SAFFLOWER PRODUCTION

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AND NATURAL RESOURCES

Library of Congress Cataloging-in- Publication

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Includes Biblographical References

ISBN 978-99968-0-607-0

Edited by Prof. Vallantino Emongor

Interior and cover designs: Mpho C. Magano

Published by:

The Botswana University of Agriculture and Natural Resources

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ISBN 978-99968-0-607-0

Printed by Impression House

Plot 14420, Off Kudumatse Drive

Gaborone West Industrial

P.O. BOX 1338

Gaborone

Botswana

Tel: +267-3922984/3163808

Fax: +267-3924777/3163811

www.impressionhouse.com

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Preface

Safflower is a multipurpose oil seed crop that can be used for cooking oil production, as vegetable crop, cut flower, forage crop for both forage and animal feed, industrial crop for dye production and medicinal crop. Safflower is a drought, heat, cold and saline tolerant crop. Despite the usefulness of safflower and its drought, heat, cold and salt tolerance, it has remained underutilized and minor crop because of lack of information on its crop management, locally adapted varieties, product development from it, and reluctance of farmers to adopt a new crop. It's essential for the scientific community to carry out research on this crop and popularize it as a commercial crop for development of pharmaceuticals, edible oil, paint and varnishes industry, dye extraction, source of α-tocopherol, livestock feed, vegetable and cut flower.

This book was written to primarily as a resource for researchers, university students, processors, product developers and farmers involved with safflower research and/or production. The book contains sections on what safflower is, uses, botany, origin, physiology, ecological requirements, and many aspects of production such as plant density, weed control, intercropping and cropping systems, fertilizer requirements, irrigation, harvesting and storage, and safflower diseases and pests.

ACKNOWLEDGEMENT

The authors acknowledge the financial support by The Regional Universities Forum for Capacity Building in Agriculture (RUFORUM)

The authors also acknowledge the Botswana University of Agriculture and Natural Resources (BUAN) for use of their facilities and administration of the grant.

CHAPTER 1

1.0 INTRODUCTION

Safflower (Carthamus tinctorius L.) is a member of the family Compositae or Asteraceae (Weiss, 2000), cultivated mainly for its seed, which is used as edible oil, birdseed or for its flowers, used as dye sources and medicinal purposes (Ekin, 2005; Dordas and Sioulas, 2008; Istanbulluoglu, 2009, Emongor, 2010). Safflower in English language and safran and batard in French, carthame in Spanish, cartamo in Latin, saflor in German, kusum in India and Pakistan and honghua in China (Chavan, 1961; Lajevardi, 1980). Its use as a less costly saffron is indicated by the names false saffron, bastard saffron, thistle saffron and dyer's saffron (Weiss, 1983). The common names of safflower vary with country, region, language and use (Chavan, 1961; Smith, 1996). 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). Between1995-2000, the world seed production of safflower was estimated at 910, 545 tons (FAO, 2001; 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, 2010). In the whole world, India is the largest producer of safflower (Carthamus tinctorius L.) that it accounts for 46% of the world production (421,000 tons) and uses it mainly in 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 (2001), 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).

Safflower is a temperate zone plant grown in arid and semi-arid regions of the world (McPherson *et al.,* 2004). Safflower is native to the Middle East and Iran is thought to be one of the centres of origin (Ashri, 1975; Weiss, 2000; McPherson *et al.,* 2004; Zareie *et al.,* 2013; Khalili *et al.,* 2014). Safflower is grown as a vegetable crop, cut flower, fodder crop, medicinal plant, a dye crop for the textile industry, and safflower oil is also used in the manufacture of high quality paint (Dajue and Mündel, 1996; Emongor, 2010; Emongor, 2015). 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). The safflower crop also tolerates a wide range of temperatures from -7 to 40°C, provided there is no frost during the elongation and flowering phases of growth and development (Mündel *et al.,* 1992; Emongor; 2010; Emongor *et al*., 2013). Alive and non-alive stresses are the factors limiting crop production, however, drought stress is the most important limiting factor to crop production in agricultural systems in arid and semi-arid regions (Mollasadeghi *et al.,* 2011). Drought stress causes reduction in plant height and decreases yield of crops. The amount of water available to a crop is consequently a key factor in determining yield. Drought adversely affects the already fragile food and agricultural situation in the arid and semi-arid regions 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 arid and semi-arid countries (Emongor, 2009). In the arid and semi-arid regions, loss of yield is the main concern of crop scientists. Therefore, growing a multipurpose, drought, saline and temperature tolerant crop such as safflower can mitigate the effects of climate change in semi-arid and arid regions of the world. However, compared to other oilseed crops worldwide and its many uses, great potential to be grown under varied climatic conditions, safflower has remained a minor and neglected crop (Ekin, 2005; Emongor, 2010). The research and product development on different aspects of safflower, despite its adaptability to varied growing conditions with very high yield potential and diversified uses of different plant parts, have not received due attention. This probably is the main reason for its status as a minor crop around the world in terms of area and production, compared to the other oilseed crops. Safflower is also reported to be severely affected by several biotic and abiotic stresses and is characterized by low yield and spiny nature which have discouraged farmers from adopting its cultivation in several countries (Nimbkar, 2008). Also the breeding lines and cultivars of safflower have low genetic diversity (Kumar *et al*., 2015), which restricts their utility in breeding programs. Therefore, an extensive characterization of the prevalent genetic and phenotypic diversity among the global germplasm of the crop is required to facilitate development of effective crop improvement and management strategies (Emongor, 2010; Kumar *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; Aghamohammadreza *et al.,* 2013). 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; Cosge *et al.,* 2007). 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). Now safflower is grown commercially in China, India, Ethiopia, Kenya, Argentina, Australia, Mexico, Canada, Spain, Italy, Turkey, Iraq, Iran, Syria, KazakhstanUzbekistan, Israel, Morroco, Pakistan and Russia (Dajue and Mündel, 1996; Emongor, 2010). It is cultivated on 800,000 ha in the world, with a yield of between 650,000-921,000 tons (Rowland; 1993; Gyulai, 1996; Camas *et al.,* 2005; Rajranshi, 2005; Singh and Nimbkar; 2006; FAO, 2011). The largest producer of safflower is India, mainly in the states of Maharashra and Karnataka (Nimbkar, 2002). India grows the crop on 402,000 ha, producing about 206,000 tons of seed annually (Camas *et al.,* 2007; Rajranshi, 2005).

1.1 Uses of safflower

Safflower is an ancient crop with numerous uses (Dajue and Dajue and Mündel, 1996; Emongor, 2010). It is a multipurpose crop grown for the orange-red dye that is obtained from its petals, medicinal properties, feed value and especially for its high quality oil (Dajue and Mündel, 1996; Dwivedi, 2005; Sirel and Aytac, 2016). Traditionally, safflower was grown for its seeds, for colouring foods, as medicines and for making red and yellow dyes, especially before cheaper aniline dyes became available (Weiss, 1971; Emongor, 2010). Currently, seeds are the major plant part used, resulting in a high-quality edible and industrial oil and bird seed (Knowles, 1989; Dajue and Mündel, 1996; Ekin, 2005; Bergman *et al*., 2007; Emongor, 2010). New uses include special edible oil types that improve human diet (Velasco and Fernández-Maryinnez, 2004), biofuel (Bergman and Flynn, 2009), and, because of the ease with which oleosin proteins are isolated from safflower seed (Lacey *et al*., 1998), production of transgenic pharmaceuticals is being done (McPherson *et al*., 2004; Mündel and Bergman, 2009). Several review articles on safflower history, cytogenetics, tissue culture, breeding methologies, molecular genetic diversity and production (Dajue and Mündel, 1996; Ekin, 2005; Singh and Nimbkar, 2006; Mündel and Bergman, 2009; Emongor, 2010; Kisha and Jonson, 2012).

1.1.1 Food Uses

Safflower oil is extracted from safflower seed, and it is often considered a healthier option than olive and canola oils (Bergman, 1997; Corleto *et al.,* 1997) as well as sunflower oil (Dajue and Mündel, 1996) because it has lower percentage of saturated fatty acids. Safflower oil consists of two types of unsaturated fatty acids oleic acid (monounsaturated fatty acids) and linoleic acid (polyunsaturated fatty acids). Oleic acid is a beneficial agent in the prevention of coronary artery disease (Dajue and Mündel, 1996) and linoleic acid has been reported to reduce blood cholesterol levels. Arslan *et al*. (2003) reported that safflower oil with greater amount of linoleic acid contained tocopherols, known to have antioxidant effects and high vitamin E content. For this reason, safflower oil is used in the diets of patients with cardiovascular diseases, and bears great importance for its anti-cholesterol effect (Pongracz *et al.,* 1995; Arslan *et al.,* 2003). Safflower in India for a long time has been grown for the orange-red dye extracted from its brilliant florets, high-quality edible oil rich in polyunsaturated fatty acids, which helps in reducing the cholesterol level in blood (Singh and Nimbkar, 2006). Safflower oil is nutritionally similar to olive oil, as it contains high levels of linoleic or oleic acid. The monounsaturated fatty acid like oleic acid is also known to reduce low-density lipoprotein (LDL; bad cholesterol) without affecting high-density lipoprotein (HDL; good cholesterol) in blood (Smith, 1996). Safflower oil is highly stable, and its consistency remains the same at low temperatures, thereby making it suitable for application in frozen/chilled foods (Weiss, 1971). Due to its heat stability, safflower oil is used as a cooking oil. It is also used in the preparation of mayonnaise, salad oil and margarine (Nimbkar, 2002). Safflower oil is also better suited to hydrogenation for margarine production than are soy or canola oils (Kleingarten, 1993).

Safflower leaves are eaten as vegetables (Weiss, 1983) and they are rich in carotene, riboflavin, vitamins A and C, iron, phosphorus and calcium (Nimbkar and Singh, 2006). Its petals are used for extraction of carthamidin and carthamine which are non-toxic food colourants, which are used in colouring and flavouring foods such as cakes, sweets, biscuits, butter, ice cream, rice, soup, sauces and breads (Zohary and Hopf, 2000; Emongor, 2010). With the advent of cheaper synthetic dyes like aniline, use of safflower flowers as a source of edible colour gradually decreased to zero during the 20th century. However, recently interest in safflower flowers as a source of colour for use in food is gaining importance owing to a recent ban on the use of synthetic colours in food in the European countries and elsewhere (Dajue and Mündel, 1996; Singh and Nimbkar, 2006). The flowers are also reported to have medicinal properties to cure several chronic diseases, like hypertension, cardiovascular diseases, arthritis, spondylosis, and sterility in both men and women (Wang and Li, 1985; Zhou, 1986; Yu, 1987; Qin, 1990; Qu, 1990; Zhou, 1992). Artificial food colourants are linked to several behavioral and health problems.

China produces approximately 1800 to 2600 MT of flowers annually to use them for extraction of dyes and in medicinal preparations (Zhaomu and Lijie, 2001). Flowers of non-spiny cultivar NARI-6 and non-spiny hybrid NARI-NH-1 in India, have been reported to be rich in protein (10.4 and 12.86%), total sugars (7.36 and 11.81%), calcium (558 and 708 mg/100 g), iron (55.1 and 42.5 mg/100 g), magnesium (207 and 142 mg/100 g), and potassium (3992 and 3264 mg/100 g), respectively. All essential amino acids except tryptophan are reported to be present in safflower flowers (Singh, 2005). With the commercialization of flowers as herbal health tea, extraction of dyes from them, and their use for medicinal purposes, the monetary returns to farmers from both seed and flowers are expected to grow to the extent of 141% of the monetary returns presently earned from the harvesting of seed alone in India (Sawant *et al.,* 2000). A pleasant-tasting tea made with safflower flowers as its main-ingredient has been developed in China (Li and Yuanzhou, 1993), India (Singh, 2005), and Botswana (Emongor, 2010).

1.1.2 Livestock feed

Not only is safflower good for human consumption, it can be grazed by animals and stored as hay or silage (Bar-Tal *et al.,* 2008). Its forage is palatable with feed value and yields similar or better than oats and alfalfa (Smith, 1996; Wichman, 1996). It makes an acceptable livestock forage if cut at or just after bloom (Berglund *et al.,* 2007). Grazed safflower has been shown to support satisfactory growth rates in Australian steers (French *et al.,* 1988) and improved fertility in Canadian ewes (Stanford *et al.,* 2001). Safflower oil cake is a valuable animal feed (Weiss, 2000). Safflower meal contains about 24% protein and is considerably high in fibre. Values of 21.8% protein, 67.4% nitrogen detergent fibre (NDF), 38.5% acid detergent fibre (ADF), 15 - 20% acid detergent lignin and 3.3% ash have recently been reported (Chidoh, 2012), which are suitable for livestock feed or supplement. It can be taken as a protein supplement in livestock and poultry feeds (Berglund *et al.,* 2007). Safflower seed is also used as birdseed especially for members of the parrot family and pigeons as well as for other small animals such as gerbils, hamsters and chinchillas (Dajue and Mündel, 1996). The birdseed industry prefers to use the white hull or normal hull type of safflower even though striped and partially hull types usually are higher in oil and protein content. The birdseed market does not have a preference for fatty acid type (Dajue and Mündel, 1996).

1.1.3 Textile industry

Dried flower petals are used to extract natural dyes. Natural dyes from plants are getting more important nowadays because they are natural and fashion trends. The colourful matter in safflower is carthamin which is benzoquinone – based (Garcia, 2009). It has a dye of flavonoid type. Hydrophilic fibres like cotton, wool and others can be dyed with safflower dye because it is a direct dye (Badiger *et al*., 2009). The water soluble yellow dye (carthamidin) and the insoluble red dye (carthamine) are used in the carpert-weaving industry in Eastern Europe and the Indian subcontinent (Weiss, 1983).

1.1.4 Cut flower industry

In Western Europe, Japan, Latin America and Kenya, spineless varieties of safflower are grown as cut flowers for the domestic and the export market (Kizil *et al.,* 2008; Emongor, 2010). Its importance is increasing due to the higher demand for dried flowers in the last two decades of the twentieth century (Ekin, 2005). Stems are normally harvested when colour is visible on most of the flowers and they are one quarter to one half open, as buds do not open well after harvest and freshly cut flowers usually last up to 10 days (Dole *et al.,* 2005). Ekin (2005) reported that in the year 2000, 35.2 million flowering stems of safflower were supplied to the Dutch flower auction and the total value of sales that year reached about € 5.3 million, so that safflower was ranked 39th amongst all cut flowers in terms of commercial importance.

1.1.5 Medicinal and clinical Uses

Safflower is also used for medicinal purposes. In traditional Chinese medicine, safflower petals are regarded as a stimulant for blood circulation, phlegm reduction, healing fractures, contusions and strains (Wang and Li, 1985). Safflower petals are reported to be useful in curing several chronic diseases such as hypertension, coronary heart ailments, rheumatism, male and female fertility problems (More *et al.,* 2005; Rajranshi, 2005) and the seed for the treatment of urinary calculi (Wang and Li (1985). According to Zhou (1986), treatment of infertility with safflower resulted in pregnancy in 56 of infertile women out of 77 women who had been infertile for 1.5-10 years. In dermatology, it is reported that safflower has many beneficial effects including clearing of vitiligo (Pu *et al.,* 1992; Tan, 1989). An alcoholic preparation of safflower and other herbs was completely effective against acne (Liu, 1985). Other medicinal uses of safflower either as topical dust or injections, are said to include a cure for ear infections (Pan, 1986; Wang and Li, 1985), and eye drops for reducing myopia, especially in children (Tao, 1990; Wang and Li, 1985). Safflower oil is non-allergenic, and therefore suitable in injectable medications (Smith, 1996).

Another important and interesting use of safflower seed has recently emerged by means of its genetic modification to produce high-value proteins as pharmaceuticals and industrial enzymes. SemBioSys- a Calgary-based (Canada) company-transforms safflower tissue genetically in order to get the proteins of interest to accumulate in the seed of the mature transgenic plant (Mündel *et al.,* 2004). The process of transformation of safflower tissues follows the patented Stratosome™ Biologics system, which facilitates the genetic attachment of target proteins of interest to oleosin, the primary protein coating the oil-containing vesicles (oil bodies) of the seed. Such attachment permits the target protein to be purified along with the oil body fraction, which upon centrifugation floats to the surface of ground seeds/water slurry (van Rooijen *et al.,* 1992). The purification process of the Stratosome system makes it more efficient than the other transgenic systems. The attachment of proteins to the oil bodies of safflower in the Stratosome Biologics system is expected to stabilize intracellular accumulation of foreign proteins, and also provide a useful attachment matrix and deliver benefits for end use applications. The transgenic safflower plants are used to produce human insulin because the global demand for the hormone has greatly grown (Anon, 2006). According to SymBioSys its safflower- produced insulin can reduce capital costs compared to existing insulin manufacturing (Anon, 2006).

1.1.6 Other uses of safflower

High linoleic acid safflower oil has an important use in the paint industry. Safflower oil is preferred for the paint and varnish industry owing to its specific properties of absence of linolenic acid, presence of high linoleic acid, low colour values, non-yellowing, low free fatty acids, low unsaponifiables, and no wax, which make the quality in paints, alkyd resins, and coatings beyond comparison (Smith, 1996; Berglund *et al.,* 2007). The high linoleic safflower oil is used in the manufacture of high quality coloured paints (Dajue and Mündel, 1996). However, with the development of cheaper petroleum products and a shift to water-based paints, the use of safflower oil in the paint and varnish industry has been reduced drastically in recent times (Singh and Nimbkar, 2006). Safflower oil is also now used as a diesel fuel substitute (Oelke *et al*., 1992; Ogut and Oguz 2006). However, for the latter use, like most vegetable oils, it is currently too expensive. Safflower is also used in cosmetics products such as hair cream, shampoo, face cream, perfume, body lotion (Shouchun *et al.,* 1993). Safflower is considered to be ideal for cosmetics and is used in 'Macassar' hair oil and Bombay 'Sweet Oil' (Weiss, 1971). Carthamin is used to create cosmetics for Geisha and Kabuki artists in Japan, where the colour is called Beni (Nishimura *et al*., 2008).

CHAPTER 2

2.0 SAFFLOWER BOTANY

Safflower (*Carthamus tinctorius* L.) belongs to the family Asteraceae or Compositae. The genus *Carthamus* is comprised of 16 species and is a member of the subtribe Centraureinae, tribe Cardueae (thistles), subfamily Tubuliflorae (López-González, 1989; Kumar, 1991; Vilatersana *et al.,* 2000). The cultivated *Carthamus tinctorius* L has a chromosome number of 2n = 24 (Knowles, 1989; López-González, 1989; Zehra, 2005). Safflower is a branching, thistle-like herbaceous annual or winter annual plant, with numerous spines on leaves and bracts. It has primary, secondary, and tertiary branches, with each branch terminating into a globular capitulum (Figure 1). Safflower plant can grow to a height of 30-210 cm tall with globular flower heads, bright yellow, orange or red flowers. It has a strong tap root that can grow to a depth of 2-3 m, enabling it to thrive under dry climates. Safflower is also grown in regions where rainfall is high and under greenhouse production as a cut flower or vegetable. It can be grown in altitudes ranging from sea level to 2000 m above sea level provided frost does not occur during the elongation and flowering stages plant growth and development in the high altitudes. Safflower is mainly grown in arid and semi-arid regions of the world as an oilseed crop, birdseed or for its flowers, used as dyes and for medicinal purposes (Mcpherson *et al.*, 2004; Emongor, 2010).

Figure 1. Safflower plant showing primary, secondary and tertiary branches with globular capitula.

Figure 2. Safflower (*Carthamus tinctorius L.)* at the start of the elongation phase.

Figure 3. Safflower one week after the start of the elongation phase.

Figure 4. Safflower four weeks after the start of the elongation phase

Figure 5. Safflower branching during the elongation phase.

Figure 6. Safflower at the start of flowering (king capitulum opens first)

Figure 7. Safflower with scarabid bird bettle as one of the pollinators (Botswana).

Figure 8. Safflower seeds (achenes) white in colour.

Figure 9. Safflower plant height (can grow up to 210 cm in winter-Botswana).

Figure 10. Safflower ground petals

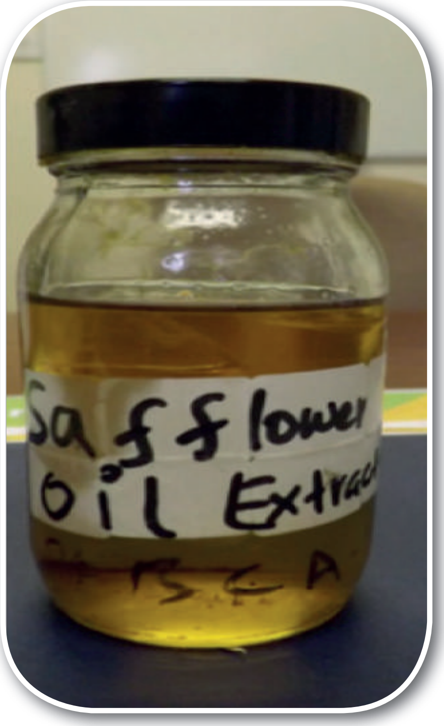

Figure 11. Safflower oil

Figures 2 to 7 show the different stages of growth and development of *Carthamus tintorius* L (safflower). It produces white, shiny, and smooth seeds (achenes), each weighing between 0.01 to 0.444 g (Figure 8) depending on genotype, climatic conditions, agronomic practices and growing season (Dajue and Mündel, 1996; Singh and Nimbkar, 2006; Arslan, 2007; Emongor, 2010). The achenes are four sided, having a thick pericarp, and may or may not have pappus (tufts of hair present on the seed). Germination takes 3-8 days depending on temperature and germination occurs at temperature as low as 2-5°C (Mündel, 1969; Emongor, 2010). Germination is followed by a slow growing rosette stage, during which numerous leaves are produced near the ground level and strong taproots develop. The rosette stage is considered as one of the main phenological phases in the growth of safflower plant (Tanaka *et al.,* 1997; Uslu, 1997). Safflower tolerates a wide range of temperatures from -15 to 40˚C, provided during the elongation and flowering stages of growth and development there is no frost. During the rosette stage, safflower plant can withstand a temperature of -7˚C (Mündel *et al*., 1992; Li *et al*., 1997; Carapetian, 2001; Emongor, 2010; Emongor *et al*., 2013). The duration of the rosette stage in safflower varies from 20 to 35 days depending on genotype, cultural practices, photoperiod and temperature after germination (Weiss, 2000; Emongor, 2010; Emongor *et al*., 2013). Increasing day length from 10 to 14 hours shortened the rosette stage from 39 days to 23 days for various safflower genotypes (Weiss, 1971; 2000). Lower temperature during winter lengthens the rosette period, which is associated with higher grain yields (Insua, 1986; Salera, 1997; Emongor *et al*., 2013). The cold requirement of long rosette safflower causes these plants to develop a very dense clump of leaves in spring planting with a total lack of stem development or delayed stem elongation (Li, 1989; Li *et al*., 1997; Emongor *et al*., 2013). After the rosette stage, the stems elongate rapidly and branch extensively (Figures 2, 3, 4, 5). The branch to angle range from 30 to 70° and the degree of branching is genetically and environmentally controlled (Dajue and Mündel, 1996). Appressed branching is recessive to spreading types and is controlled both digenically (Fernandez-Martinez and Knowles, 1978; Singh, 2005) and monogenically (Deokar and Patil, 1975). Each stem ends with a globular flower capitulum, enclosed by clasping bracts, which are typically spiny (Figure 1, 6, 7). Safflower can grow to a height of 44 cm to 210 cm, depending on planting date, spacing, soil moisture availability, soil fertility, photoperiod and temperature (Figure 9). Time to flowering is genetically controlled, but genotype and environment interact with day length, and flowering can be accelerated by high temperatures (Weiss, 2000). Flowering begins from the primary capitulum, then secondary capitula and so forth. Within a capitulum, flowering begins in the outer circle of florets and progresses centripetally towards the centre of the capitulum. The flowering period lasts 4-6 weeks depending on the cultural practices and climatic conditions especially temperature. Shades of orange, yellow and red flowers are produced. The pollen of safflower is yellow. Pollination occurs as the style and stigma protrude out of the fused anther tube. Unpollinated stigma remains receptive for several days. The florets are tubular and largely self-pollinating (Knowles, 1969). Safflower, is diploid with 12 chromosome pairs (Ashri and Knowles, 1960) and is predominately self-pollinating species, but has the potential for considerable outcrossing with pollen transfer by a variety of insects (Butler *et al*., 1966; Rudolphi *et al*., 2008). Moreover, the degree of outcrossing depends on genotype and environment. The thin-hulled trait has a pleitropic effect on anther dehiscence which deters pollen collectors, which prefer lines with normal hull morphology or anatomy (Rubis *et al*., 1966; Weiss, 2000). High temperatures during pollination can reduce the time that pollinators spend collecting pollen, which can decrease the amount of outcrossing (Ahmadi and Omidi, 1997). Outcrossing in safflower has been reported to range from 0 to as high as 59% in different genotypes (Knowles, 1969; Patil *et al*., 1987). The outcrossing in genetic male-sterile lines in safflower is reported to be 100%, as no difference in seed yield of male-sterile and male-fertile plants under open pollination was observed (Singh, 1996). Safflower pollen is transferred by insects and not by wind. The most prevalent pollinator agent in safflower is honey bees. Bees visit the safflower flowers for both pollen and nectar. Bumblebees, beetles and other insects also promote the level of cross-pollination (Figure 7). Bumblebees, beetles and other insects also promote the level of cross-pollination (Figure 7). Each safflower capitulum produces 13 to 71 seeds (achenes), which mature in 4-5 weeks after flowering.

Safflower seed is composed of 33-60% hull and 40-67% kernel (Dajue and Mündel, 1996; Pahlavani, 2005). The seed oil content ranges between 20 to 45% depending on the variety and growing environment. Leaf size varies significantly among varieties and even within the individual plant, but ranges between 2.5 to 5 cm wide and 10 to 15 cm long. Leaves are usually deeply serrated on the lower stem, but short and stiff, ovate to obovate around the inflorescence, where they form the involcral bracts (Dajue and Mündel, 1996). Lower leaves are generally spineless, but further up the stem spines develop in the bud stage and become strong, hard spines by full flowering. Varieties that are spineless have been developed for cut flower and seed production, and petal harvest for medicinal purposes in China and India (Dajue and Mündel, 1996).

CHAPTER 3

3.0 SAFFLOWER PRODUCTION

3.1 Introduction

Safflower (Carthamus tinctorius L.) as a species is very diverse and adaptated to many semi-arid regions of the world (Mündel *et al.,* 1997a). Knowles (1989) described three general climatic areas to which safflower is most adapted: 1) areas like south central India, where the crop is autumn-sown in October or November into heavy soils moist from summer rains or irrigated and harvested in the dry spring; 2) areas that have a Mediterranean type climate like Australia, Mexico, Spain, Middle East countries, California in the USA, where typically the winters are moist and the summers are dry; and 3) areas that have a climate similar to the Northern Great Plains of the USA and Canada, where safflower is sown in the spring and harvested in the dry fall months of September and October. Safflower can also be grown in Southern Africa (Botswana, Republic of South Africa, Angola, Namibia and Swaziland) during summer under rain-fed conditions and in winter under irrigation. Safflower is an ancient multipurpose oil seed crop, grown for its seeds, and used for colouring and flavouring foods, making red (carthamin) and yellow (carthamidin) dyes used in the textile industry, medicinal purposes, vegetable, cut flower, forage crop and an oil crop (Li and Mündel, 1996; Ekin, 2005; Kizil *et al.,* 2008; Emongor, 2010; Kisha and Johnson, 2012; Moatshe *et al.,* 2016). Currently, safflower seeds are used in the production of high quality edible oil, industrial oil and bird feed (Knowles, 1989; Bergman *et al.,* 2007; Emongor *et al.,* 2016), biofuel (Bergman and Flynn, 2009), speciality oil types to improve human diet (Velasco and Fernández-Maryinez, 2004), and, because of the ease with which oleosin proteins are isolated from safflower seed (Lacey *et al.,* 1998), production of transgenic pharmaceuticals (McPherson *et al.,* 2004; Mündel and Bergman, 2009) is done. Spineless genotypes have been used as cut flowers in Western Europe, Japan, Latin America and Kenya (Ashri, 1975; Emongor, 2010). Safflower can be grazed by animals and stored as hay or silage (French *et al.,* 1988; Smith, 1996; Bar-Tal *et al.,* 2008), it makes an acceptable livestock forage if cut at or just after bloom (Berglund *et al.,* 2007), and the oil cake is a valuable animal feed (Weiss, 2000).

3.2 Origin of Safflower

Safflower is probably native to an area bounded by the eastern Mediterranean and Persian Gulf, Eastern Europe, Central Asia and Abyssinia [Ethiopia and Eritrea] (Vavilov, 1951; El-Bassam, 2010). Its seeds have been found in Egyptian tombs over 4,000 years ago, and its use was recorded in China over 2200 years ago (Weiss, 2000). After the breeding of high yielding cultivars, it is now grown in many countries of the world such as United States of America, Canada, Mexico, Argentina, India, Pakistan, Eastern European Countries, Kazakhstan, Ethiopia, Kenya, Australia, Uzbekistan, Afghanistan, China, Turkey, Egypt, etc. India, Mexico and USA are the major producers of safflower (Rowland, 1993). In the whole world, India is the largest producer of safflower (*Carthamus tinctorius* L.), producing one third of the world's production and uses it mainly for oil production (Rowland, 1993, Kedikanetswe, 2012; Emongor *et al.*, 2013). Mexico also produces large quantities of safflower oil for domestic consumption and export (Bassil and Kaffka *et al.*, 2001). The area under safflower production in China is in the range of 35,000-55,000 ha mainly for medicinal purposes and producing 50,000-80,000 tons of seeds annually (Esendal, 2001; FAO, 2010). In Africa, Ethiopia (72,000 ha) is the virtual producer with production estimated at 34,000 tons per annum (Rowland, 1993).

3.3 Ecological Requirements

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 -7-15 °C, depending on the genotype or variety (Li, 1989; Mündel *et al.*, 1992; Li *et al.*, 1997; 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, 2002; 2007).

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; FAO, 2010). Optimum precipitation of between 600 to 1000 mm per annum (Marchione and Corleto, 1993; Corleto *et al.*, 1997). 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, 1996). 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 Maiti, 1990). A dry period is necessary for ripening (FAO, 1988). 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).

3.4 Plant density

3.4.1 Effects of plant density on plant growth, development and yield

The aim in plant density is to obtain the correct plant population per unit area in order to maximize yield by fully exploiting the environment. Establishing correct plant population ensures that the crop produced is of acceptable quality with regards to size, oil content and yield (Ngugi *et al*., 1990). Desirable plant density and ultimate best plant density depends on factors such as type and growth habit of the crop, soil fertility, rainfall, purpose for which the crop is grown and accessibility (Ngugi *et al*., 1990; Emongor *et al*., 2013; 2015). As plant population increases per unit area, a point is reached at which each plant begins to compete for certain essential growth factors such as nutrients, sunlight and water. The effect of increasing competition is similar to decreasing the concentration of a growth factor. Yield should be interpreted in both quantitative and qualitative terms. The value of the total yield is not merely the total bulk, but is related to quality of the yield (size per unit, colour, appearance and oil composition). The optimum population is the one that produces the greatest returns to the grower (farmer) per unit area.

Light has a pronounced effect on stem growth. In the dark, etiolation is extreme. Internodes of shaded plants such as in the dense stands are more etiolated (Gardner *et al*., 1985). This means plants in dense stands (high population) have most of their internodes in the shade. This will contribute to etiolation taking place making the plants to grow taller. Growing tall could also be because there is competition for light.

As the plants compete for this essential factor light, each of them will tend to grow taller to intercept light. When the population is not high, it is expected that competition for light is not high and each plant will receive the right amount of light that it will need for its biochemical processes to make food (Gardner *et al.,* (1985).

It is also expected that when plant density is high, nutrient elements in the soil may not be enough for all the plants, therefore resulting in competition. Increase in nutrient competition may affect plant growth. The plants may not grow to their full height because indispensable elements will not be adequate. For instance, when an element like nitrogen is in short supply the result is stunted growth. Not only nitrogen may be in short supply when crop stand is high. Essential elements such as potassium and phosphorus may also be inadequate causing poor root development which results in poor water and nutrient absorption and may cause stunting. It is also expected that high plant density depletes water in the soil resulting in competition for the same. When water is in short supply for plants, growth is affected. The plants may grow slowly and ultimately get stunted. Shortage of water may cause plants to mature early in preparation for making new seeds. Therefore, high plant density may affect maturity time frame.

3.4.2 Effects plant density on the growth and development of safflower

Safflower plant density varies greatly among countries. The plant density adopted is influenced by the variety, climatic factors and cultural practices. When soil moisture is not limiting, safflower compensates for low plant density by increased branching and other yield components adjustments (Mündel, 1969). Proper plant population is important for optimum production of safflower in order to design a management system which allows maximum expression of genetic potential of the crop under different climatic conditions. Plant population also plays an important economic role, as seed price is an important part of the total production cost.

Moatshe *et al*. (2016) researching in Botswana reported that there was a significant ($P < 0.0001$) interaction between genotype and plant density of safflower for all the variables studied in winter or summer growing seasons. Plant height significantly ($P < 0.0001$) increased with increase in plant density from 62,500 (40 cm x 40 cm) to 100,000 (40 cm x 25cm) plants/ha, thereafter plant height reduced as plant density increased from 125,000 (40 cm x 20 cm) to 200,000 (25 cm x 20 cm) plants/ha across the different genotypes, irrespective of season (Moatshe *et al.,* 2016). Plant density of 100,000 (40 cm x 25 cm) plants/ha produced the tallest plants, irrespective of genotype, but the genotype Sina recorded the tallest plants of 172.63 cm in winter and 122.22 cm in summer (Moatshe *et al.,* 2016). Safflower plants grown in winter were significantly ($P < 0.0001$) taller than summer plants with seasonal plant height differences of 29.20%, 40.06%, 46.25%, 37.77% and 39.22% for the genotypes Sina, Gila, Kiama, PI-527 710 and PI-537 636, respectively (Moatshe *et al.,* 2016). Similar results had earlier been reported by Emongor *et al*. (2013; 2015). Emongor *et al*. (2013; 2015) in Botswana reported that increasing safflower plant density from 100,000 plants /ha to 250,000 plants /ha grown in winter and summer, significantly reduced plant height by

21.3 and 13.2 %, respectively. Safflower plants grown in summer were significantly shorter (P < 0.001) than plants grown in winter (Emongor *et al*. 2013; 2015). Safflower plants grown in winter were significantly taller by 35.2% than plants grown in summer (Emongor *et al.,* 2013; 2015). Oad *et al*. (2002) reported that as safflower plant density increased from 74,074 (45 cm x 30 cm) to 266, 667 (25 cm x15 cm) plant height decreased. The average plant height for the densities 74, 074, 129,870 and 266, 667 plants per hectare were 131, 126 and 120.23 cm, respectively (Oad et al., 2002). Similar results have been reported by Qayyum *et al*. (1986). Qayyum *et al*. (1986) reported that safflower height decreased with increase in plant density. However, Abel (1976) reported that safflower planted at a density of 430,547 plants per hectare were taller by 3 cm than plants at a density of 258,328. Miller and Fick (1978) also reported that plant height in safflower increased as plant density increased.

Plant density significantly influences safflower plant dry weight (Emongor *et al*., 2013; 2015). Increasing plant density from 100,000 plants/ha to 250,000 plants/ha, reduced plant dry weight by 50 % (Emongor *et al*., 2013; 2015). Safflower plants grown in winter had significantly higher dry matter than plants grown in summer (Emongor *et al*., 2013, 2015). Safflower plants grown in winter were significantly heavier by 17% than plants grown in summer (Emongor *et al*., 2013; 2015). Safflower plant density has a significant effect on plant biomass (Blackshaw, 1993). Increasing safflower plant density from 10 to 160 plants/m^2 increased shoot biomass production (Blackshaw, 1993). The differences in biomass due to density were evident 6 weeks after emergence and remained evident until maturity (Blackshaw, 1993). Blackshaw (1993) further reported that the effect of safflower plant density on canopy light interception was greatest early in the growing season prior to stem elongation. This is a critical time for safflower since many weeds become established during this period (Mündel *et al*., 1992) and subsequent competition is strongly influenced by development during this early growth phase.

3.4.3 Effects of plant density on yield components of safflower

The yield components of safflower are plant height, branch number/plant, achene number/capitulum, achene number/plant, capitula number/plant, achene weight and biological yield (Moatshe *et al*., 2016; Emongor *et al*., 2013, 2015; Gonzalez *et al*., 1994). Kedikanetswe (2012) reported that the yield components of safflower were capitula number/plant, capitula size, number of achenes (seed)/capitula, and achene weight (100-seed weight). The optimum plant population required in achieving the maximum achene and oil yield depends on the interaction of genotype, environment and other factors of production that will allow full agronomic expression of a given cultivar (Moatshe *et al*., 2016; Gonzalez *et al*., 1994). This interaction requires an evaluation of the safflower management system, including the response of safflower cultivars to plant density.

Moatshe *et al*. (2016) reported that capitula number/plant significantly increased with increase in plant density from 62,500 to 100,000 plants/ha across genotypes and seasons, then decreased when plant density was increased above 100,000 plants/ha. The genotype Sina had the highest capitula number/plant compared to other genotypes, irrespective of plant density or season (Moatshe *et al*., 2016). All genotypes produced more capitula number/plant in winter than summer with exception of PI-527710 which had a higher capitula number/plant in summer than winter (Moatshe *et al*., 2016). Emongor *et al*. (2013, 2015) reported that increasing safflower plant density from 100,000 to 250, 000 plants/ha, reduced capitula number/plant by 39.5 and 50.5%, in winter and summer, respectively. Safflower plants grown in summer had significantly ($P < 0.001$) fewer capitula than plants grown in winter (Emongor *et al*., 2013, 2015). Gonzalez *et al*. (1994) reported that even though capitula number is genetically controlled, it does respond with various degrees of flexibility to plant density. Increasing safflower plant density from 247, 000, 494,000 to 741, 000 plant/a, significantly reduced number of capitula produced per plant from 9.3, 6.4 and 4.7, respectively (Gonzalez *et al.,* 1994). Similarly, Baghdad-Abadi and Ehsanzadeh (2000) reported that increasing safflower plant density from 166, 000 to 500, 000 plants/ha significantly reduced the number of capitula produced per plant. Oad *et al*. (2002) reported that increasing safflower plant density from 74, 074 (45 cm x 30 cm), 129, 870 (35 cm x 22 cm) to 266, 667 (25 cm x 15 cm) plants/ha significantly reduced the number of capitula per plant to 59.00, 39.35 and 18.15, respectively. Nasr *et al.,* (1976) in a two year study reported that increasing safflower plant density from 133, 333 to 533, 333 plants per hectare reduced the number of capitula produced per plant. Increasing plant density from 133, 333 to 533, 333 plants /ha, reduced capitula number on average by 31-47%, depending on the year of study (Nasr *et al.,* 1976). The reduction in capitula number/plant was attributed to competition for plant growth resources such as light, nutrients and water (Oad *et al.,* 2002).

As plant density increased from 62,500 to 100,000 plants/ha, seed number/capitulum significantly increased, thereafter decreased as plant density increased across genotypes and seasons (Moatshe *et al*., 2016). There was a 34.43, 39.40, 26.62, 38.80, 40.73% reduction in seed number/capitulum as plant density increased from 125,000 to 200,000 plants/ha for Sina, PI-527710, PI-537636, Kiama and Gila, respectively, in winter (Moatshe *et al*., 2016). While in summer seed number/capitulum decreased by 25.43, 26.79, 3517, 28.36 and 32.51% when plant density increased from 125,000 to 200,000 plants/ha for Sina, PI-527710, PI-537636, Kiama and Gila, respectively (Moatshe *et al*., 2016). Emongor *et al*. (2013) reported that plant density significantly ($P < 0.05$) affected the number of seeds/capitulum. Increasing plant density from 100, 000 to 250, 000 plants/ha significantly ($P < 0.01$) reduced seed number per capitulum in safflower grown both in winter and summer (Emongor *et al*., 2013). The reduction in seed number /capitulum was 45 and 39% in winter and summer, respectively (Emongor *et al*., 2013). Safflower plants grown in winter produced more seeds per capitulum than summer grown plants (Emongor *et al*., 2013). Gonzalez *et al*. (1994) reported that number of seeds per capitulum was influenced by plant density. Increasing safflower plant density from 247,000 to 741,000 plants /ha reduced the number of achenes produced per capitulum from 24.8 to 20.1, respectively (Gonzalez *et al*., 1994). Abel (1976) reported that increasing safflower plant density from 258, 000 to 431,000 plants/ha reduced the number of achenes per capitulum from 27 to 25, respectively. Blackshaw (1993) reported that increasing safflower plant density from 100, 000 to 700,000 plants /ha increased the number of achenes /capitulum produced and remained constant after wards showing no effect of safflower plant density on seed yield after a density of 700, 000 plants/ha.

Moatshe *et al.* (2016) reported that increasing plant density from 62,500 to 100,000 plants/ha significantly (P<0.0001) increased thousand-seed weight. The increase ranged between 17.42-45.62% in winter and 15.37-31.55 % in summer in all the genotypes under study. As plant density increased above 100,000 plants/ha, thousand-seed weight decreased by 34.43, 39.40, 26.62, 38.80 and 40.73% in winter in all genotypes. While in summer thousand-seed weight decreased by 25.43, 26.79, 35.17, 28.36, 32.51% for Sina, PI-527710, PI-537636, Kiama and Gila, respectively (Moatshe *et al.*, 2016). Among genotypes, PI-537636 had highest thousand-seed weight of 53.33 g in winter , while in summer Sina had a thousand-seed weight of 45.40 g as the highest weight compared to other genotypes. Emongor *et al.* (2013) reported that plant density did not have a significant effect on 100–seed weight of safflower. However, lower plant densities tended to have a higher 100–seed weight than higher plant densities (lower than 133, 333 plants/ha). Increasing plant density from 62,500 to 100,000 plants/ha significantly (P < 0.0001) increased safflower biological yield across all genotypes under study and growing seasons (Moatshe *et al.*, 2016). However, as plant density increased above 100,000 plants/ha, biological yield significantly (P<0.0001) decreased both in winter and summer grown safflower (Moatshe *et al.*, 2016). The biological yield was significantly (P < 0.0001) higher in winter than summer, with variations ranging between 7.43-15.16 % from winter to summer across genotypes (Moatshe *et al.*, 2016; Emongor *et al.*, 2013). The decrease in the yield components with increase in plant density was attributed to inter and intra plant competition for light, nutrients and water necessary for growth and development (Emongor *et al.*, 2013; Moatshe *et al.*, 2016).

3.4.3 Effects of plant density on seed yield of safflower

There was a significant interaction between plant density and safflower genotypes as they affected seed yield (Moatshe *et al.*, 2016). Seed yield significantly (P < 0.0001) increased as plant density increased from 62,500 to 100,000 plants/ha (Moatshe *et al.*, 2016). However, as plant density increased above 100,000 plants/ha, safflower seed yield significantly (P < 0.0001) decreased among all genotypes and between seasons (Moatshe *et al.*, 2016). Emongor *et al.* (2013) reported that increasing plant density of safflower from 100,000 to 250,000 plants/ha significantly (P < 0.0001) decreased seed yield. In seasons 1 and 2, increasing plant density from 100, 000 plants /ha to 250, 000 plants /ha, reduced seed yield by 67.9 and 69.8%, respectively (Emongor *et al.*, 2013). There was also significant (P < 0.0001) differences between winter and summer grown safflower with respect to seed yield (Moatshe *et al.*, 2016; Emongor *et al.*, 2013). Winter grown safflower significantly (P < 0.0001) produced higher seed yield than summer among all genotypes under study (Moatshe *et al.*, 2016; Emongor *et al.*, 2013). Safflower plants are reported to have a high capacity to compensate for seed yield in relation to increasing plant density (Gonzalez *et al.*, (1994). As plant population density increased, achene (seed) yield per plant decreased (Gonzalez *et* *al.* 1994), with maximum achene yield per plant obtained at the lowest plant density of 247, 000 plants/ha. Increasing safflower plant density from 247, 000 to 741, 000 plants/ha, decreased seed weight by 4.2 % (Gonzalez *et al.* 1994). However, plant population density did not influence safflower seed yield/ha (Gonzalez *et al.* 1994). The stability in seed yield across all plant population (247,000, 370, 500, 494, 000, 617, 500 and 741, 000 plants/ha) was attributed to compensatory effect produced by the changes in number of plants per unit area and yield/plant (Gonzalez *et al.* 1994). There was a highly significant cultivar and environmental interaction on safflower seed yield (Gonzalez *et al.* 1994). From a 3-year study in Nebraska, Peterson (1965) reported that as safflower plant density increased from 300, 000 to 600, 000 plants/ha, achene (seed) yield decreased. Alessi *et al.* (1981) reported similar results when they obtained a highest safflower seed yield at a plant population of 217, 000 plants/ha compared to 1, 280, 000 plants/ha. Oad *et al*. (2002) reported that increasing safflower plant density from 74, 074 to 266, 667 plants/ha decreased seed yield/ha by 37%. The highest seed yield was obtained with a safflower plant density of 74, 074 plants/ha (45 cm x 30 cm). Abel (1976) reported no yield differences between safflower plant population of 258, 000 and 431, 000 plants/ha; their analysis of yield components indicated that fewer achenes per capitulum and lighter achenes were produced at the higher plant population.

The reduction in seed yield with increase in plant density was attributed to mutual competition for nutrients, water and sunlight. Mutual shading resulting from high plant density was believed to have led to light being the limiting factor to high seed yield. In safflower plants with plant density greater than 100, 000 plants/ha, the photosynthetic rate and NAR rate were decreased as evidenced by reduction in leaf number and plant biomass (dry matter) as plant density increased. The reduction in safflower seed yield due to increasing plant density was also explained by the reduction in capitula size, capitula number/plant, achene number per capitulum and achene weight (100-seed weight) which are the primary yield components of safflower. Peterson (1965) reported that as safflower plant density increased from 300, 000 to 600, 000 plants/ha, seed (achene) yield decreased. Alessi *et al.* (1981) reported similar results when they obtained the highest safflower seed yield/ha at a plant density of 217, 000 plants/ha compared to 1, 280, 000 plants/ha. Oad *et al.* (2002) reported that increasing safflower plant density from 74, 074 to 266, 667 plants/ha decreased seed (achene) yield/ha by 37%. The higher seed yield obtained in winter grown safflower irrespective of plant density than summer grown safflower could be explained by the longer growth and maturation period (138 days after emergence) in winter, resulting in higher dry matter accumulation and partitioning to grain formation. The higher average temperatures in summer resulted in faster growth and maturation period (116 days after emergence) which resulted in low dry matter production and seed yield (Emongor *et al.*, 2013).

Safflower seeding rates vary greatly around the world, seeding rate or plant density depends on variety growth habit, growth environment and cultural methods, particularly row spacing. As long as soil moisture reserves are present, safflower compensates for low plant populations by increased branching and other yield component adjustments (Kedikanestwe, 2012; Emongor *et al.*, 2013; Moatshe *et al.*, 2016). Seeding rates for optimum production vary from around 10-15 kg/ha in very drought prone regions (semi-arid regions), or those where branching is to be encouraged, up to 40-45 kg/ha or even more for irrigated environments, in regions and with varieties showing minimal branching. In semi-arid regions the recommended spacing should be 40-45 cm between rows and 25-30 cm within rows (Emongor *et al.*, 2013; Emongor *et al.*, 2015; Moatshe *et al.*, 2016).

Safflower does not require any specialized equipment to be farmed successfully. In developed parts of the world, 15–70 kg of seed are planted per hectare, with the lower ranges being planted either because moisture is a limiting factor or because the crop is to be managed in cultivated rows. In areas with only 250–400 mm of annual rainfall, 15 kg of seed are planted with a grain drill, much as a crop of wheat would be picked. In an area where plentiful irrigation water is available, a 20 kg of seed may be planted per hectare. Seed may be planted in three or four drilled or precision-planted rows on an elevated bed. In areas where moisture is plentiful, 35–70 kg of seed may be planted per hectare; the higher rate is used to ensure that weeds do not gain a competitive edge.

In conclusion, under semi-arid conditions (250 mm of precipitation per annum) with supplemental irrigation at the start of flowering, a spacing of 40 cm between rows and 25 cm within the row gives optimum seed and oil yield (Emongor *et al.*, 2013). Safflower is a very plastic crop and can modify its architecture according to the space available (Emongor *et al.*, 2013; Moatshe *et al.*, 2016).

3.5 Weed control

Weed control in safflower is an important management practice to maximize seed production. Safflower seedlings spend three to six weeks in the rosette stage of growth, a period of time when as many as six or seven leaves develop without substantial plant elongation (Tanaka *et al.*, 1997; Uslu, 1997; Carapetian, 2001; Emongor, 2010). During the rosette stage of growth, safflower is a poor competitor with weeds. The rosette state lasts four to six weeks, allowing weeds to become established before the plants can shade the soil surface. Safflower is not a good competitor with weeds and competition at the rosette stage is detrimental to yield. Blackshaw *et al.* (1990) showed in a three-year study that broad-leaved weeds in safflower reduced seed yield by 58-73%. Do not attempt to grow safflower without a good weed control program. Many herbicides have been tried on safflower as a means of controlling both grassy and broadleaf weeds. The following herbicides can be used for weed control in safflower: metolachlor (Eptam or EPTC), trifluralin (various brand names), ethalfluralin (Sonalan), Dual/generic S/ metolachlor, Harmony SG (thifensulfuron), sethoxydim (Poast), Select Max (clethodim) and Select/generic clethodim. Preharvest herbicides: Roundup/generic glyphosate, Valor+ MSO adjuvant (flumioxazin) and Drexel Defol (sodium chlorate) (Blackshaw *et al.*, 1990). Post-emergence herbicides that control broadleaf weeds and can be applied successfully to safflower with little or no crop injury include chlorsulfuron, metsulfuron and thiafensulfuron (Anderson, 1985; Riveland and Bradbury, 1993; Riveland *et al.*, 1993; Wichman, 1987; Wichman *et al.*, 1987, 1988). These post-emergence herbicides will control the hard-to-control weeds such as *Kochia scoporia* L. (kochia) and *Salsola iberia* L. (Russian thistle). Grassy weeds can be controlled with sethoxydim, clethodim and quizalofop (Wichman, 1987; Riveland, 1993). Perennials weeds such as Canada thistle and perennial sow thistle can be serious problems. Safflower should not be grown on fields with heavy infestations of perennial weeds. If weeds emerge before the safflower, harrowing with a light spike tooth or light coil spring harrow may control some weeds, but damage to the emerging safflower can occur. When irrigated safflower is planted in wide rows (40 to 45 cm), early cultivation between the rows before stem elongation will kill most small weeds. After stem elongation, cultivation may be used to move soil into the row to cover small weeds in the row.

3.6 Intercropping and cropping systems

One of the more innovative techniques to increase farmer awareness of safflower and also increase production in non-traditional growing regions is intercropping with other crops (Mündel *et al.*, 1997). Nikam (1987) in India intercropped safflower with chickpea and obtained a higher return than either monocrop. He used a 5:1 row ratio of chickpea:safflower. He also intercropped sorghum and safflower successfully, growing safflower in every fourth row. Intercropping of safflower with chickpea, coriander and linseed in 2:1 row ratio increased net returns substantially compared to their respective sole crops in Andhra Pradesh, India (Hegde and Koli, 1997). Sawant *et al.* (1993) intercropped safflower with gram and linseed and found that a row ratio of 6 rows linseed to 2 rows safflower was most profitable. Safflower alone and in combination with gram and linseed appeared to be more profitable than the monoculture (Sawant *et al.*, 1993). Li (1993) intercropped maize and safflower, and found that the intercrop was more profitable than either monoculture. Safflower attracted many insects such as green lacewing and lady beetles, a large number of which were natural enemies to maize pests (Li, 1993). Other crops that have been intercropped successfully with safflower include lentils, amaranthus, mustard and toria (*Brassica rapa* L.) in India and sweet potato, cotton, buckwheat, cabbage and cauliflower in China (Zheng *et al.*, 1993; Yang *et al.*, 1993).

3.7 Safflower nutrition

3.7.1 Rotation

Safflower most often is grown on re-crop or in rotation with small grains or fallow and annual legumes. Volunteer grain from the previous crop may be a problem when safflower follows cereals. Volunteer grain is controlled easily with registered grassy weed herbicides such as Poast or Select Max. Safflower should not follow safflower in rotation or be grown in close rotation with other crops susceptible to the disease Sclerotinia (white mold). These crops include dry bean, field pea, sunflower, mustard and canola. Reduced tillage and/or chemical fallow is advisable to preserve residue and reduce erosion when summer fallowing after safflower.

3.7.2 Fertilizer requirements

Safflower requires adequate supply of nutrients for its full production potential even under limiting moisture conditions (Rao, 1985; Kubsad *et al*., 2001). The yield levels obtained in research farms are an indication that the productivity can be increased to a great extent if proper technology is used. It is however, known that farmers are unable to adopt the entire package as per recommendation due to certain difficulties, sometimes beyond their control.

3.7.2.1 Effects of nitrogen and phosphorus on vegetative growth of safflower

3.7.2.1.1 Nitrogen

Tunçtürk and Yildirim (2004) reported that application of N at 40, 80, and 120 kg/ha significantly ($P < 0.05$) increased safflower plant height compared to control plants, with 120 kg N/ha producing the tallest plants. They further reported that N in the form of ammonium nitrate significantly ($P < 0.05$) increased safflower plant than ammonium sulphate or urea. Siddiqui and Oad (2006) reported that application of N to safflower at 30, 60, 80, 120, 150, and 180 kg/ha increased plant height and branches number per plant than control plants, but these variables peaked at 120 kg N/ha. Application of N above 120 kg/ha had no significant ($P > 0.05$) effect on safflower plant height and branch number (Siddiqui and Oad, 2006). However, increasing application of N from 30 to 180 kg/ha, significantly ($P < 0.05$) delayed safflower crop maturity by 3.34-24.34 days compared to plants with no N application (Siddiqui and Oad, 2006). Strašil and Vorlíćek (2002) in the Czech Republic reported that N application at 40 or 80 kg/ha had no effect on safflower plant. Similar results were reported by Malek and Ferri (2014) and Haghighati (2010) who reported that application of 30, 60 or 90 kg N/ha had no significant ($P > 0.05$) effect on plant height of safflower. While, Taleshi *et al*. (2012) reported that application of N at 84, 120 and 154 kg/ha increased primary and secondary branch number by 31% and 44%, respectively compared to control plants. Haghighati (2010) reported that of N application at 30, 60 and 90 kg/ha increased safflower plant biomass by 13.4, 15.3, 22.9%, respectively, compared to control plants. In another study increasing N application from 0 to 300 kg/ha improved ensiling quality of safflower by improving the aerobic stability, lactic acid production and smaller fermentation losses (Weinberg *et al*., 2007). Increased supply of N enhanced total dry matter production and accumulation in various plant parts, explaining the increase in safflower vegetative growth (Weinberg *et al*., 2007; Mündel *et al*., 1997). Nitrogen is an integral part of amino and nucleic acids, proteins, nucleotides, chlorophyll and all enzymes (Weinberg *et al*., 2007; Mundel *et al*., 1997). Increased supplies of N, leads to increased leaf area index and thereby increased light absorption, enhancing total dry matter production and accumulation in various plant parts, explaining the increase in safflower vegetative growth (Weinberg *et al*., 2007; Mündel *et al*., 1997).

Application of N at 0, 25, 50, 75, 100, 125, 150 and 175 kg/ha had significant ($P < 0.05$) effect on safflower physiology and productivity (Mohamed *et al.*, 2012). Increasing N to 100 kg/ha significantly ($P < 0.05$) increased the assimilation and transpiration rates, stomatal conductance and leaf area index (LAI) by 42, 32, 52 and 42%, respectively, compared to control plants (Mohamed *et al.*, 2012). The above ground dry weight and water use efficiency (WUE) increased by an average of 42 and 41% on N applied safflower plants compared to control plants (Mohamed *et al.*, 2012). Chlorophyll a, b and total chlorophyll contents at anthesis were significantly ($P < 0.05$) influenced by N application of 25, 50, 75, 100, 125 and 150 kg/ha, however, application of N above 150 kg/ha had no effect ($P > 0.05$) on chlorophylls a and b, and total chlorophyll contents (Mohamed *et al.*, 2012). Dordas and Sioulas (2008) reported that safflower plants treated with N had increased net assimilation rate by 51% compared to control plants. Nitrogen fertilization at 100 and 200 kg/ha increased safflower biomass at anthesis by an average of 24% and at maturity by an average of 25% compared with control plants (Dordas and Sioulas, 2009). Nitrogen application also increased dry matter partitioning in leaves and stems of safflower (Dordas and Sioulas, 2009).

3.7.2.1.2 Phosphorus

Phosphorus is the most limiting nutrient for crop growth and yield in many regions of the world (Rodríguez *et al.*, 1999) including Botswana (Emongor and Mabe, 2012), and application of P fertilizer represents an important measure to correct nutrient deficiencies and to replace nutrients having removed in the products harvested (Dambroth and El-Bassm, 1990). Abbadi and Gerendás (2011) reported that application of P to safflower at 0.04, 0.08, 0.024 and 0.72 g/pot in 2004 and 0.25, 0.5, 1 and 2 g/pot in 2005, significantly ($P < 0.05$) increased plant growth and morphology (stem diameter, leaf dry matter and stem dry matter). Maximum total dry matter of safflower was obtained with application of 1 g P/pot (Abbadi and Gerendás, 2011). Application of P at 50, 75 or 100 kg P_2O_5/ha to safflower plants increased plant biomass by 2.8 to 9.4% compared to control plants, depending on the irrigation regime and stage of safflower plant growth and development when irrigation regime was applied (Arani *et al.*, 2011). The highest plant biomass was obtained with application of 100 kg P_2O_5/ha, irrespective of irrigation regime and stage of plant growth and development when irrigation regime was applied (Arani *et al.*, 2011). Golzarfar *et al.* (2011) found similar results when they reported that application of P to safflower at 50 or 100 kg P_2O_5/ha significantly ($P < 0.01$) increased plant height, stem diameter, number of branches/plant and plant biomass compared to control plants. The highest plant height, stem diameter, number of branches/plant and plant biomass was obtained with application of 100 kg P_2O_5/ha (Golzarfar *et al.*, 2011). Singh and Singh (2013) reported that P application at 40 or 80 kg P_2O_5/ha significantly ($P < 0.05$) increased safflower plant biomass and P uptake by 24.6-31.2% and 17.9-35.3%, respectively, compared to control plants. Application of 40 and 80 kg P2O5/ha to safflower plants also increased the uptake of N and sulphur (S) by 17.0-24.1% and 11.5-23.8%, respectively, compared to control plants (Singh and Singh, 2013). However, Haghighati (2010) reported that application of P at 30 or 60 kg/ha had no significant ($P > 0.05$) effect on safflower plant height and biomass.

3.7.2. 3 Yield components

The yield components of safflower are days to 50% flowering, capitula number/plant, capitulum size, number of achenes (seed) per capitula, and achene weight (100-seed weight) (Gonzalez *et al*.; 1994; Kedikanestwe, 2012; Emongor *et al*., 2013). Even though yield components are under genetic control, they do respond with various degrees of flexibility to cultural practices (Gonzalez *et al*., 1994; Emongor *et al*., 2013).

3.7.2.3.1 Effects of nitrogen and phosphorus on the yield components of safflower

3.7.2.3.1.1 Nitrogen

Sufficient N supply increases leaf expansion resulting in increased interception and efficient utilization of solar radiation leading to greater accumulation of dry matter in the leaves and shoots, increased yield components and yield of crops (Ahmed *et al*., 2007). Bonfim-Silva *et al*. (2015) reported in a pot experiment, application of N at 60, 120, 180, 240 and 300 mg/dm^3 to safflower plants increased the capitula number/plant (61.79%) compared to control plants and the response was quadratic to increasing N application rate. Safflower plants applied with 180 mg N/dm3 produced highest capitula number of 18/plant. Abd El-Mohsen and Mahmoud (2013) reported that application of 0, 40, 80 and 120 kg N/ha to safflower plants significantly ($p < 0.05$) increased 1000-seed weight, capitula number/plant and days to 50% flowering and the response was quadratic to increasing N application rate. Application of 80 kg N/ha gave the highest 1000-seed weight and capitula number/plant. Application of N beyond 80 kg/ha resulted in a decrease in all the yield components traits (Abd El-Mohsen and Mahmoud, 2013). Elfadl *et al*. (2009) reported that variance components for agronomic traits, yield components and yield were significantly ($P < 0.05$) influenced by the environment. Nitrogen application at 0, 40 and 80 kg/ha only had a significant ($P < 0.05$) increase on 1000-seed weight compared to control, but N application had no effect number of seeds/plant, harvest index, number of capitula/plant and number of seeds/capitulum (Elfadl *et al*., 2009). Soleimani (2010) reported that the application of N at 50, 75, 100, 125, and 150 kg/ha significantly ($P < 0.05$) increased 1000-seed weight and number of seed/capitulum, and the response was quadratic to increasing N application rate. Application of N increased 1000-seed weight and number of seeds/capitulum by 4.7% and 5.5%, respectively, compared to the same variables on control plants (Soleimani, 2010). Application of 100 kg N/ha to safflower plants produced the optimum yield components (Soleimani, 2010). Soleimani (2010) also reported that split application of N at sowing, early stem elongation and early flowering stages significantly ($P < 0.01$) increased 1000-seed weight than split application of N at sowing and late stem elongation. Siddiqui and Oad (2006) in Pakistan, reported that N application at 0, 30, 60, 80, 120, 150 and 180 kg/ha significantly ($P < 0.05$) increased the capitula number/plant and 1000-seed weight compared to control plants. Increasing N application from 30 to 180 kg/

ha significantly ($P < 0.05$) increased capitula number/pland and 1000-seed weight by 31.4-167% and 13.9-61.1%, respectively, compared to control plants.

Tunçtürk and Yildirim, (2004) reported that application of safflower plants with 0, 40, 80, and 120 kg N/ha significantly ($P < 0.05$) increased the capitula number/plant. Increasing N application from 40 to 120 kg/ha increased the capitula number/plant by 6.1-23% compared to control plants and the response plateaued at 80 kg N/ha (Tunçtürk and Yildirim, 2004). They further reported that the form of N-fertilizer had a significant ($P < 0.05$) effect on capitula number/plant. Application of N in the form of ammonium nitrate significantly ($P < 0.05$) improved the yield components, yield and agronomic traits of safflower compared to when N was applied either as urea or ammonium sulphate, however, ammonium sulphate was better than urea (Tunçtürk and Yildirim, 2004). Application of N in the form of urea to safflower plants at 75 and 150 kg/ha significantly ($P < 0.05$) increased capitula number/plant, capitula number/primary branch, capitula number/secondary branch, seed number/capitulum, seed number/primary capitulum, seed number/secondary capitulum and 1000-seed weight compared to control plants (Golzarfar *et al.,* 2012). Application of 75 or 150 kg N/ha significantly ($P < 0.05$) increased the safflower yield components in the range of 27.9 to 125% compared to control plants, depending on the yield component trait (Golzarfar *et al*., 2012). Mohamed *et al.* (2012) in the United Kingdom, reported that application of N at 0, 25, 50, 75, 100, 125, 150, 175 kg/ha increased capitula number/plant and seed number/plant in the range of 16.6-41.7% and 16.6-308.3%, respectively, compared to the same variables from control plants.

3.7.2.3.1.2 Phosphorus

Increasing P application to safflower plants increased yield components of safflower (Arani *et al*., 2011; Golzarfar *et al*., 2012; Singh and Singh, 2013). Singh and Singh (2013) reported that application of 0, 40 and 80 kg P_2O_5/ha significantly ($P < 0.05$) increased capitula number/plant, seed weight/capitula, 1000-seed weight and harvest index. Application of P at 0, 40 and 80 kg P_2O_5/ha significantly ($P < 0.05$) increased capitula number/plant, seed weight/capitula, 1000-seed weight and harvest index in the range of 22.4-49.4, 15.5-35.2, 14.0-38.5 and 2.0-4.7%, respectively (Singh and Singh, 2013). Application of P to safflower plants at 50 and 100 kg/ha significantly ($P < 0.05$) increased capitula number/plant, capitula number/primary branch, capitula number/secondary branch, seed number/capitulum, seed number/primary capitulum, seed number/secondary capitulum and 1000-seed weight compared to control plants (Golzarfar *et al.,* 2012). Application of 50 or 100 kg P/ha significantly ($P < 0.05$) increased the safflower yield components in the range of 7.9 to 25.4% compared to control plants, depending on the yield component trait (Golzarfar *et al*., 2012). Phosphorus application at 0, 50, 75 and 100 kg P_2O_5/ha significantly ($P < 0.01$) increased a 1000-seed weight and harvest index of safflower (Arani *et al*., 2011). Increasing P application from 0, 50, 75 and 100 P_2O_5 kg/ha increased a 1000-seed weight and harvest index from 20.1 to 45.5 g and 7.63 to 26.74, respectively, depending on the P applied and irrigation regime (Arani *et al*., 2011). Application of P at 0, 0.25, 0.5, 1.0 and 2.0 g/pot significantly ($P < 0.05$) increased capitula dry matter and capitula number/pot per pot from 15.4 to 26.5 g and 8.7 to 16.0, respectively (Abbadi and Gerendás, 2011).

3.7.2.4 Seed Yield

3.7.2.4.1 Effects of nitrogen on seed yield

3.7.2.4.1.1 Nitrogen

Nitrogen and P have been reported to be the two essential nutrients for safflower growth and development, therefore optimization of their application rates can strongly increase seed yield and oil content of safflower (Steer and Harrigan, 1986; Belanger *et al*., 2000; Antoniadou and Wallach, 2002; Henke *et al*., 2007). Safflower response to N is reported generally to be greater than other nutrients (Weiss, 2000). Malek and Ferri (2014) in Iran researching on N fertilizer application in two locations and different safflower cultivars, reported that application of 0, 30, 60 and 90 kg N/ha significantly ($P < 0.01$) increased safflower seed yield, irrespective of location or cultivar. Safflower plants fertilized with 30, 60 and 90 kg N/ha produced 769.5, 779.6 and 837.1 kg/ha of seed yield compared to control plants that produced 679.3 kg/ha. Singh and Singh (2013) in India, reported that application of N at 40 or 80 kg/ha to safflower plants significantly ($P < 0.05$) increased seed yield compared to seed yield from control plants. Safflower plants applied with 40 and 80 kg N/ha produced seed yield of 2270 and 2520 kg/ha, respectively, while control plants produced 1570 kg/ha. Abd El-Mohsen and Mahmoud (2013) in Egypt, reported that N fertilizer application at 0, 40, 80 and 120 kg/ha increased safflower seed yield and the response was quadratic with increase in N application rate. Nitrogen fertilizer application at 40, 80 and 120 kg significantly ($P < 0.05$) increased safflower seed yield by 38.2, 52.1 and 49.6%, respectively, compared to plants with no N application (Abd El-Mohsen and Mahmoud, 2013). The best seed yield was obtained with 80 kg N/ha, beyond which safflower seed yield significantly ($P < 0.05$) decreased (Abd El_Mohsen and Mahmoud, 2013). Nitrogen fertilizer application in the United Kingdom (Britain) at 0, 25, 50, 75, 100, 125, 150 and 175 kg/ha, significantly ($P < 0.05$) increased safflower seed yield (Mohamed *et al*., 2012) and the response was linear with increase in N application rate. Increasing N fertilizer application rate from 25 to 175 kg/ha, increased safflower seed yield from 4.76 to 323.8% and the best N application rate was 175 kg/ha (Mohamed *et al*., 2012). While, Golzarfar *et al*. (2012) in Iran, reported that application of N at 0, 75 and 150 kg/ha significantly ($P < 0.05$) increased seed yield of safflower by 180.3-228.1% compared to safflower plants where N was not applied. Application of N at 0, 75 and 150 kg/ha increased safflower seed yield from 983.83 kg/ha (control) to 2757.83 and 3227.5 kg/ha, respectively. Taleshi *et al*. (2012) reported that application rate of 0, 84, 120 and 154 kg N/ha increased safflower seed yield. The response of safflower yield to increasing N application was linear, with application of 154 kg N/ha producing the maximum seed yield of 1507.6 kg/ha. Earlier studies in Iran on N fertilizer application showed that application of 0, 50, 100 and 150 kg N/ha significantly ($P < 0.05$) increased the safflower seed yield by 36.1-111.1% compared to control plants (Bitarafan *et al*., 2011). Safflower plants fertilized with 50, 100 and 150 kg N/ha produced seed yield of 2245, 3023 and 3481 kg/ha, respectively, while safflower plants with no N application produced 1649 kg/ha (Bitarafan *et al*., 2011). Zareie *et al*. (2011) studied the effects of N and iron fertilizers on seed yield and yield components of safflower genotypes and found that N fertilizer application at 0, 50, 100 and 150 kg/ha increased seed yield. Safflower plants fertilized with 50, 100, and 100 kg N/ha produced 5.48, 9.08 and 7.04 tons/ha of seed yield, respectively, and 100 kg N/ha produced the best effect on seed yield and yield components (Zareie *et al*., 2011). Haghighati (2010) also in Iran, reported that application of N at 0, 30, 60 and 90 kg/ha increased safflower seed yield irrespective of cultivar and the optimum N application rate was 60 kg/ha beyond which seed yield decreased. Soleimani (2010) reported that in Western Iran, reported that application of N fertilizer at 50, 75, 100, 125, and 150 kg/ ha to safflower plants significantly ($P < 0.05$) increased seed yield. The increase in seed yield was quadratic to increasing N fertilizer application, with 100 kg N/ha giving the best results on yield and yield components of safflower (Soleimani, 2010). Application of N above 100 kg/ha resulted in a decrease in seed yield (Soleimani, 2010). Dordas and Sioulas (2009) in Greece, reported N fertilizer application at 0, 100 and 200 kg/ha significantly ($P < 0.05$) increased safflower seed yield and the response was quadratic to increasing N fertilizer application. Safflower plants fertilized with 100 and 200 kg N/ha produced 3.99 and 3.98 tons/ha, respectively, while the control plants produced 3.54 tons/ha of seed yield (Dordas and Sioulas, 2009). Siddiqui and Oad (2006) reported that application of N at 0, 30, 60, 80, 120, 150 and 180 kg N/ha in Pakistan, significantly ($P < 0.05$) increased safflower seed yield and the response of seed yield to increasing N application was quadratic. Seed yield peaked at 120 kg N/ha, beyond which seed yield decreased (Siddiqui and Oad, 2006).

3.7.2.4.1.2 Phosphorus

Increasing P application to safflower plants has been reported to increase seed yield (Malek and Ferri, 2014; Singh and Singh, 2013; Golzarfar *et al*., 2012; Golzarfar *et al*., 2011; Arani *et al*., 2011; Haghighati, 2010; Purvimath *et al*., 1993). Malek and Ferri (2014) reported that application of 0, 30 and 60 kg P/ha to safflower plants produced a non-significant ($P > 0.05$) increase in seed yield. Singh and Singh (2013) reported that application of 40 and 80 kg P_2O_5/ha to safflower plants significantly ($P < 0.05$) increased seed compared to control plants, however, there was no significant ($P > 0.05$) difference in seed yield of plants fertilizer either with 40 or 80 kg P_2O_5/ha. Safflower plants fertilized with 40 and 80 kg P_2O_5/ha produced a seed yield of 2.22 and 2.36 ton/ha, respectively, while the control plants produced a seed yield of 1.77 ton/ha (Singh and Singh, 2013). Golzarfar *et al*. (2012) reported that safflower plants fertilized with 50 and 100 kg P_2O_5 kg/ha produced a seed yield of 2391.5 and 2641.83 kg/ha, respectively, compared to control plants which produced 1935.83 kg/ha. Phosphorus application significantly ($P < 0.05$) increased seed yield by 23.5 and 36.5%, respective to 50 and 100 kg P_2O_5/ha compared to control plants (Golzarfar *et al*., 2012). Earlier in 2011, Golzarfar *et al*. (2011) had reported similar results in a different site that

P application at 0, 50 and 100 kg P_2O_5/ha significantly ($P < 0.05$) increased seed yield of safflower by 23 and 38%, respectively, compared to the control plants. Arani *et al*. (2011) in Iran, reported that P applied at 0, 50, 75, and 100 kg P/ ha significantly ($p < 0.05$) increased the seed yield of safflower by 7, 13 and 15.8% , respectively, compared to control plants. Haghighati (2010) reported that application of P at 0, 30 and 60 kg/ha had no significant ($P > 0.05$) effect on seed yield of safflower. While, Purvimath *et al*. (1993) reported that increasing P fertilizer application rate from 75 to 150 kg P/ha increased the seed yield of safflower by 17.6%.

3.7.2.5 Effects of nitrogen and phosphorus on safflower oil content

3.7.2.5.1 Nitrogen

Safflower plants applied with 40 and 80 kg N/ha significantly ($P < 0.05$) produced higher seed oil content of 33.3 and 33.5%, respectively, than control plants that produced seed oil content of 32.4% (Singh and Singh, 2103). However, there was no significant ($P > 0.05$) difference in the oil seed contents of safflower plants fertilized with either 40 or 80 kg N/ha (Singh and Singh, 2013). Application of N at 40, 80 and 120 kg/ha to safflower plants significantly ($P < 0.01$) increased the seed oil content and oil yield compared to seed oil content and oil yield from control plants (Abd El-Mohsen and Mahmoud, 2013). The response of safflower seed oil content and oil yield was quadratic to increasing N application rate. Maximum seed oil content (33.9%) and oil yield (594.7 kg/ha) was produced with fertilizer application to safflower plants of 80 kg N/ha (Abd El-Mohsen and Mahmoud, 2013). Bitarafan *et al*. (2011) reported that application of N at 50, 100 and 150 kg/ha significantly ($P < 0.05$) increased the seed oil content of safflower compared the seed oil content from control plants. Increasing N application from 50 to 100 kg/ha resulted in a slight increase in seed oil content of safflower, but applying 150 kg N/ha decreased the seed oil content (Bitarafan *et al*., 2013). Soleimani (2010) reported that application of 50, 75, 100, 125 and 150 kg N/ha to safflower plants increased the seed oil content and oil yield. Application of 100 kg N/ha gave the highest seed oil content and oil yield of 29.9% and 755 kg/ha, respectively (Soleimani, 2010). Elfadl *et al*. (2009) reported that application of 0, 40 and 80 kg N/ha had no significant ($P > 0.05$) effect on safflower seed oil content and oil yield. Dordas and Sioulas (2008) did not find any relationship between rates of N and safflower seed oil content. Tunçtürk and Yildirim (2004) reported that N application at 40 and 80 kg/ha significantly ($P < 0.05$) increased safflower seed oil content compared to seed oil content of control plants. However, application of 120 kg N/ha significantly ($P < 0.05$) decreased the seed oil content compared to control plants or plants fertilized with either 40 or 80 kg N/ha (Tunçtürk and Yildirim, 2004). However, application of 40, 80 and 120 kg N/ha increased safflower seed oil yield compared to control, but there was no significant ($P > 0.05$) difference in the oil seed yield from safflower plants treated with 40, 80 or 120 kg N/ha (Tunçtürk and Yildirim, 2004). El-Nakhlawy (1991) reported that application of nitrogen at 0, 46, 92, 138 kg/ha decreased safflower seed oil content by 1.0%, 7.8% and 3.9% respectively, compared to control plants.

3.7.2.5.1.2 Phosphorus

Phosphorus is required for the formation of fats, being a component of the glycerol unit and its needed for conversion of acetate units into fatty acids and its energy expensive, because 2NADPH and 1ATP are needed for each acetyl group present containing a high energy phosphate group that drives most energy requiring biochemical process (Salisbury and Ross, 1992). Singh and Singh (2013) reported that application of 40 and 80 kg P_2O_5/ha to safflower plants significantly ($P < 0.05$) increased the oil seed content compared to control plants. Phosphorus application increased the safflower oil seed content by between 6.0 and 6.6%, respectively. However, there was no significant ($P > 0.05$) difference in the oil seed content of plants fertilized with 40 or 80 kg P_2O_5/ha (Singh and Singh, 2013). Arani *et al*. (2011) reported that P application at 0, 50, 75, and 100 kg/ha significantly ($P < 0.05$) increased safflower seed oil yield. Safflower plants treated with 50, 75 and 100 kg P/ha produced oil yield of 1124, 1262 and 1344 kg/ha, while control plants produced 955.7 kg of oil/ha (Arani *et al*., 2011). The response of safflower seed oil yield to increasing P application was linear (Arani *et al*., 2011).
From literature reviewed above, the amount of commercial fertilizer required for safflower production will depend on the yield potential, genotype, water availability, season in which safflower is grown, soil type and geographical location. Safflower will root deeper than small grains. This allows the safflower plant to utilize deeper positioned nutrients, such as nitrogen (N), that are unavailable to small grains and other crops. Nitrogen is most often the limiting nutrient on non-fallow land. Phosphorus can be limiting on fallow and non-fallow land, and safflower responds well to phosphorus. Local climate, soil type and management (timeliness of planting, plant population, variety and weed control) influence yield. Because safflower roots penetrate to depths of more than 2 m, sampling to depths greater than 60 cm would increase the accuracy of fertilizer recommendations. Yield potential targets should be realistic, based on longtime averages and the management ability of the farmer. Yields range from 400 kg/ha when moisture is limiting or weed and/or disease pressures were high, to more than 5,500 kg/ha under conditions relatively free of weeds, diseases and insects and when adequate moisture and fertility were available depending on season (winter or summer) (Emongor *et al*., 2013; Moatshe *et al*., 2016). A general rule of thumb is that for every 100 kg of seed produced, safflower plants will require 3-5 kg of nitrogen applied and in the soil, depending on genotype, growing season, soil type and water availabilty. A 1,500 kg/ha yield potential requires 45-75 kg of total N. The method of nitrogen application will depend on the nitrogen source used. Because of position availability, banding or drill applying phosphorus is more efficient than broadcasting. Phosphorus can be applied at the rate 50-60 kg/ha. Safflower has not responded consistently to potassium application unless the soil tests are in the low range.

3.7.2.2 Potassium

Studies of potassium (K) fertilization effects on safflower growth and seed yield, which also included N and P fertilizers did not give consistent results, perhaps because of variation in cultural practices such as safflower variety, sowing date, plant density and past crop history (Haby *et al*., 1982; Hoag *et al*., 1968). When K response was positive, K was applied along with N and P fertilizer and K usually reduced the influences of high rates of N fertilizer on the dependent variables determined (Haby *et al*., 1982).

3.8 Irrigation

Safflower is drought tolerant due to its deep tap root and can reach the deep-lying water (Bassir *et al*., 1977; Weiss, 2000; Bassil and Kaffka, 2002; Emongor, 2010). All the biotic and abiotic stresses are the most factors that reduce crop production, however, drought stress is the most important limiting factor to crop production in arid and semi-arid regions (Mollasadeghi *et al*., 2011). In regions receiving ≤ 250 mm of precipitation during the safflower growing cycle requires supplemental irrigation at the onset of flowering. However, safflower is not able to stand water logged soils for any length of time. The crop may use considerable amounts of soil moisture, but it does not survive standing water for even a few hours in warm weather (air temperature above 20 °C). This response relates partially to the rapid spread of soil borne pathogens such as *Pythium* (Mündel *et al*., 1995) and *Phytophthora* (Rubis, 1981), which increase dramatically as temperatures increase; but also to the anaerobic conditions, which combined with soil pathogens, cause plant death very quickly. In regions afflicted with dry-land salinity, safflower uses surplus water from recharge areas, drawing down the water table with the salts dissolved in it, and by that preventing the expansion of saline seeps (Dajue and Mündel, 1996).

Throughout the world, most safflower is grown without irrigation (Mündel *et al*., 1997). However, where irrigation is available it is important to use it in moderation to avoid wet feet, to prevent undesirable delays in maturity and reduce the risk of a vast array of leaf and head diseases such as *Alternaria* leaf blight, *Sclerotinia* and *Botrytis* head rots (Dajue and Mündel. 1996; Mündel *et al*., 1997b).

3.9 Harvesting and Storage

The days to harvest maturity of safflower ranges between 90-280 days (Weiss, 2000; Emongor, 2010; Emongor *et al*., 2013). It is physiologically mature about 30 days after flowering and ready to harvest when most of the leaves have turned brown and only a tint of green remains on the bracts of the latest flowering heads. Seeds should rub freely from the heads. Seed shattering is usually not a problem, although safflower should be harvested as soon as it is mature to minimize the danger of seed damage from excessive moisture. Excessive rain and high humidity after physiological maturity of the seed may cause sprouting in the head. Bird damage to mature standing fields rarely has been a problem but may develop when fields adjoin a bird sanctuary. Most safflower grown in North Dakota is ready to harvest in early to late September, depending on planting date and weather conditions during the growing season. Safflower is directly harvested with a small-grain combine. To prevent cracking of the seed, the combine cylinder speed should not exceed a peripheral speed of 914.4 m per minute. This will be about 500 rpm for a 55.9-cm cylinder. Suggested concave clearance is 1.6 cm at the front and 1.27 cm at the back. Shaker speeds greater than those used for small grains are required to prevent plant residue from plugging the machine. Air should be adjusted to remove most of the empty or unfilled seeds. During the harvest operation, a white fuzz from the seed heads is abundant in the air and may clog combine radiators and air intakes, causing the combine to overheat. Small-meshed screen enclosures over these cooling mechanisms should minimize this problem, and blowing out radiators with air once or twice daily may be necessary. Accumulations of this fuzz can be a fire hazard. For safe, long-term storage, threshed seed should not exceed 8 percent moisture. Drying the seed can be accomplished following the same precautions and procedures as for sunflower. Drying temperatures should not exceed 43.3 °C to ensure highest seed quality and no seed damage.

Safflower grows well in well-drained, deep, fertile, sandy loam soils. In heavy clay soils, crusting may reduce seedling emergence. In general, if soil moisture is limiting, good irrigation just prior to bloom increases seed yield significantly. Safflower seed yield is affected cultural practices (Siddiqui and Oad, 2006; Nikabadi *et al*., 2008), cultivar (Arslan, 2007; Pahlavani, 2005; Pahlavani *et al*., 2006; Khoshnoud and Jirair, 2006; Mahasi *et al*., 2006; Oad *et al*., 2002), and climatic factors (Kolte, 1985; Abdulahi *et al*., 2007). Siddiqui and Oad (2006) reported that application of 120 kg N ha^{-1} significantly increased safflower branches, seed index, plant height and seed yield, but delayed maturity.

3.10 Safflower diseases and pests

Safflower was developed from wild species of desert or arid environment and is very susceptible to foliar diseases favoured by a moist growing environment. Safflower is susceptible to leaf blight caused by *Alternaria carthami* in growing areas with high rainfall and where rainfall occurs between the late bud stage and near maturity. *A. carthami* is an important seed-borne pathogen of safflower in western Canada, USA, Australia and India (Chowdhury, 1944; Burns, 1974; Petrie, 1974; Irwin, 1976; Mündel *et al*., 1997b). Mortensen *et al*. (1983) reported that *A. carthami* was pathogenic on safflower at all growth stages in Montana, causing up to 50% seed rot and seedling blight in susceptible cultivars. Other foliar diseases of concern are those caused by *Botrytis cinerea*, *Cercospora carthami*, *Pseudomonas syringae*, *Puccinia carthami* and *Ramularia carthami* (Mündel *et al*., 1992). Safflower is also susceptible to root-rot caused by several species of *Phytophthora*, *Fusarium oxysporum* f. sp. *carthami*, and *Verticillium dahliae*. The most serious insect pest that has limited safflower distribution is the safflower fly (*Acanthiophilus helianthi*) which is confined to Africa, Asia and Europe (Mündel *et al*., 1992). Aphids are also a major problem in India, Spain and Botswana (Mündel *et al*., 1992). The phytophagous insects found in Italy belong to the *Orthoptera*, *Rhynchota*, *Lepidoptera*, *Diptera* and *Coleoptera* species (Corleto *et al*., 1997).

4.0 CONCLUSION

Despite the many uses of safflower, it has remained a minor crop. Safflower is a crop which should be particularly prized by scientists due to its high nutritional value of its oil, pharmacological and medicinal, industrial, textile, food, animal feed and cut-flower uses. Therefore, awareness of the usefulness of this neglected and underutilized economically important crop be created to the international community. It is hoped that scientists will develop interest on safflower and develop multidisciplinary research projects to address issues related with the agronomy, ecophysiology, diseases and pests, developmental patterns, morphological ideotypes, increase seed yield through genetic manipulation, product-related research, utilization research, development of pharmaceuticals and clinical trials to elucidate the effectiveness of safflower products, decoctions and concotions in the treatment of various human diseases.

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