



Elfadl Yousif Elmogtaba Elfadl (Autor)

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Telefon: +49 (0)551 54724-0, E-Mail: info@cuvillier.de, Website: <https://cuvillier.de>

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 Saudi 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 5th and 6th 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 16th and 17th 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 Albuquerque, 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).

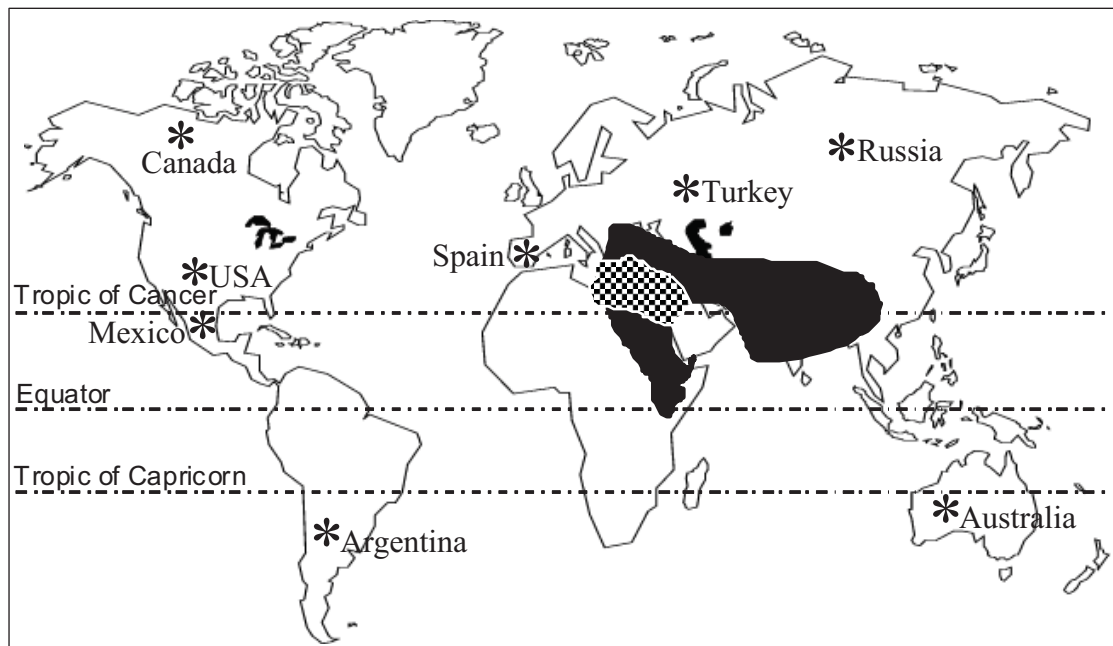


Figure 1.1: Probable center of origin and center of domestication of safflower (dotted area), area of ancient cultivation (solid area), and main producing countries (*).

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. tinctorius* (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).

1 General Introduction

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).