Elfadl Yousif Elmogtaba Elfadl

Suitability of Safflower (*Carthamus tinctorius* L.) for Cultivation as an Oil Crop under the Conditions of Organic and Low-Input Farming Systems in Central Europe

Cuvillier Verlag Göttingen
Internationaler wissenschaftlicher Fachverlag

Institute of Crop Sciences
University of Hohenheim
Department of General Crop Farming
Prof. Dr. Wilhelm Claupein

Suitability of Safflower (*Carthamus tinctorius* L.) for Cultivation as an Oil Crop under the Conditions of Organic and Low-Input Farming Systems in Central Europe

A Dissertation

submitted in fulfillment of the requirements for the degree of

Dr. sc. agr. in Agricultural Sciences
“Doktor der Agrarwissenschaften“

to the
Faculty of Agricultural Sciences

Presented by

Elfadl Yousif Elmogtaba Elfadl

M. Sc. in Agricultural Sciences

Born in Sudan

Stuttgart-Hohenheim
2010

Bibliografische Information der Deutschen Nationalbibliothek
Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über http://dnb.d b.de abrufbar.
1. Aufl. - Göttingen : Cuvillier, 2010
Zugl.: Hohenheim, Univ. Diss., 2010

978-3-86955-274-3

Date of oral examination: Monday, 1st of Feb. 2010

Examination Committee:

1st Examiner:	Prof. Dr. W. Claupein
2nd Examiner:	Prof. Dr. R. Gerhards
3rd Examiner:	Prof. Dr. J. Wünsche
Vice Dean:	Prof. Dr. W. Bessei

This study was financed by Pfister Foundation, Bern, Switzerland.

Nonnenstieg 8, 37075 Göttingen
Telefon: 0551-54724-0
Telefax: 0551-54724-21
www.cuvillier.de

1. Auflage, 2010
Gedruckt auf säurefreiem Papier

978-3-86955-274-3

Dedication

To my late parents and Beloved sisters and brothers

Table of contents

List of Tables

List of Figures

List of abbreviations

AIC	The Akaike's Information Criterion.
ALS	Alternaria Leaf Spot Disease.
AMMI	Additive Main Effects and Multiplicative Interaction.
ASE	Accelerated Solvent Extraction.
AVE	Average.
CV	Coefficient of Variation.
DBF	Days to Beginning of Flowering.
DEF	Days to End of Flowering.
E	Environment.
Env σ_{ii}	Environmental Variance.
G	Genotype.
GCV	Genotypic Coefficient of Variation.
GEI	Genotype by Environment Interaction.
HER	Heritability.
HROT	Head Rot Disease.
KP%	Percentage of Kernel Proportion.
LSD	Least Significant Difference.
MAT	Days to Maturity.
MS	Means of Squares.
N	Nitrogen.

NIRS	Near Infrared Reflectance Spectroscopy.
OY	Oil Yield.
PCA	Principal Component Analysis.
PLS	Partial Least Squares.
PRESS	Predicted Residual Error Sum of Squares.
PROC	Procedure.
Q	Quality of Calibration.
r	Regression Coefficient.
R^2	Coefficient of Determination.
r_g	Genotypic Coefficient of Correlation.
r_p	Phenotypic Coefficient of Correlation.
REML	Restricted Maximum Likelihood.
RPD	Relative Prediction Deviation.
SD	Standard Deviation.
SEE	Standard Error of Estimation.
SEP	Standard Error of Prediction.
Sh $\sigma^2_{f(i)}$	Shukla's Stability Variance.
SS	Sums of Squares.
TKW	Thousand Kernel Weight.
UPGMA	Unweighted Pair Group Method with Arithmetical Averages.

General introduction

Worldwide, adoption levels for organic farming systems are currently the highest in European Union countries. The major crops grown in the organic farming system in Germany are cereals, they occupied 23% of the organic acreage in 2004 (Ghaouti et al., 2008). However, the oilseed crops production under organic farming conditions decreased from 2.5% in 1998 to 0.9% out of the total area of organic farming in 2002 (Reinbrecht, 2003). Rapeseed is the major oilseed crop grown in Europe for production vegetable oil. The seed yield of organic oilseed rape crop is low and variable in organic farming (Valantin-Morison and Meynard, 2008). Organic farming requires cultivars that are specifically adapted to this low input cropping system. The desired variety traits include adaptation to organic soil fertility management, implying low and organic inputs, a better root system, ability to suppress weeds, contributing to soil, crop and seed health, good product quality, high seed yield level and high yield stability (Lammerts van Bueren et al., 2002). The existing oilseed crops, such as rapeseed and sunflower, require high amount of nutrients and this represents a challenge in organic cultivation particularly if oilseeds are cropped on farms with no or few animals (Rathke et al., 2004). In addition, the management of weeds, pests and diseases for these oilseed crops still relies heavily on chemical herbicides and pesticides (Williams, 2004). Thus, a research should be carried out to introduce an alternative oilseed crops that suite the organic farming system.

Safflower (*Carthamus tinctorius* L.) nowadays has gained the reputation of being an edible oil of superior quality containing high levels of unsaturated fatty acids, such as oleic and linoleic acids, associated with the reduction of cholesterol level in the human blood (Chaturvedi et al., 2001). It is also a source of important biochemicals like tocopherol in oil and carthamin in flowers (Ramaswamy, 2001). Safflower has a deep root system allowing the plant to utilize efficiently the nutrients that may not be available to small-grain crops. Hence, introduction of such crop will enhance the sustainability of the organic farming system and benefits consumers and farmers.

Basically, safflower is a dryland crop which grows best in arid climates on land with a high water table (Paredes-Loepez, 1991). In areas of high atmospheric humidity, safflower is quite susceptible to diseases. In order to introduce safflower in cool and temperate zones, stable, high yielding, and oil rich cultivars should be developed (Weiss, 2000). In addition, disease problems need to be overcome (Esendal, 2001). It has been observed, in temperate climate, that safflower varietal performance in seed yield under chemical-free conditions fluctuated tremendously from one year to another depending on the climate (Reinbrecht et al., 2005). Hence, identification of morphological and phenological characteristics to develop a plant ideotype as well as stable cultivars adapted to such conditions are the key objectives of this project to introduce safflower in organic farming in Central Europe.

1.1 Safflower origins and history

Safflower (*Carthamus tinctorius* L.) is one of the oldest domesticated crops. It has been grown since ancient times both as a dye and as an oil crop in a wide range of geographical regions (Knowles, 1976). Kupzow (1932) was the first to study the range of variability in cultivated safflower and the wild *Carthamus* species. He concluded that safflower had two centers of variability: Ethiopia and Afghanistan. The phyto-geographical work of Vavilov (1951) suggested three areas of origin for cultivated safflower in India, Afghanistan and Ethiopia based on variability, ancient culture, proximity of wild species, and presence of wild species. However, Knowles (1969) described seven centers of similarity based on the similarity between cultivated safflower and closely related wild species of *C. palaestinus and C. flavescens.* These centers of similarity are:

1) Far East: China, Japan, and Korea.
2) India-Pakistan: India, Pakistan and Bangladesh.
3) Middle East: Afghanistan to Turkey, southern USSR to the Indian Ocean.
4) Egypt (Mediterranean): Bordering the Nile north of Aswan.
5) Sudan: Bordering the Nile in northern Sudan and southern Egypt.
6) Ethiopia.
7) Europe: Spain, Portugal, France, Italy, Romania.

Weiss (1971) reported that safflower has been recorded as being grown for centuries in a wide area covering southern and western China, much of India and westward across present-day Pakistan, Afghanistan, Iran, Iraq, northern Saudia Arabia, Kazakhstan, Turkey, and numerous others middle eastern countries, as well down Nile valley of Egypt, Sudan, and Ethiopia (Figure 1.1). The western expansion of the Arabs in creating the Muslim Empire of the 5^{th} and 6^{th} centuries AD probably helped the cultivation of safflower along the Maghreb and into Europe via Iberian Peninsula (Paredes-Loepez, 1991). In Central Europe, safflower was grown in Germany, Poland, Hungary, Czechoslovakia and Alsace region in 16^{th} and 17^{th} century for red and/or as a garden plant (Weiss, 1971). As reported by Reinbrecht and others (2005), three publications (Scheibe and Yekta, 1934 and 1938, Sessous, 1940) demonstrated that safflower was successfully cultivated under German climatic conditions for producing edible oil. It was found that specific safflower genotypes originating mainly from European botanical gardens potentially produced sufficient seed yields and proved to compete well with other oil crops developed at that time.

1.2 Safflower production and economy

Worldwide, safflower is a comparatively minor oilseed crop, being limited in its distributions by the constraints of the environment and the plants spiny nature (Pascual-Villalobos and Alburquerque, 1996). Safflower is most adapted to: 1) areas like south central India where the crop is autumn-sown 2) areas that have Mediterranean type climate 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 (Knowles, 1989). Since 1975, world production of safflower has decreased as the crop suffered from increased cultivation of sunflower, soya and rape (Weiss, 2000). The estimated world production is about 0.622 million tons of seed per year from about 0.736 million hectares (FAO, 2009).

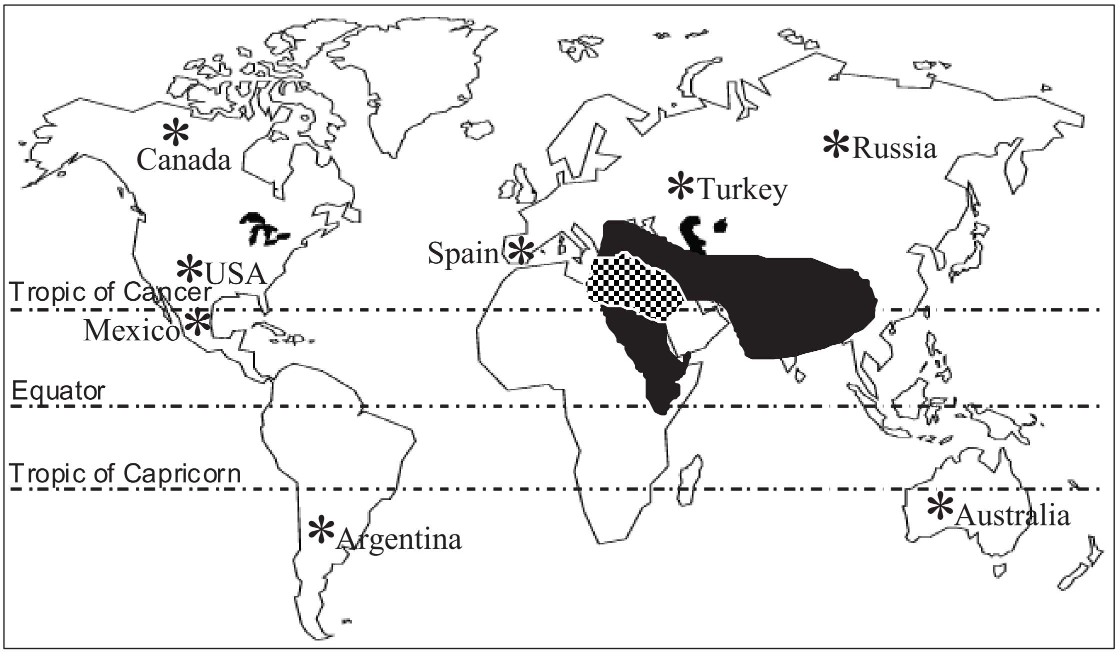

Figure 1.1: Probable center of origin and center of domestication of safflower (dotted area), area of ancient cultivation (solid area), and main producing countries (*).

Variable production performance may partly explained by the nature of safflower which, as a semi-arid crop, is often cultivated in marginal areas susceptible to erratic climatic fluctuations. Variations are also induced by other factors which are country specific such as the effects of the government policies, competing crops and relative pricing and returns to production (Johnson and Marter, 1993). Worldwide, safflower ranks eighth after soybean, groundnut, rapeseed, sunflower, sesame, linseed, and castor. India, Mexico, USA, Ethiopia, Argentina, and Australia together account for 99% and 87% of the world safflower area and production, respectively (Damodaram and Hegde, 2002). The world average seed yield of safflower (0.72 t/ha) is much lower than those reported for soybean (2.34 t/ha), rapeseed (1.51 t/ha), groundnut (1.37 t/ha), and sunflower (1.14 t/ha) (Dwivedi et al., 2005).

1.3 Safflower genomics

Safflower is a member of the family *Asteraceae* (*Compositae*), tribe *Cardueae*, and subtribe *Centaureinae*. *Carthamus spp*. are classified into four sections having 2n=20, 24, 44 and 64 chromosomes. The first two sections are diploids, the third (2n=44) is a tetraploid and the fourth section (2n=64) consists of hexaploid species (Khidir, 1969). Previously, approximately 25 species of safflower were reported for the genus *Carthamus*, but 15 annual species have been reported more recently (Vilatersana et al., 2005). Among these species, the cultivated safflower grown around the world is only *Carthamus tinctorius* L. which containing 12 pairs of chromosomes (2n=24) (Kumar et al., 1981). It can potentially hybridize with at least six species of wild *Carthamus*. However, only *C. oxyacantha* and *C. creticus* (*C. lanatus* subsp. *creticus*, *C. baeticus*) have produced fertile F1 hybrids when crossed with *C. tinctorius* (McPherson et al., 2004). There is still controversy over whether *C. oxyacantha* or *C. plaestinus* is the wild progenitor of *C. tinctoriu*s (Ashri and Knowles, 1960, Kumar, 1991, Zohary and hopf, 2000).

Safflower is usually considered to be a self-pollinated crop. However, out-crossing between safflower crops has been reported to be anywhere from 0 to 100% (Claassen, 1950), with an average between 15 and 20% (based on dominant flower-color markers). Insects and bees are the primary pollinator for safflower (Eckert, 1962). However, wind is not known to be a significant pollen dispersal agent, most likely due to the pollen's large size (mean diameter of 53-56 μm). Characteristics that have been used to measure out-crossing include allozymes, flower color (Figure 1.2), spiny versus non-spiny, dominant white seed hull versus recessive gray strip (Figure 1.3), and high linoleic/low oleic versus low linoleic/high oleic fatty acid content.

1.4 Safflower as a multi-purpose crop

Safflower is primarily grown for three products: oil, meal and birdseed. The oil is mainly used for cooking, salad dressings and margarine (Johnson and Marter, 1993).

Safflower oil also is used in paint bases and can be converted into biodiesel. High-fiber, high-protein meal from crushed seeds is fed to livestock, while intact safflower seeds are marketed as birdseed. Safflower can be used also as green forage or as hay silage for feeding animals (Bar-Tal et al., 2008). Including safflower in wheat-based rotations can improve use of deep soil water and nitrogen (Black, 1993). The long growing season required by the crop permits deep root growth, enabling safflower to use water and nutrients from a greater soil depth than crops with a shorter growing season. As a rotational crop, safflower also can be beneficial for breaking disease cycles (Ghanavati and Knowles, 1977).

Figure 1.2: Safflower flower colors.

Figure 1.3: Normal (left) and thin strip hull (right) safflower seeds

Safflower is thought to be one of the highest quality vegetable oils and a medicinal plant (Dajue and Mündel, 1996). High-oleic safflower oil is lower in saturates and higher in monounsaturates than olive oil and is beneficial in preventing coronary artery diseases and tend to lower blood levels of LDL ("bad" cholesterol) without affecting HDL ("good" cholesterol). Polyunsaturated fatty acids, such as linoleic acids, are associated with lowering blood pressure, enhance physique, improve the middle-aged and old obesity, improve microcirculation and recover nerve function if taken for long (Zhaomu and Lijie, 2001). The content of lenoleic fatty acid in safflower oil ranks first in all kinds of vegetable oils. Linoleic acid can keep cell membranes soft and strengthen the elasticity and vitality. Safflower oil has been determined as valuable oil in cosmetics (Jingzhong, 1993).

The whole plants, flowers, and seeds have a wide range of medicinal uses in different countries (Mündel et al., 2004). A tea from safflower foliage is used to prevent an abortion and infertility by women in India and Afghanistan. Flowers are used as tonics for a multitude of conditions in China, such as dilatation of arteries, reduction of hypertension, increase of blood flow, and oxygenation of tissue. Seed decoctions are used with sugar as laxative for flushing out urinary tracts and ground up to reduce rheumatic pains. Petals of safflowers are used as a traditional medicine in Korea and China. Composition of safflower petals is associated with thrombolytic, anti-inflammatory, and antioxidative effects (Akihisa et al., 1996). In Europe, safflower is also used for both fresh-cut and dried flowers (Uher, 1997). Research safflower group in China (1993) reported that the levels of essential elements, which are important for human body in safflower oil, are generally higher than those of several kinds of edible oils. Safflower oil is rich in elements which are beneficial for human health. Pb, As, Hg and Cd elements have not been detected or lower in safflower.

1.5 General safflower characteristics

Safflower is a highly branched, herbaceous, thistle-like annual crop, usually with many long sharp spines on the leaves (Dajue and Mündel, 1996). Safflower has strong taproot system that penetrates deep in the soil to a depth of 4 m depending on type of soil and depth of available moisture (Kaffka and Kearney, 1998). The height of the plant ranges from 60 to 120 cm depending on variety and date of sowing. The stem is branched and a flower head grows at the end of each branch. The central stem branches to form secondary stems and these branch into tertiary stems. Cultivars are classified as appressed, intermediate, spreading and decumbent if they have stem to branch angle in the range of 10-20, 20-40, over 40°, and if the branch droop more than 90°, respectively (Weiss, 1971). Each head produces 15 to 30 seeds (Oelke et al., 1992). The seed (achene) is white or lightly striped and smooth with thick pericarp. A mature achene composed of 33-66% hull. The oil content varies from 20 to 45% based on the hull or kernel content (Dajue and Mündel, 1996). The seed contains nearly 15-20 % protein (Betschart et al., 1975).

1.6 Production requirements

Knowledge of development stages is essential for management of post emergence application of water, fertilizers and pesticides. Tanaka and others (1997) described the development stages and determined the growing degree days associated with each stage. The safflower plant development was divided into vegetative and reproductive stages. Vegetative plant development stages begin when the cotyledons are fully emerged. Each vegetative plant development stage is determined by counting the number of true leaves in excess of 4 cm in length. The number of true leaves can range from 15 to 35. The vegetative plant development growth stages require 670 to 800 growing degree days. The six reproductive plant development stages begin with the formation of a floral head of about 0.6 cm in diameter and proceed through physiological maturity of the seed. Reproductive plant development stages require 795 to 905 growing degree days. Generally, safflower is considered as a day-length-neutral or a long- day plant (Johnston et al., 2002).

Depending on soil temperature and moisture, safflower seed germinates in 8 to 15 days when sown in April or early May (Keso, 1961). It does not begin to germinate until soil temperature is above 5°C. After germination, a slow-growing rosette stage develops and a tap root penetrates deep into the soil. Stems then elongate quickly forming sturdy branches. Flowering starts on the central stem and spreads outwards. The seed matures within 30 to 35 days from flowering. It takes about two more weeks to dry the crop for harvest (Mündel et al., 2004). Safflower produces many leaves in the rosette stage. The duration of rosette stage is determined by temperature and variety (Zimmerman, 1973). The same cultivar, autumn sown, may remain in the rosette stage until spring. If it planted in spring, it may last only a few weeks. The elongation stage is rapid with growth at 4-5 cm/day and is followed by the bud stage. Buds grow from the apical leaf axils and primary branches. The petal, stamen and pistil primordia develop centripetally. The seed dry matter accumulation approaches maximum 25 days after fertilization (Smith, 1996). Safflower is not ready to harvest until nearly all the leaves have turned brown, and when the moisture content of the seed is less than eight per cent (Keso, 1961). Emerging plants need cool temperatures for root growth and rosette development and higher temperatures during stem growth, flowering and seed yield formation periods (20 to 30°C). The seedling is frost-resistant (up to -7°C) but after this stage frost below -2°C kills the plant.

Safflower requires a fertile, fairly deep and well drained soil. For irrigated production a medium-textured soil is preferable. Shallow soils seldom produce high seed yields. Dense subsoils retard root growth. The crop is well adapted to the presence of a water table at a depth of up to 1 m (Oelke et al., 1992). Though there is a rather wide tolerance to pH, high yields are obtained on soils with a neutral reaction.

Optimum row spacing, plant density, and fertilizer application play a vital role in enhancing safflower production (Kaffka and Kearney, 1998). Row spacing varies from 50 to 80 cm, with 15 to 35 plants per meter of row. Seed rate for broadcast sowing of the irrigated