperature and germination occurs at temperature as low as 2-5°C (Mündel, 1969; Emongor, 2010).Warm weather results in higher oil contents in the safflower seed. Emerging plants needs cool temperatures of 15-20°C for root growth and rosette development, and high temperatures of 20-30°C during stem development, flowering and seed formation. The seedling at the rosette stage is frost resistant, it can tolerate temperatures of -7 to -15 °C, depending on the genotype or variety (Li, 1989; Mündel *et al.*, 1992; Carapetian, 2001; El-Bassam, 2010; Emongor, 2010). The mature plant is destroyed by slight frost of -2°C. Temperature significantly affects plant height of safflower plants. In Botswana, safflower plants grown in winter were significantly taller than plants grown in summer (Emongor *et al.*, 2013; 2015). When the difference between night and day temperatures (DIF) during the elongation phase is between 16.4-20.7°C (when minimum temperature in the field is between 5-12°C), DIF significantly enhances safflower plant height (Emongor *et al.*, 2013; 2015). Increasing the day temperature relative to the night temperature increases internode elongation for many plant species (Berghage and Heins, 1991; Myster and Moe, 1995; Dole and Wilkins, 2005). The positive DIF in winter might have promoted biosynthesis of gibberellins which are known to promote cell and internode elongation hence explaining the increase in safflower plant height (Taiz and Zeiger, 2002; Emongor, 2007; 2010).

For optimal growth safflower requires medium-deep and well-drained, sandy loams soil. The soil pH should be in the range of 5-8 (Oyen and Umali, 2007; Emongor, 2010). Safflower is tolerant to salinity and drought (Bassil and Kaffka, 2002). Safflower is tolerant to salinity caused by sodium, but less so of calcium and magnesium salts (Oyen and Umali, 2007). However, high salinity alters safflower growth and seed yield (Oyen and Umali, 2007). Optimum precipitation of between 600 to 1000 mm per annum (Marchione and Corleto, 1993; Corleto *et al.*, 1997) favours safflower growth.Supplemental irrigation at the start of flowering under semi-arid and arid conditions increases seed yield. Its deep rooting system (2-3 m) makes it drought tolerant and it can survive on an annual precipitation of 250 mm provided the rainfall is equally distributed through the cropping cycle. Seed yields do not exceed 2 tons/ha, but with supplemental irrigation the seed yield can reach 5 tons/ha (Emongor, 2010; Emongor *et al.*, 2013; Moatshe *et al.*, 2016). The humidity should be medium to low. Bees and other insects are important for optimum fertilization and yield (FAO, 2008). Irrigation may be necessary depending on the precipitation levels. To ensure good yields it's important that the crop receives sufficient water at least during the flowering stage (Zaman and Das, 1990). It does not survive standing in water in warm weather, even for a few hours. Excess rainfall, especially after flowering begins, causes leaf and capitula diseases, which reduce the yield or even causes the loss of the crop (Kolte, 1985; Dajue and Mündel, 1996). Prolonged rainfall during flowering interferes with pollination and seed set, so do high temperatures greater than 32°C (Mündel *et al.*, 1992).

Safflower is a day neutral plant. However, the origin of varieties is very important because summer crop varieties from temperate regions, planted during short days as a winter crop in subtropical and tropical regions, have a very long rosette phase, with delayed maturity (Dajue and Mündel, 1996; Emongor, 2010).

2.3. Yield and yield Components of safflower

The common components used as main parameters influencing safflower yield includes seed weight, plant height, first branch height, number of branches, capitula diameter, number of seed per capitulum and number of capitula per plant (Gonzalez *et al.*, 1994; Omidi and Tabrizi, 2000; Camas and Esendal, 2006; Emongor *et al.*, 2013; 2015; Moatshe *et al.*, 2016).Chaundry (1990) conducted a study on 50 safflower genotypes and concluded that for selection of high yielding varieties, number of seed per capitulum, number of capitula per plant and thousand (1000)-seed weight could be used as a primary selection criterion. In another study conducted by Ahmadzadeh *et al.* (2012) revealed a significant effect between number of seeds per head, 100-seed weight, days to 50% flowering on grain yield, while a negative direct effect was observed for days to maturity on grain yield under drought stress conditions. Ahmadzadeh *et al.* (2012) then concluded that improvement of grain yield will be efficient through 100-seed weight under both irrigated and rain fed conditions. It was further reported that direct selection could be made for plant height, plant weight and hectolitre weight for improvement of grain yield under irrigated conditions while in drought conditions number of seeds per head and 50 % days to flowering was more significant (Ahmadzadeh *et al.*, 2012).

Yield can be achieved by increased biomass production or harvest index (HI) or both (Ying *et al.*, 1998). This is because biomass production is associated with leaf area expansion and duration (Evans, 1993). The extent to which the plant canopy intercept available radiation depends on the leaf area index (LAI) displayed both in space and time (Monteith, 1977). Therefore, the dynamics of leaf area index (LAI) and leaf area duration (LAD) are some other parameters reported as important determinants of growth and yield (Evans, 1993). It is further reported that the rate of seed filling, rapid leaf formation, leaf expansion and delayed plant senescence are the characteristics of a high yielding safflower. This is closely related to high dry matter accumulation, harvest index (HI), seed weight per capitulum, thousand seed weight and capitulum diameter (Mokhtassi-Bidgoli *et al.*, 2007). Schoefs (2002) reported that the leaf chlorophyll content also has a great impact on the rate of photosynthesis and thereby influences seed yield, this was confirmed by Morrison *et al.* (1999) who found a positive correlation between seed yield and chlorophyll a + b content in soybean.

2.4. Evaluation of safflower germplasm on growth performance, yield rates and oil content

Safflower varieties possess enormous diversity for different traits of economic importance (Singh and Nimbkar, 2006). Hybrids with different morphological and physiological characters are available under different macro-climatic conditions. Thus, different safflower accessions respond differently depending on the environmental conditions, genotypic characters and management practices (Esendal 2001; Singh and Nimbkar, 2006;Rahamatalla *et al.* 2001). Studies in Turkey have demonstrated that safflower seed yield varied with regions (locality where the crop is grown) due to climatic differences and cultivars (genotypes) grown

(Beyyavas *et al.*, 2011). In Turkey, it was reported that safflower seed yield ranged between 570-2515 kg/ha (Esendal and Tosun, 1972; Gur and Ozel, 1997; Ozel *et al.*, 2004; Uysal *et al.*, 2006; Camas *et al.*, 2007; Beyyavas *et al.*, 2011). It was also reported that the growth of safflower cultivars differed with arid and lowland conditions, while seed yield increased with irrigation and rainfall during branching and seed formation periods, and seed yield and crop traits varied with cultivar, ecological conditions and cultivation techniques (Sinan, 1984; Gencer *et al.*, 1987; Hulihalli *et al.*, 1997; Camas *et al.*, 2007; Beyyavas *et al.*, 2011).

In the past several decades, safflower varieties with higher oil content (34–50%) and mutant types with high levels of oleic and linoleic fatty acids have been developed (Moatshe *et al.*, 2016). Safflower cultivars with an oil content of 13-46%, and approximately 90% of the oil composed of unsaturated fatty acids oleic and linoleic are reported (Dajue, 1993; Johnson *et al.*, 1999; Ada, 2013). While Kizil *et al.* (2008) in Turkey reported of safflower cultivars with oil content in range of 26.1-35.1% with major constituents of fatty acids of linoleic, oleic and palmitic in the range of 41.0-60.1%, 24.5-44.7% and 11.3-16.0%, respectively.

In the Eastern Mediterranean, safflower is adapted to relatively low rainfall areas during winter and spring with dry atmosphere during flowering and maturation (Knowles, 1989). Kose (2012) conducted a study in Turkey and Iran on fifteen (15) safflower lines and revealed that yield, yield components and oil content were significantly different in all 15 safflower lines and varieties. The overall highest plant height value was in line 357/s6/697. Under dry conditions line PI-592391 and variety 324-s6-697 had 74.5 cm height while line 366/s6/697 had 74.0 cm. Under irrigated condition, 366/s6/697 resulted with height of 100.0 cm. It was therefore concluded that safflower varieties had higher plant height values under irrigated compared to rain-fed conditions (Kose, 2012). There were a large number of secondary branches under irrigated condition compared to dry conditions, though there were variations within treatments. The dincer variety had the least number of secondary branches under both conditions (Kose, 2012). This was supported by Esendal (1990), who reported that rainfall, plant density and genetic factors affects the number of branches of safflower cultivars.In another study conducted in the Mediterranean region revealed that there were significant varietal differences among seed growth rate and economic growth rate (Koutroubas *et al.*, 2008). There was a positive linear correlation between seed growth rate and/or economic growth rate to seed yield, with yield ranging between 0.83 and 0.99 (Koutroubas *et al.*, 2008). The results confirmed that safflower seed yield varied among genotypes by a range between 1333 to 2870 kg/ha(Koutroubas *et al.*, 2005). Esendal *et al.* (2008) also reported similar findings when they reported that seed yield of safflower accessions varied significantly among cultivar and location. According to Koutroubas *et al.* (2004) and Poorhadian and Khajehpour (2007), seed yield of a cultivar in a given location varied significantly due to different environmental conditions such as light, water, precipitation, temperature, humidity and nutrient competition. Koutroubas *et al.* (2004) further reported variations in harvest index (HI) among safflower genotypes. The seed yield and harvest index of winter safflower genotypes ranged from 2310 to 4600 kg/ha and 29% to 35%, respectively. Mokhtassi-Bidgoli*et al.*, (2007) also reported similar results. They reported that genotypes varied in HI with values ranging from 21.83 % to 29.62 % for varieties LRK_262 and IL.111, respectively.

In Kordestan-Iran, the cultivars CW-74 and PI 537 598 recorded the highest seed yields of 513.8 and 504.3 kg/ha, respectively (Alizadeh, 2001). Poordad (2003) also conducted another study in three different locations of Iran under rainfed conditions and reported that among 20 safflower germplasm evaluated, PI 537 598, PI 250 537 and SYRIAN recorded the highestyields. Among the three varieties PI 537 598 was ranked the highest in all locations with the mean grain yield of 1110.9 kg/ha, yielding oil content of 30.1%. Therefore, it was recommended that PI 537 598 was the most adaptable and stable variety in rainfed conditions of warm and semi-cold areas of Iran. In Kermanshah, the cultivar PI 250 537 recorded 471 kg/ha while LESAF resulted in 756 kg/ha (Poordad, 2003). Another study was conducted in Iran on 17 safflower varieties under rainfed conditions, the results showed that four varieties PI 537 598, 537598, S-541, and SYRIAN were ranked as very high yielding with ranges of 800.0-728.5 kg/ha while low yielding varieties (PI-250537, LESAF and GILA) ranged between 449.6-426.7 kg/ha(Vafaei *et al.*, 2012). In conclusion,PI 537 598 had highest grain and oil yield of 800 and 236.8 kg/ha in average, while ISFAN had the lowest yields (Vafaei *et al.*, 2012).

The oil content of safflower germplasm from different production areas of the world is reported as 23.86- 40.33% (Zhang and Chen, 2005), 26.72-35.78% (Koutroubas and Papadoska, 2005), 26.3-28.5% (Gawand *et al.*, 2005) and 31.3-36.3% (Arslan and Küçük, 2005). Rahamatalla *et al.*, (2001) reported that oil content of a crop varies depending on factors such as cultivar, genetic traits, soil characteristics and climate. Genotypically, the spiny safflower cultivars contain more oil yields than spineless ones (Weiss, 2000). This was confirmed on a study conducted in Maharashtra-India with spiny hybrid cultivars named NIRA, NARI-H-15 and NARI 38 in comparison to the two non-spiny hybrids named NARI-6 and NARI-NH-1 (Nimbkar, 2008). The results showed that the spiny hybrid cultivars yielded high rate of safflower seeds ranging from 2012 to 2201 kg/ha while the non-spiny cultivars yields ranged from 1024 and 1895 kgha/ha. The results on the oil yields also showed the same findings where spiny cultivars recorded high oil yields ranging between 534-669 kg/ha compared to non-spiny ones with the least range of 304-593 kg/ha. In the same study, NARI-H-15 was the most outstanding cultivar in both seed and oil yields while NARI-6 had the lowest oil yield values (Nimbkar, 2008).According to a study conducted by Kose (2012), variations in seed oil content resulted among cultivars between dry and irrigated environments. Thus seed oil content was between 30.6 and 38.7% under dry conditions and 29.1 to 35.7% under irrigated conditions. This means that there was a 2.0% decrease of safflower oil under irrigation compared to dry conditions (Kose, 2012).

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Experimental site

Two field experiments were conducted at the Botswana University of Agriculture and Natural Resources Content Farm, situated at Notwane, Sebele, (24^0 35' S: 25^0 58' E) at an altitude of 998 m above sea level. The first and second trials were done between May-October 2015 and January-April 2016, respectively. The experimental site has an average maximum and minimum temperature varying between 33.1–34.7^{0}C and 19.2–19.5^{0}C, respectively in summer. However, during the coldest months (April and September) the average maximum and minimumtemperatures range between 26-34^{0}C and 7-16^{0}C, respectively (Ramolemana, 1999). The soils are deep sandy loam. The rainfall amount varies between 250-600 mm per annum.

3.2 Experimental design

The experimental design was a randomized complete block design with three replications. Blocking has been done in order to spread the effects of the 1% slope in the experimental site. The treatments were nine genotypes of safflower. The safflower genotypes evaluated were: PI 314650-MILUTIN-114-KAZAKISTAN, PI 306830-BJ-1632-INDIA, PI 30441-BJ-2621-IRAN, PI 537634-1040-USA, PI 537598-SINA-USA, PI 537632-1038-USA, PI 537668-BJ-1085-USA, PI 407616-BJ-2131-TURKEY and Kiama Composite (control-local cultivar). Safflower was planted in single rows in experimental units measuring 5 m x 5 m. Seeds were sown at a depth of 6 mm.

3.3 Crop husbandry

The planting density adopted was 100,000 plants/ha(0.40 m×0.25 m). The soil was cultivated with a disc plough, and then harrowed with a disc harrow to prepare a fine tilth for seed sowing. Weeding has been done manually using a hand hoe between rows throughout the crop growth stages. Minimal irrigation was done in winter at weekly intervals to a depth of 6mm because the country does not experience winter rain (May to August). Other management practices such as fertilizer application, irrigation and pest control were carried out when necessary. Fertilizer application was at 80 kg N/ha (calcium ammonium nitrate-28% N) and 50 kg P/ha (single super phosphate-10.5% P).

3.4 Dependent variables determined

The dependent variables determined wereplant height, first branching height, leaf area, leaf chlorophyll content, number of branches/plant, number of flower heads/plant, days to maturity, days to elongation phase, flower head size, number of seeds/flower head, 1000-seed weight, seed yield /ha, flower head size, and seed oil contentand yield.

3.4.1 Plant height and number of branches

Ten plants per replication were sampled randomly from each replication and the plant heights measured from the ground to the top using a meter ruler at flowering stage. The primary branches were alsocounted from the same plants sampled for height determination.

3.4.2 Leaf area

Ten plants per replication wererandomly sampled where ten leaves per plant were collected for leaf area analysis using the leaf area meter (CI 202).

3.4.3 Determination of chlorophyll content

Chlorophyll a and b and total carotenoids contents were estimated by extraction of the leaf materials in 0.1N HCl in Methanol at 25^0C in the dark for 24 hours. The optical density was measured by the absorption at 645,653 and 663 nm then calculated with the following equation of the pigment amount in mg per ml extract solution

Chlorophyll a (mg/cm^2) = $12.7\ A_{663} - 2.069\ A_{645}$

Chlorophyll b (mg/cm^2) = $22.9\ A_{645} - 4.68A_{663}$

Total chlorophyll (mg/cm^2) = $24.88A_{653}$

3.4.4 Determination of flower heads per plant and flower head size

Ten plants per replication were randomly selected and the number of flower heads per plant was counted. The flower head diameter was also measured with a venier caliper.

3.4.5 Number of seeds per head

Upon maturity seeds were allowed to dry before determining this variable and ten plants were randomly sampled to count the number of seeds from each of their flower heads.

3.4.6 Seed yield

All the plants were harvested in an area of 4 m^2 in the center of the experimental plots from each replication, seeds were then threshed and weighed to determine seed yield (kg/ha).

3.4.7 Weight of 1000 seed

One thousand seeds per genotype per replication were counted. from the seeds that have been threshed off. Then seeds were weighed with a digital balance to determine the 1000-seed weight.

3.4.8 Determination of seed oil content

Safflower oil was extracted by pressing safflower seeds using an electric oil expeller (Oil Love, National ENG CO.LTD). The oil expeller was preheated to a temperature of 180°C for 20 minutes. Safflower seeds (1 kg) were used for oil extraction. The oil content was determined by weighing the oil expressed. The oil content was expressed as a percentage of the seed that was used for expressing the oil.

3.4.9 Oil yield determination

Oil yield (kg/ha) was calculated as a function of grain oil content and grain yield.

3.5 Data analysis

The data collected was subjected to analysis of variance (ANOVA) using Statistical Analysis System (SAS) programme. Where a significant F- test was observed, treatment means were separated using the Least Significant Difference (LSD) at $P<0.05$. Appropriate regression models were used to analyze the different correlations (Snedecor and Cockran, 1989).

CHAPTER 4

4.0 RESULTS

4.1 Vegetative growth

4.1.1 Plant height

Safflower genotypes and growing season significantly ($P< 0.05$) influenced plant heights (Figure 1, Table 1). Safflower plantsgrown in summer were significantly ($P< 0.001$) shorter than plants grown in winter (Table 1). Plants grown in winter were significantly ($P < 0.0001$) taller by 64.3% than plants grown in summer (Table 1).In summer grown safflower, the genotype Kiama Composite had the tallest plants, but was not significantly ($P > 0.05$) different from the plant heights of the genotypes PI 30441-BJ-2621-Iran and PI 407616-BJ-2131-Turkey(Figure 1). The genotype Kiama Composite had significantly ($P < 0.01$) taller plants than the genotypes PI 537632-1038-USA, PI 537598-SINA-USA, PI 537634-1040-USA, PI 537668-BJ-1085-USA, PI 314650-Milutin-114-Kazakistan, and PI 306830-BJ-1632-India in winter grown safflower (Figure 1). Also in winter grown plants, the genotypes PI 537632-1038-USA, PI 537598-SINA-USA, PI 537634-1040-USA, PI 537668-BJ-1085-USA, PI 314650-Milutin-114-Kazakistan, and PI 306830-BJ-1632-India did not statistically differ in their plant heights (Figure 1). While in summer grown safflower, the genotype PI 30441-BJ-2621-Iran had significantly ($P < 0.0001$) taller plants than all the other genotypes with exception of the genotype PI 407616-BJ-2131-Turkey (Figure 1). The genotype PI 306830-BJ-1632-India had the shortest plants in summer, but was not significantly ($P > 0.05$) different in plant height with the genotypes PI 537632-1038-USA, PI 537598-SINA-USA, PI 537634-1040-USA, PI 537668-BJ-1085-USA, and PI 314650-Milutin-114-Kazakistan (Figure 1). In summer grown safflower, the genotypes Kiama Composite, PI 407616-BJ-2131-Turkey and PI

314650-Milutin-114-Kazakistan did not significantly ($P > 0.05$) differ in their plant heights (Figure 1).

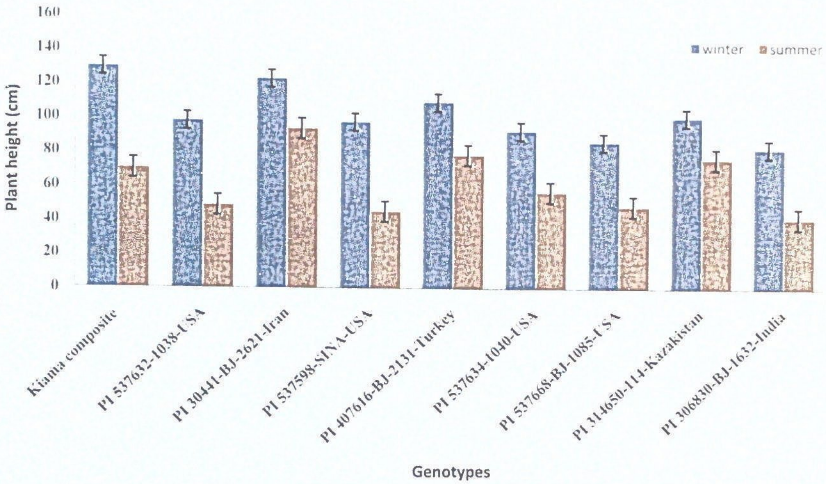

Figure 1. Effect of genotype and season on plant height; bars are standard error

Table 1. Effect of growing season on vegetative growth of safflower

Season	Plant height (cm)	Leaf area (cm^2)	Primary branch number/plant	Cholorophyll a content (mg/cm^2)	Chlorophyll b content (mg/cm^2)	Total chlorophyll content (mg/cm^2)
Winter	103.29a	64.34a	16.1a	1.43a	1.80b	2.62b
Summer	62.87a	25.32b	9.5b	1.28b	1.94a	2.93a
Significance	****	****	****	****	****	****
LSD	7.30	7.26	1.92	0.02	0.05	0.04

**** Significant at $P = 0.0001$. Means separated using the Least Significant Difference (LSD) at $P = 0.05$; means within column followed by the same letter are not significantly different.

4.1.2Primary branches

Safflower genotypes and growing season significantly ($P < 0.05$) influenced primary branch number (Figure 2, Table 1). Safflower plants grown in winter significantly ($P < 0.0001$) produced 69.5% more primary branch numbers/plant than summer (Table 1). The genotype PI 537634-1040-USA produced significantly ($P < 0.01$) higher primary branch number/plant than the genotypes Kiama Composite, PI 30441-BJ-2121-Iran and PI 407616-BJ-2131-Turkey in winter, but was not significantly ($P > 0.05$) different from the primary branch number/plant of the genotypes PI 537632-1038-USA, PI 537598-SINA-USA, PI 537668-1085-USA, PI 314650-Milutin-114-Kazakistan, and PI 306830-BJ-1632-India (Figure 2). In summer grown safflower, there was no significant ($P > 0.05$) difference among genotypes with respect to primary branch number/plant (Figure 2).

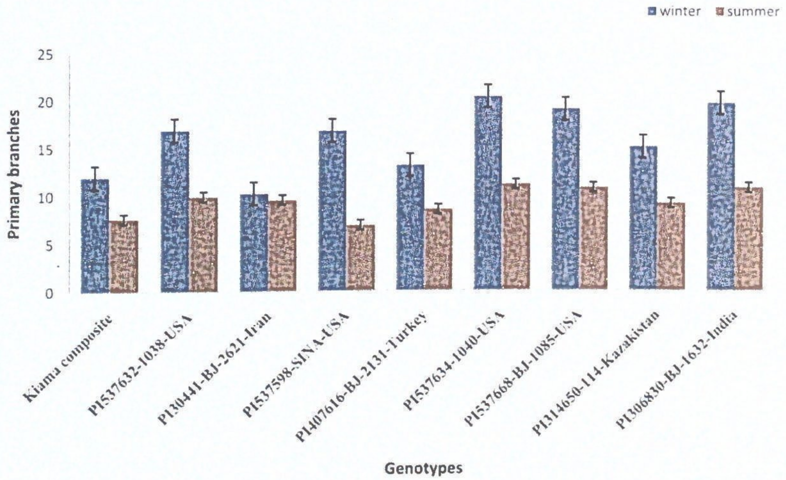

Figure 2: Effects of genotype and season on primary branches; bars are standard errors.

4.1.3 Leaf area

Safflower leaf area was significantly ($P < 0.01$) influenced by genotype and growing season (Figure 3, Table 1). The leaf area of safflower grown in winter was significantly ($P < 0.0001$) higher by 154.1% than that grown in summer (Table 1).The genotype PI 314650-Milutin-114-Kazakistan had significantly ($P < 0.01$) higher leaf area in winter grown safflower than all other genotypes, with exception of the genotype PI 537598-SINA-USA (Figure 3). The genotype PI 306830-BJ-1632-India had the lowest leaf area of 38.03 cm^2 which was significantly ($P < 0.01$) lower than that of the other genotypes, with exception of the genotype Kiama Composite in winter (Figure 3). In summer, the genotype PI 30441-BJ-2621-Iran had the highest leaf area of 42.8 cm^2 which was significantly ($P < 0.0001$) higher than that of the genotypes PI 537632-1038-USA, PI 537598-SINA-USA, PI 537634-1040-USA, PI 537668-BJ-1085-USA and PI 306830-BJ-1632-India (Figure 3). However, the leaf area of the genotype PI 30441-BJ-2621-Iranwas not significantly ($P > 0.05$) different from that of the genotypes Kiama Composite, PI 407616-BJ-2131-Turkey and PI 314650-Milutin-114-Kazakistan in summer (Figure 3). In summer, the genotype PI 537668-BJ-1085-USA had the lowest leaf area of 13.07 cm^2, but was not significantly ($P > 0.05$) different from the leaf area of the genotypes PI 537632-1038-USA, PI 537598-SINA-USA, PI 537634-1040-USA and PI 306830-BJ-1632-India (Figure 3).

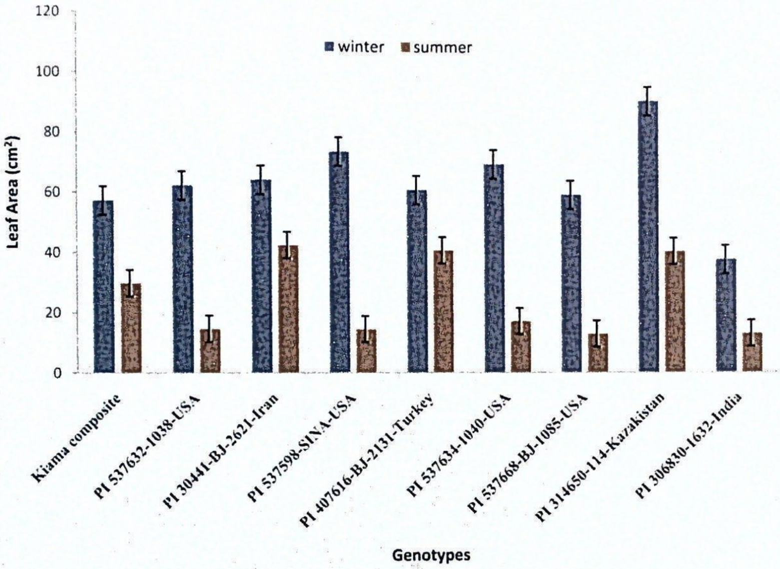

Figure 3. Effect of genotype and season on safflower leaf area; bars are standard error

4.1.4 Chlorophyll content

Safflower genotypes did not significantly ($P > 0.05$) differ in their leaf chlorophyll contents (chlorophyll a, chlorophyll b and total chlorophyll) (Table 2). However, the growing season significantly ($P < 0.0001$) influenced leaf chlorophyll a, b and total chlorophyll contents (Table 1). Leaf chlorophyll a content was significantly ($P < 0.0001$) higher in winter grown safflower than summer grown plants (Table 1), while chlorophyll b and total chlorophyll was significantly ($P < 0.0001$) higher in summer grown safflower than winter (Table 1).

Table 2. Effect of genotype and season on leaf chlorophyll content

Genotype	Chlorophyll a (mg/cm^2)		Chlorophyll b (mg/cm^2)		Total leaf chlorophyll (mg/cm^2)	
	Winter	Summer	Winter	Summer	Winter	Summer
Kiama Composite	1.41a	1.30a	1.82a	2.08a	2.63a	3.01a
PI 537632-1038-USA	1.43a	1.29a	1.77a	2.00a	2.62a	2.97a
PI 30441-BJ-2621-Iran	1.43a	1.29a	1.80a	2.02a	2.60a	2.98a
PI 537598-SINA-USA	1.42a	1.27a	1.81a	1.80a	2.62a	2.87a
PI 407616-BJ-2131-Turkey	1.45a	1.26a	1.80a	1.94a	2.63a	2.82a
PI 537634-1040-USA	1.41a	1.28a	1.79a	1.95a	2.60a	2.96a
PI 537668-BJ-1085-USA	1.42a	1.26a	1.79a	1.89a	2.61a	2.91a
PI 314650-Milutin-114-Kazakistan	1.42a	1.27a	1.81a	1.89a	2.63a	2.95a
PI 306830-BJ-1632-India	1.45a	1.28a	1.81a	1.89a	2.64a	2.90a
Significance	NS	NS	NS	NS	NS	NS
LSD	0.08	0.03	0.07	0.21	0.08	0.19

NS none-significant at $P = 0.05$. Means separated using the Least Significant Difference (LSD) at $P = 0.05$; means within column followed by the same letter are not significantly different.

4.2 Yield and yield components

4.2.1 Capitula number per plant

Safflower genotypes significantly ($P < 0.05$) influenced capitula number/plant (Table 3). However, the growing season had no significant ($P > 0.05$) influence on capitula number/plant (Table 4). The genotype PI 30441-BJ-2621-Iran had significantly ($P < 0.05$) the lowest capitula number/plant of 17than all the genotypes under study, with exception of the genotype PI 537598-SINA-USA in winter grown safflower (Table 3). On the other hand, the genotype PI 306830-BJ-1632-India had the highest capitula number/plant of 35.1, but was not significantly ($P > 0.05$) different from that of the other genotypes, with exception of the genotypes PI 30441-BJ-2621-Iran and PI 537598-SINA-USA in winter grown safflower (Table 3). In summer, the genotype PI 537668-BJ-1085-USA had a capitula number/plant of 40.4 which was significantly ($P < 0.05$) higher than that of the genotypes Kiama composite, PI 537598-SINA-USA, and PI 314650-Milutin-114-Kazakistan, but was not significantly ($P < 0.05$) different from that of the other genotypes under investigation (Table 3).

4.2.2 Capitula diameter

Safflower genotypes and growing season significantly ($P<0.01$) influenced capitula diameter (Table 3 and 4). Safflower grown in winter had larger capitula diameter (21.69 mm) than summer grown plants (8.44 mm) (Table 4). In winter, the genotype PI 537598-SINA-USA had a capitula diameter of 25 mm which was not statistically different from that of the genotypes PI 407616-BJ-2131-Turkey and PI 314650-Milutin-114-Kazakistan, but was significantly ($P < 0.01$) higher than that of the other genotypes (Table 3). In summer, the genotype PI 314650-Milutin-114-Kazakistanhad capitula diameter of 11.1 mm, but was not significantly ($P > 0.05$) different from that of the genotypes Kiama Composite, PI 30441-BJ-2621-Iran and PI 407616-

BJ-2131-Turkey, but was significantly ($P < 0.001$) higher than the capitula diameter of the genotypes PI 537632-1038-USA, PI 537598-SINA-USA, PI 537634-1040-USA, PI 537668-BJ-1085-USA and PI 306830-BJ-1632-India (Table 3). In summer, the genotype PI 306830-BJ-1632-India had a capitula diameter of 5.35 mm and was significantly ($P < 0.001$) lower than that of all the other genotypes with exception of the genotype PI 537668-BJ-1085-USA (Table 3).

Table 3. Effect of genotype and season on safflower yield components

Genotype	Capitula number per plant		Capitulu diameter (mm)		Seed number per capitulum		1000-seed weight (g)	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
Kiama Composite	31.3a	23.3bcd	20.28cd	9.60abc	28.0b	47.3ab	35.5bc	43.4bc
PI 537632-1038-USA	28.2a	27.3abcd	19.00d	8.10bc	28.7b	36.7bc	35.8bc	42.1bcd
PI 30441-BJ-2621-Iran	17.0b	26.7abcd	21.27bcd	9.83ab	29.3b	46.0ab	39.0ab	51.8a
PI 537598-SINA-USA	26.6b	19.7d	25.00a	8.23bc	37.5ab	39.3abc	34.7bc	40.5cde
PI 407616-BJ-2131-Turkey	28.2a	34.0abc	24.15ab	9.87ab	34.1ab	49.3a	34.7bc	44.8bc
PI 537634-1040-USA	27.6a	26.7abcd	21.96bcd	8.47bc	42.7a	43.7ab	35.4bc	36.2de
PI 537668-BJ-1085-USA	30.1a	40.3a	20.61cd	7.07cd	43.7a	29.3c	32.7c	34.0e
PI 314650-Milutin-114 Kazakistan	27.9a	20.3cd	22.52abc	11.10a	38.1ab	42.0ab	44.2a	47.6ab
PI 306830-BJ-1632-India	35.1a	35.7ab	20.36cd	5.35d	37.1ab	34.0bc	37.8bc	42.5bcd
Significance	*	*	**	***	*	**	*	***
LSD	10.4	14.0	2.97	2.58	10.24	11.48	5.35	6.62

*, **, *** Significant at $P = 0.05, 0.01, 0.001$, respectively. Means separated using the Least Significant Difference (LSD) at $P = 0.05$; means within column followed by the same letter(s) are not significantly different.

Table 4. Effect of growing season on yield components and yield of safflower

Season	Capitula number per plant	Capitula diameter (mm)	Seed number per capitulum	1000-seed weight (g)	Seed yield (kg/ha)
Winter	28.0a	21.69a	35.5a	36.65b	1452.6b
Summer	28.2a	8.44b	40.9a	42.55a	1752.6
Significance	NS	****	NS	****	****
LSD	4.90	0.86	5.64	2.89	292.7

****, NS Significant at $P = 0.0001$ or non-significant, respectively. Means separated using the Least Significant Difference (LSD) at $P = 0.05$; means within columns followed by the same letter are not significantly different.

4.2.3 Seed number per capitulum

Safflower genotypes significantly ($P < 0.05$) influenced the seed number/capitulum, irrespective of the growing season (Table 3). However, the growing season had no significant effect on seed number/capitulum (Table 4). In winter, the genotypes PI 537635-1040-USA and PI 537668-BJ-1085-USA had no significant ($P > 0.05$) differences in their seed number/capitulum, but was significantly ($P < 0.05$) higher than that of the genotypes Kiama Composite, PI 537632-1038-USA and PI 30441-BJ-2621-Iran (Table 3). However, the genotypes PI 537635-1040-USA, PI 537668-BJ-1085-USA, PI 537598-SINA-USA, PI 407616-BJ-2131-Turkey, PI 314650-Milutin-114-Kazakistan, and PI 306830-BJ-1632-India did not significantly ($P > 0.05$) differ in their seed number/capitulum in winter (Table 3). Similarly in winter grown safflower, the genotypes PI 537598-SINA-USA, PI 407616-BJ-2131-Turkey, PI 314650-Milutin-114-Kazakistan, PI 306830-BJ-1632-India, Kiama Composite, PI 537632-1038-USA, and PI 30441-BJ-2621-Iran did not significantly ($P > 0.05$) differ in their seed number/capitulum (Table 3). In summer, the genotype PI 407616-BJ-2131-Turkey had a seed number/capitulum of 49.3, but was significantly ($P < 0.01$) higher than the seed number/capitulum of the genotypes PI 537632-1038-USA, PI 537668-BJ-1085-USA and

PI 306830-BJ-1632-India, but not significantly (P > 0.05) different from that of the other genotypes (Table 3).

4.2.4 1000 seed weight

Safflower genotypes and growing season significantly (P < 0.05) influenced 1000-seed weight (Table 3, 4). Summer grown safflower had significantly (P < 0.0001) higher 1000-seed weight than winter grown safflower (Table 4). In winter, the genotype PI 314650-Milutin-114-Kazakistan had a 1000-seed weight of 44.2 g which was significantly (P < 0.05) higher than the 1000-seed weight of all the other genotypes under study, with exception of the genotype PI 30441-BJ-2621-Iran (Table 3). While, the genotype PI 537668-BJ-1085-USA had the lowest 1000-seed weight of 32.7 g, but was not significantly (P > 0.05) different from the 1000-seed weight of all the other genotypes, with exception of the genotypes PI 30441-BJ-2621-Iran and PI 314650-Milutin-114-Kazakistan (Table 3). In summer, the genotype PI 30441-BJ-2621-Iran had a 1000-seed weight of 51.8 g which was significantly (P < 0.001) higher than that of all the other genotypes, with exception of the genotype PI 314650-Milutin-114-Kazakistan (Table 3). While in summer, the genotype PI 537668-BJ-1085-USA had a 1000-seed weight of 34.0 g which was significantly (P < 0.001) lower than that of all the other genotypes, with exception of the genotypes PI 537598-SINA-USA, PI 537634-1040-USA and PI 537668-BJ-1085-USA (Table 3).

4.2.5 Seed yield

Safflower genotypes and growing season significantly (P < 0.05) influenced seed yield. Plants grown in summer seed yielded an average of 1752.6 kg/ha which was significantly (P < 0.0001) higher than the seed yield in winter (1452.6 kg/ha) (Table 4). In winter grown safflower, the genotype PI 537598-SINA-USA produced the highest seed yield of 3113 kg/ha which was significantly (P < 0.0001) higher than the seed yield of all other genotypes (Figure 4). Also in winter grown safflower, the genotype Kiama Composite had the lowest yield of 913 kg/ha, but was not significantly (P > 0.05) different from the seed yield of the genotypes PI 30441-BJ-2621-Iran, PI 407616-BJ-2131-Turkey, PI 537634-1040-USA, and PI 537668-BJ-1085-USA. However, the genotypes Kiama Composite, PI 30441-BJ-2621-Iran, PI 407616-BJ-2131-Turkey, PI 537634-1040-USA and PI 537668-BJ-1085-USA had significantly (P < 0.0001) lower yield than the other genotypes in winter (Figure 4). The genotypes PI 537632-1038-USA, PI 314650-Milutin-114-Kazakistan and PI 306830-BJ-1632-India did not significantly (P > 0.05) differ in their seed yield, but were significantly (P < 0.0001) higher than the seed yield of the genotypes Kiama Composite, PI 30441-BJ-2621-Iran, PI 407616-BJ-2131-Turkey, PI 537634-1040-USA, and PI 537668-BJ-1085-USA in winter (Figure 4). While in summer, the genotype PI 537598-SINA-USA still produced the highest seed yield of 2140 kg/ha, but was not significantly (P > 0.05) different from the seed yield of all the other genotypes with exception of the genotype PI 537634-1040-USA (Figure 4).

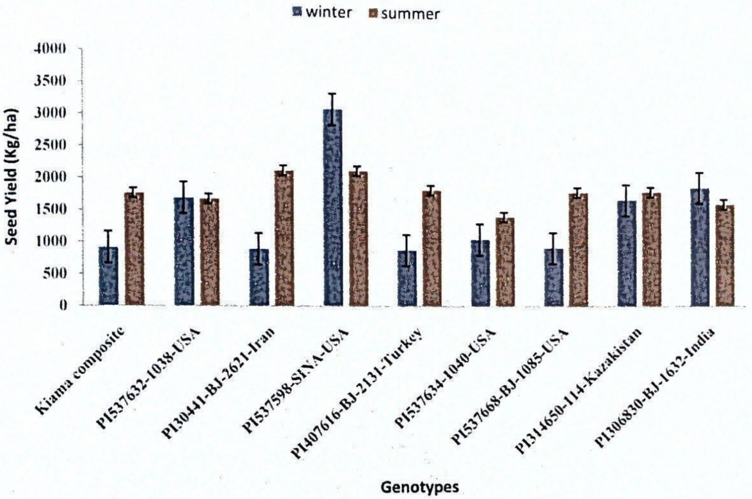

Figure 4. Effect of genotypes and season on safflower seed yield; bars are standard error

4.3 Oil content and yield

4.3.1 Oil content

Safflower genotypes significantly (P < 0.0001) influenced the seed oil content in winter grown safflower (Table 5). The genotype PI 537598-SINA-USA had the highest oil content of 42.17% which was significantly (P < 0.0001) higher than the seed oil content of all the other genotypes with exception of the genotype PI 537632-1038-USA (40.97%) (Table 5). The genotype PI 30441-BJ-2621-Iran had the lowest seed oil content of 26.13% which was significantly (P < 0.0001) lower than the seed oil content of all the other genotypes with exception of the genotype PI 407616-BJ-2131-Turkey (26.40%) (Table 5).

4.3.2 Oil yield

Safflower genotypes significantly ($P < 0.0001$) influenced the oil yield in winter grown safflower (Table 5). The genotype PI 537598-SINA-USA had an oil yield of 1313 kg/ha, which was significantly ($P < 0.0001$) higher than the oil yield of all the other genotypes under study in winter grown safflower (Table 5). The genotype PI 537632-1038-USA had an oil yield of 692 kg/ha which second highest, but was not significantly ($P > 0.05$) different from the oil yield of the genotypes PI 314650-Milutin-114-Kazakistan and PI 306830-BJ-1632-India, but significantly ($P < 0.05$) higher than the oil yield of the other genotypes with exception of the genotype PI 537598-SINA-USA (Table 5). The genotype PI 30441-BJ-2621-Iran had the lowest oil yield of 226 kg/ha, but not significantly ($P > 0.05$) different from the oil yield of the genotypes Kiama Composite, PI 407616-BJ-2131-Turkey, PI 537634-1040-USA and PI 537668-BJ-1085-USA (Table 5).

Table 5. Effect of genotypes on seed oil content and oil yield of winter grown safflower

Genotype	Seed oil content (%)	Oil yield (kg/ha)
Kiama Composite	32.27c	302d
PI 537632-1038-USA	40.97ab	692b
PI 30441-BJ-2621-Iran	26.13d	226d
PI 537598-SINA-USA	42.17a	1313a
PI 407616-BJ-2131-Turkey	26.40d	236d
PI 537634-1040-USA	33.17c	357cd
PI 537668-BJ-1085-USA	34.93c	326d
PI 314650-Milutin-114-Kazakistan	36.50bc	550bc
PI 306830-BJ-1632-India	32.00c	605b
Significance	****	****
LSD	4.97	200

**** Significant at $P = 0.0001$. Means separated using the Least Significant Difference (LSD) at $P = 0.05$; means within columns followed by the same letter(s) are not significantly different.

CHAPTER 5

5.0 DISCUSSION

5.1 Vegetative growth

A wide variety of agronomic traits have been evaluated in safflower germplasm collections for their possible use in the improvement of the productivity of safflower cultivars (Fernández-Martínez, 1997). An extensive evaluation of safflower germplasm was carried collaboratively between the US and Israeal (Ashri, 1971; Ashri *et al.*, 1974; Ashri *et al.*, 1975 and Ashri *et al.*, 1976; Fernández-Martínez, 1985), China (Yang*et al.*, 1993), India (Rao *et al.*, 1990; Patil *et al.*, 1990; Rao *et al.*, 1992; Mehthre *et al.*, 1995), and in Pakistan (Urage and Weyessa, 1991; Aslam and Hazara, 1993). A significant genetic variation in yield and yield components, plant height, flowering time, duration of rosette stage, primary branches and other morphological traits were observed. In the current study, safflower genotypes had significant variation in vegetative growth (plant height and primary branch number/plant) both in winter and summer.Zarcie *et al.* (2013), Hamza (2015), Killi *et al.* (2016),and Moatshe *et al.* (2016) reported significant genotype variation for plant height, primary branch number/plant and other traits of safflower. Abd El-Lattief (2012) reported that there was significant ($P < 0.01$) genetic variation among 25 safflower genotypes in the traits plant height and primary branch number/plant in Egypt. While Carapetian (2001) reported that there was significant variation for plant height, spineness, and length of rosette stage between winter- and spring-type safflower genotypes in Iran. After evaluating 400 accessions of safflower in Romania, Bratuleanu (1997) reported that vegetative growth (period of vegetative growth, rosette stage, plant height, height of first branching and angle of branching) was largely determined by genotype, though they can be influenced by the environment and cultural practices (Dajue *et al.*, 1993; Dajue and Mündel, 1996; Weiss, 2000; Camas *et al.*, 2007). Biometrical analyses have been carried out to evaluate gene action for morphological traits of safflower (Golkar, 2014). Safflower plant height as an important morphological trait is under the effect of additive gene action (Kotecha, 1979; Shahbazi and Saeidi, 2007; Golkar *et al.*, 2012). It is also reported that safflower plant height is not affected by extra-nuclear genes (Mandal and Banerjee, 1997). While the morphological traits, stem diameter and leaf length of safflower are reported to be under the effects of additive and non-additive gene action, respectively (Kotecha, 1979). Regarding number of branches/plant, Gupta and Singh (1988) found additive gene effects as playing an important role in its genetic control. Branching habit in safflower is also reported to be controlled both digenically and environmentally (Deokar and Patil, 1975). Apprised branching is recessive to separating types and is controlled both digenically and monogenically (Deokar and Patil, 1975).

Also in the current study, there was no significant variation among safflower genotypes with respect to leaf chlorophyll content (chlorophyll a, b and total chlorophyll), but Golkar *et al.*(2009) reported significant differences among 20 safflower genotypes and FI hybrids in leaf chlorophyll a, b and total chlorophyll content. The content of chlorophyll b was lower than chlorophylla in all genotypes (Golkar *et al.*, 2009), which was contrary to the results of the current study. In the current study, leaf chlorophyll b was higher than chlorophyll a content in all the genotypes. The difference in chlorophyll a and b contents in the current study and the results of Golkar *et al.* (2009) was attributed to the different safflower genotypes used in the studies. The results of the present study for genetic variation for leaf chlorophyll (antioxidant) content in safflower are in agreement with those of previous workers in other plants (Tosun *et al.*, 2009; Hakiman and Maziah, 2009; Ercisil *et al.*, 2007; Rupasinghe *et al.*, 2006).

Seasonal variation in vegetative growth (plant height, primary branch number/plant and leaf chlorophyll content) observed in the current study was probably due to climate especially change in temperature between winter and summer. Emongor *et al.* (2013) and Moatshe *et al.* (2016) reported that in Botswana, safflower plants grown in winter were significantly taller, had more primary branch numbers/plant, leaf number/plant, leaf area and plant dry matter than summer grown safflower plants. The difference in plant height between winter and summer grown safflower was attributed to the difference between night and day temperatures (DIF) (Emongor *et al.*, 2013; Emongor *et al.*, 2015). On average the DIF during the elongation phase in winter and summer is 20.7-24 and 16.4-17.3° C (Emongor *et al.*, 2013; Emongor *et al.*, 2015).Went (1944) reported that changes in day and night temperatures have morphological effects on stem extension. The higher the day temperature relative to the night temperature (DIF), the greater the stem elongation (Berghage and Heins, 1991; Erwin *et al.*, 1989 a,b). Increasing the day temperature relative to the night temperature increases internodes elongation for many plant species (Berghage and Heins, 1991; Myster and Moe, 1995; Dole and Wilkins, 2005). The higher positive DIF and chilling morning temperatures (8.4-12 °C) in winter increased stem elongation, hence taller safflower plants in winter than in summer where DIF was lower and the morning temperatures were not chilling (17.2 – 18 °C) (Emongor *et al.*, 2013). The positive DIF in winter might have promoted gibberellins biosynthesis which are known to promote cell and internode elongation hence further explaining the increase in safflower plant height (Taiz and Zeiger, 2002).

In this study winter grown safflower plants had more branches than summer plants. Emongor *et al.* (2015) and Moatshe *et al.* (2016) reported similar results concerning safflower branching in winter and summer in Botswana. Salisbury and Ross (1992) reported that long days have a suppressive effect on branching, this could explain why summer grown safflower plants had fewer branches in summer than winter.Safflower branching was also reported to be influenced by environmental factors and cultural practices (Dajue *et al.*, 1993; Dajue and Mündel, 1996; Bratuleanu, 1997; Weiss, 2000). Also in the current study, the leaf chlorophyll content was higher in summer grown safflower than winter. This was probably due to to temperature especially the low minimum temperatures in winter. In the experimental site, the average minimum temperatures in summer and winter are 19.2-19.5 °C and 7-16 °C, respectively. Smillie *et al.* (1978) reported that temperatures between 2-11 °C inhibited chloroplast biosynthesis and development hence resulting in leaf chlorosis and abnormal chloroplasts and grana in barley. High temperatures above 32 °C inhibits chloroplast development in higher plants (Pringsheim and Pringshiem, 1952; Feierabend and Mikus, 1976; Smillie *et al.*, 1978; Dutta *et al.*, 2009; Kusum and Iba, 2014), while low temperatures of 2-16 C also inhibits chloroplast development in chilling-sensitive crops (Faris, 1927; McWilliam and Naylor, 1967; Slack *et al.*, 1974; Smillie *et al.*, 1978; Dutta et al., 2009).

5.2Yield and yield components

The success of safflower introduction in a new area largely depend on the extent of improvement made in yield and oil content (Malleshappa *et al.*, 2003; Abdolrahmani, 2005). The yield components of safflower includes seed weight, plant height, first branch height, number of branches, capitula diameter, number of seed per capitulum, number of capitula per plant and 1000-seed weight (Chaundry, 1990; Gonzalez *et al.*, 1994; Omidi *et al.*, 2000; Bagheri *et al.*, 1995; Camas and Esendal, 2006;Camas *et al.*, 2007; Ahmadzadeh *et al.*, 2012; Emongor *et al.*, 2013; 2015; Moatshe *et al.*, 2016; Emongor and Oagile, 2017). The results of the current study showed that safflower genotypes significantly ($P < 0.05$) influenced the yield components (capitula number/plant, capitula diameter, seed (achene) number/capitulum and 1000-seed weight).Irrespective of growing season, the genotypes PI 537598-SINA-USA, PI 537632-1038-USA, PI 537668-1085, Kiama Composite, PI 306830-BJ-1632-India, and PI 314650-Milutin-114-Kazakistan consistently had high yield components in the current study.Killi *et al.* (2016), Moatshe *et al.* (2016), Asghar and Younes (2015), Hamza (2015), and Camas *et al.* (2007) all reported significant genetic variation of safflower genotypes on capitula number/plant, seed number/capitulum, 1000-seed weight and biological yield. Zareie *et al.* (2013)evaluating 10 genotypes of safflower in Iran, reported that genotype significantly influenced capitula number/plant, seeds/capitulum and 1000-seed weight. The genotype Esfahan 14 performed better than the other nine safflower genotypes with respect to yield components and seed yield (Zareie *et al.*, 2013). Abd El-Lattief (2012) reported significant ($P < 0.01$) genetic variation among 25 safflower genotypes with respect to the traits capitula number/plant and 1000-seed weightin Upper Egypt. Earlier, Kizil *et al.* (2008) reported that the safflower genotypes Dincer, Yenice and 5-154 significantly ($P < 0.05$) differed in their capitula diameter, seeds/capitulum and 1000-seed weight. Safflower genotypesare reported to possess enormous diversity for different traits of economic importance (Singh and Nimbkar, 2006). Hybrids with different morphological and physiological characters have been developed for different macroclimatic conditions (Dajue and Mündel, 1996; Singh and Nimbkar, 2006). The genetic control of safflower capitula diameter is reported to be under dominance gene effects (Golkar *et al.*, 2012). While Camas and Esendal (2006) reported that safflower capitula diameter has low broad-sense heritability. This finding reveals the importance of environmental effects on safflower capitula diameter which is a good index for ornamental application of safflower. The capitula number/plant is reported to be under the control of dominance gene effects (Pahlavani *et al.*, 2007). Deshmakh *et al.* (1991) carried out a line x tester analysis to find a high heterosis for capitula number/plant. Shahbazi and Saeidi (2007) reported that additive x additive and dominance x dominance epistasis had important roles in the genetic control of capitula number/plant. Sahu and Tewari (1993) reported on the importance of additive-dominance model for its genetic control. While Ramachandram and Goud (1981), reported that mean comparison of reciprocal effects showed that maternal effects played an important role in the inheritance of capitula number/plant and 1000-seed weight. Number of seeds/capitulum is affected by additive gene effects (Mandal and Banerjee, 1997; Singh and Pawar, 2005; Singh *et al.*, 2008). This suggests that selection breeding method could be applied for the improvement of seed number/capitulum in safflower. Additive gene effects are also reported to play a significant role in the genetic control of 1000-seed weight (Golkar *et al.*, 2012). Also, the digenic model (additive-dominance) has been reported to be involved in 1000-seed weight (Shahbazi and Saeidi, 2007).

The results of the current study also showed that there was significant variation in safflower yield components between winter and summer grown safflower. Different safflower genotypesare reported to respond differently depending on the environmental conditions, genotypic characters and management practices (Singh and Nimbkar, 2006;Rahamatalla *et al.* 2001).Mahasi *et al.* (2006) reported significant genotype by environment interaction and stability in safflower for the yield components traits of capitula number/plant, capitula diameter,seednumber/capitula and 100-seed weight. The significant genetic and environment interaction indicated the existence of a wide range of variations between genotypes and between seasons, and that different genotypes reacted differently to varying seasons (Scott *et al.*, 1997; Singh *et al.*, 2004; Mahasi et al., 2006). Ashri *et al.* (1974) studied variation in yield components (capitula number/plant, seed number/capitulum and 1000-seed weight) of safflower 903 accessions from different regions of the world and found that there was significant genotype and environment interaction and source of safflower accession (locality) in safflower performance. Regional evaluations of safflower are important to breeding efforts as genotype by environment interactions requires breeding for local conditions. Elfadl *et al.* (2010) evaluated 467 accessions of safflower from 11 geographical regions using principal component and cluster analysis showed that safflower accessions from the Americas, Africa, the Mediterranean, and West Central Europe formed one cluster, accessions from Central and South-Eastern Europe and Germany formed another cluster, and those from Central Asia, South Asia, and East Asia formed another cluster. They concluded that enough diversity existed among safflower accessions evaluated to provide an opportunity for selection in a breeding program for local conditions. The results of the current study and those in literature suggests that environmental effects are important in understanding safflower plant growth and development, and it should be given consideration in safflower breeding programs.

The success of safflower introduction in new regions of the world largely depends on the extent of improvement made in seed yield and oil content (Malleshappa *et al.*, 2003; Abdolrahmani, 2005). In the current study, safflower genotypes and growing season significantly ($P < 0.05$) influenced seed yield. Safflower grown in summer seed yielded on average of 1752.6 kg/ha which was significantly ($P < 0.0001$) higher than the seed yield in winter (1452.6 kg/ha). In winter grown safflower, the genotype PI 537598-SINA-USA produced the highest seed yield of 3113 kg/ha which was significantly ($P < 0.0001$) higher than the seed yield of all other genotypes. Also in winter grown safflower, the genotype Kiama Composite had the lowest yield of 913 kg/ha. While in summer, the genotype PI 537598-SINA-USA still produced the highest seed yield of 2140 kg/ha, but was not significantly ($P > 0.05$) different from the seed yield of all the other genotypes with exception of the genotype PI 537634-1040-USA. The variation in seed yield due to growing season was attributed to the length of the growing season (120-140 days from emergence to maturity in winter and 90-114 days in summer depending on genotype) as influenced by genotype and environment interaction. Seed yield of a given safflower cultivar in a given location may vary because of light, water availability, precipitation, temperature, humidity and nutrient availability and competition (Koutroubas *et al.*; 2004; Emongor and Oagile, 2017). Moatshe *et al.* (2016) reported the higher vegetative growth, yield components and seed yield of safflower grown in winter than summer irrespective of genotype in Botswana. They attributed the higher vegetative growth, yield components and seed yield of safflower grown in winter than summer to longer growing in winter (140 days after emergence) than summer (114 days after emergence) hence more accumulation of biological yield or dry matter (Emongor *et al.*, 2013). Emongor *et al*. (2013) reported that winter grown safflower plants accumulated more dry matter (plant biomass) than summer grown plants (116 days after emergence- DAE) because of the longer maturation period (138 DAE). The longer growth period of winter grown safflower implied longer leaf area duration (LAD) than summer grown safflower. There is a positive linear correlation between yield (biomass or dry matter) and LAD in most crops (Heggenstaller, *et al.*, 2009; Evans *et al.*, 1976). Leaf area durationwhich is the integral of leaf area index (LAI)from emergence to physiological maturity significantly determines yield of many crops (Emongor, 2007). Emongor *et al.* (2013) further reported a higher number of capitula /plant, achene number/capitulum and achene weight (100-seed weight) in winter than summer grown safflower plants. These was attributed to longer maturation period in winter 138 DAE compared to summer 116 DAE as influenced by temperature (Emongor *et al.* 2013). Optimum temperatures produce high-quality plants most rapidly while tolerable temperatures allow plants to continue growing but may result in long production times or low quality (Nau, 1993). Average daily temperature controls the rate of plant development. The high average daily temperatures in summer accelerated safflower growth and reduced the maturation period by 30-50 days, yield components and seed yielddepending on genotype in the current study. Environmental factors, especially temperature, are the key factor which influences the growth and development of safflower plants (Shabana*et al.*, 2013). Significant differences among safflower genotypes for growing degree days showed that different safflower genotypes had varying maturity periods (Shabana*et al.*, 2013).Significant variation in phenology, growth and yield across safflower genotypes and seasons has also been reported in different studies (Riche and NeSmith, 1991; Isoda *et al.*, 2011; Hassan *et al.*, 2015 and Tahmasebpour *et al.*, 2016). The seasonal variation among genotypes was mainly attributed to difference in environments, temperatureand sunshine (Emongor *et al.*, 2013; Hassan *et al.*, 2015 and Tahmasebpour *et al.*, 2016). Ritche and NeSmith (1991) and Kaleem *et al.* (2009) confirmed that temperature and photoperiod regulates plant growth and development processes, while Shabana *et al.* (2013) and Orchard (1975) emphasized that phenological development of safflower is largely dependent on temperature rather than photoperiod. This has a great impacton crop yield and yield attributes especially during seed development and maturationof safflower (Orchard,1975).

The variation in safflower seed yield among genotypes and growing season in the current study could also be attributed to the variation in the yield components (plant height, primary branch number, capitula diameter, capitula number/plant, seed number/capitulum and 1000-seed weight). Moatshe *et al.* (2016) reported significant positive correlations between seed yield and capitula number/plant, seed number/capitulum, 1000-seed weight, biological yield, plant height and primary branch number/plant). Karimi *et al.* (2013) reported positive significant correlations of 1000-seed weight, number of seed/capitulum, number of seed/plant, biological yield, plant height, harvest index and days to flowering and days to physiological maturitywith seed yield in safflower. In the current study, positive correlations (r) between plant height, primary branch number, capitula number/plant, seed number/capitulum and 1000-seed weight with seed yield were observed as follows 0.39, 0.31, 0.13, 0.12 and 0.27 in winter, and 0.38, 0.63, 0.28, 0.16 and 0.5 in summer, respectively. Moatshe *et al.* (2016) reported significant and strong correlations between safflower seed yield and capitula number/plant (r = 0.96), branch number/plant (r = 0.94), plant height (r = 0.96) seed number/capitulum (0.91), 1000-seed weight (r = 0.920 and biological yield (r = 0.97). Abd El-Lattief (2012) reported significant and positive correlations between safflower seed yield and plant height (r = 0.55), branch number/plant (r = 0.58), capitula number/plant (r = 0.62), 1000-seed weight (r = 0.18), and seed weight/plant (r = 0.84). Camas *et al.* (2007) also reported positive and significant correlations between safflower seed yield and branch number/plant (r = 0.49), capitula diameter (r = 0.33), seed number/capitulum (r = 0.44), and 1000-seed weight (r = 0.45). Positive correlations between safflower seed yield and yield components have been reported in literature (Gupta and Singh, 1997; Patil, 1998; Johnson *et al.*, 2001; Singh *et al.*, 2004; Choulwar *et al.*, 2005; Omidi, 2006; Eslam *et al.*, 2010; Bagavan and Ravikumar, 2011; Karimi*et al.*, 2013).The variation in the correlations between safflower seed yield and yield components in the current study and those reported in literature is an indication that even though yield components and yield are under genetic control, they are also influenced by the environment, genetic x environmental interaction, and agronomic practices. The results of the current study and those reported in literature showed that any positive increase in the yield components will suffice a boost in seed yield.

The variation in seed yield among safflower genotypes in the current study was also attributed to genetic differences among the genotypes.In the current study, the safflower seed yield ranged between 900-3113 kg/ha (winter) and 1421-2140 kg/ha (summer) depending on genotype. Moatshe *et al.* (2016) in Botswana reported safflower seed yield in the range of 2000 to 5500 kg/ha depending on genotype, plant density and growing season. Kizil *et al.* (2008) in Turkey reported safflower seed yield of 1706-3111 kg/ha depending on genotype and growing season. Camas*et al.* (2007) and Killi *et al.* (2016) from also from Turkey reported a safflower seed yield of 913-2482 and 827-992 kg/ha, respectively, depending on genotype. While Abd El-lattief (2012) and Hamza (2016) in Egypt reported a safflower seed yield of 512-2846 and 1978-2510 kg/ha, respectively, depending on genotype. There are literature reports citing safflower seed yield ranging from 800 to 3325 kg/ha depending on genotype (Inan and Kirici, 2001; Dadashi and Khajehpour, 2004, Eslam, 2004; Azari and Khajehpour *et al.*, 2005, Bayraktar *et al.*, 2005; More *et al.*, 2005; Cosge and Kaya, 2008; Tonguc and Erbas, 2009; Okcu *et al.*, 2010; Beyyava *et al.*, 2011; Sirel and Aytac, 2016). The high variations in seed yield values in the current study and those reported in literature may be due to environmental conditions or genetic potential for seed yield. Seed yield and its components in safflower are affected by additive gene action, with exception of capitula number/plant (Golkar *et al.*, 2012; Golkar, 2014). High estimates of broad-sense heritability for seed yield and its components have been reported in literature (Mather and Jinks, 1982; Falconer and Mackay, 1996; Camas and Esendal, 2006; Golkar, 2014). It is also reported that other types of genetic effects might be involved in the variation of yield among safflower genotypes (Mather and Jinks, 1982; Golkar *et al.*, 2012; Golkar, 2014).

5.3 Seed oil content and oil yield

Safflower seed oil content is a very important economic trait for safflower cultivars or genotypes and is considered one of the most important factors affecting the success of safflower production (Dajue and Mündel, 1996; Bassil and Kaffka, 2002; Singh and Nimbkar, 2006; OGTR, 2015). In the current study, safflower genotypes significantlyinfluenced the seed oil content oil yield in winter grown safflower. The genotype PI 537598-SINA-USA had the highest oil content of 42.17% which was higher than the seed oil content of all the other genotypes, with exception of the genotype PI 537632-1038-USA (40.97%). The genotype PI 30441-BJ-2621-Iran had the lowest seed oil content of 26.13% which was lower than the seed oil content of all the other genotypes, with exception of the genotype PI 407616-BJ-2131-Turkey (26.40%).Significant difference in safflower oil content due to genotype is reported in different regions of the world (Dajue and Mündel, 1996; Weiss, 2000; Samanci and Ozkaynak, 2003; Elfadl *et al*., 2005; Camas *et al*., 2007; Kizil *et al*., 2008; Abd El-Lattief, 2012; Hamza, 2015; Killi *et al*., 2016). Samanci and Ozkaynak (2003) in Turkey reported that safflower seed oil content varied between 34.27 to 40.5% depending on genotype. Killi *et al*. (2016) also from Turkey reported that safflower seed oil content ranged between 29.53-33.89% depending on genotype. While Abd El-Lattief (2012) evaluating 25 genotypes of safflower in Egypt reported that the seed oil content ranged between 26.36 to 36.50% depending on genotype. Hamza (2015) reported that safflower genotypes (six) grown under reclaimed soils in Egypt and irrigated with saline water (4.2 dS/m) varied in seed oil content between 28.5 to 34.3% depending on genotype.Yeilaghi *et al*. (2012) evaluated 64 genotypes of safflower from different countries (seed sources from Iran, Syria, Turkey, USA, Cyprus, Mexico Egypt, Palestine, Portugal, Pakistan, China and France) in Iran and they found that seed oil content ranged between 23.39 to 35.49% depending on genotype and origin of seed (country).The ranges of 20-45% seed oil content of safflower have been reported by other researchers (Weiss, 2000). In the USA, safflower cultivars with oil content ranging from 30.0 to 47.7% are reported (Smith, 1996; Bergman and Kandel, 2013). The oil content of safflower genotypes from different production areas of the world is reported also as 23.86- 40.33 % (Zhang and Chen, 2005), 26.72-35.78 % (Koutroubas and Papadoska, 2005), 26.3-28.5 % (Gawand *et al.*, 2005) and 31.3-36.3 % (Arslan and Küçük, 2005; Camas *et al.*, 2007; Abd El-Lattief *et al.*, 2009).The results of the current study found that the safflower seed oil content ranged between 26.13 to 42.17% depending on genotype which is within the range reported elsewhere in literature. The differences in the seed oil content among safflower genotypes was attributed to genetic differences among them. Rahamatalla *et al.* (2001) reported that oil content of a crop varies depending on factors such as cultivar, genetic traits, soil characteristics and climate. Safflower seed oil content is a qualitative trait which is influenced by genotype, environment, and genotype x environment interaction (Golkar, 2014). Both additive (Golkar *et al.*, 2011) and dominance (Gupta and Singh, 1988) gene effects are observed in the genetic control of safflower seed oil content. Pahlavani *et al.* (2007) reported that epistatic effects had a significant impact on the genetic control of safflower seed oil content. Ramachandram and Goud (1981) reported that dominant alleles are involved in the genetic control of safflower seed oil content. Genotypically, the spiny safflower cultivars are reported to contain more oil content than spineless ones (Weiss, 2000). The genotypes under the current study were all spiny partly explaining the high seed oil content. For commercial production of safflower the seed oil content should be at least 28% (Dajue and Mündel, 1996; Smith, 1996; Singh and Nimbkar, 2006). From the results of the current study, all the safflower genotypes qualify for commercial oil production with exception of the genotypes PI 30441-BJ-2621-Iran and PI 407616-BJ-2131-Turkey.

There was also a positive significant correlation (r = 0.61) between seed yield and seed oil content. Kizil *et al.* (2008) and Abd El-Lattief (2012) reported that safflower seed yield and seed oil content was positively correlated (r = 0.574) and (r = 0.837), respectively. Camas *et al.* (2007) reported a positive correlation (r = 0.51) between safflower seed yield and seed oil content. Significant positive correlations between safflower seed yield and seed oil content are reported in literature (Esendal and Tosun, 1972; Ozturk *et al.*, 2007; Ada, 2013). However, Omidi *et al.* (2012) reported a negative non-significant correlation (r = - 0.073) between safflower seed yield and seed oil content.

Similarly, the genotype PI 537598-SINA-USA had an oil yield of 1313 kg/ha, which was significantly (P < 0.0001) higher than the oil yield of all the other genotypes under study. The genotype PI 537632-1038-USA had an oil yield of 692 kg/ha which second highest, but was not significantly (P > 0.05) different from the oil yield of the genotypes PI 314650-Milutin-114-Kazakistan and PI 306830-BJ-1632-India, but significantly (P < 0.05) higher than the oil yield of the other genotypes, with exception of the genotype PI 537598-SINA-USA. The genotype PI 304441-BJ-2621-Iran had the lowest oil yield of 226 kg/ha. The oil yield ranged between 226-1313 kg/ha depending on the safflower genotype in the current study.Camas *et al.* (2007) and Omidi *et al.* (2012) reported safflower oil yield of 193-821 and 412-522 kg/ha depending on genotype, respectively. Gawad *et al.* (2005) recorded oil yield among four safflower cultivars in the range of 322 to 460 kg/ha. While Koutroubas and Papadoska (2005) evaluating 21 genotypes of safflower reported oil yield of 416-701 kg/ha. Abd El-Lattief (2012) in Egypt evaluated 25 safflower genotypes and reported an oil yield of 141-1039 kg/ha depending on genotype. While Hamza (2016) also from Egypt evaluated six safflower genotypes and reported oil yield of 579.5-859.7 kg/ha. Omidi (2006) in a four-year study evaluating 10 safflower genotypes reported oil yield of 238.2-966.6 kg/ha depending on genotype and year. Omidi (2006) also reported that year x location, and year x location x genotype interactions were significantly different, implying that safflower genotypes respond differently under different climatic conditions. Therefore, the safflower oil yield of the current study is within the range reported in literature.

There was a significant positive correlation (r = 0.97) between seed yield and oil yield in the current study. Abd El-Laffief (2012) also reported a significant positive correlation (r = 0.99) between seed yield and oil yield. The results of the current study are also in agreement with other results reported in literature (Johnson *et al.*, 2001; Omidi, 2006; Eslam *et al.*, 2010; Bagavan and Ravikumar, 2011) who all reported positive significant correlations between safflower seed yield and oil yield.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

The results of this study showed that safflower can be grown both in summer and winter seasons in Botswana. There were significant variations among safflower genotypes within and between growing seasons, indicating genetic, and genetic x environmental effects. All the nine safflower genotypes evaluated in the study performed well in all the variables investigated, but the genotype PI 537598-SINA-USA outperformed all the other genotypes including Kiama Composite the local genotype. If safflower is to be grown primarily for vegetable oil production in Botswana,all the safflower genotypes qualify for commercial oil production with exception of the genotypes PI 30441-BJ-2621-Iran and PI 407616-BJ-2131-Turkey which had a seed oil content of less than 28% which is the minimum requirement for a safflower cultivar to qualify for commercial oil production. However, safflower is a multipurpose oil crop that can be used as a vegetable, cut flower, fodder crop, medicinal plant and meal as livestock feed supplement, all the genotypes evaluated in the study can be grown in Botswana. Due to excellent adaptability of safflower genotypes evaluated; safflower has high potential to mitigate the effects of drought and climate change, improve food security, increase income and social welfare of farmers in Botswana, and to reduce reliance on food and animal feed importation. It is also recommended that the safflower genotypes evaluated in this study be evaluated for phenological, morphological and biochemical traits in different locations of Botswana.

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