

THESIS

ADAPTABILITY OF OILSEED SPECIES AT HIGH ALTITUDES OF COLORADO
AND TECHNOLOGY TRANSFER TO AFGHANISTAN

Submitted by

Mohammad Navid Sediqi

Department of Soil and Crop Sciences

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Master's Committee:

Advisor: Jerry J. Johnson

Co-Advisor: Patrick F. Byrne

Ajay K. Jha

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ABSTRACT

ADAPTABILITY OF OILSEED SPECIES AT HIGH ALTITUDES OF COLORADO AND TECHNOLOGY TRANSFER TO AFGHANISTAN

High altitude farmers around the world have a limited set of crops that are adapted to the short growing season and cold temperatures prevalent at high altitudes. Despite the suitability of oilseed crops for high altitude agriculture, little research has been published on the adaptability of various species to particular altitudes in Colorado. Research on adaptability of oilseed crops in Afghanistan is lacking, although Afghanistan has altitudes and environmental conditions similar to those in Colorado, suggesting that oilseed crops suited to Colorado might also be suited to Afghanistan. This study reviewed the literature on nine oilseed species (flax, camelina, sunflower, safflower, sesame, cuphea, canola, Indian mustard, and Ethiopian mustard), agricultural technology transfer, and oil composition. Adaptability estimates were developed for nine oilseed species at eight Colorado locations. These estimates were based on long-term cumulative temperature data at each location in combination with the required cumulative growing degree day (GDD) requirement for each species and species field trials at six locations in 2010. Eight varieties of flax were planted in field trials at six in 2011 and evaluated for yield, oil content, fatty acid composition, and yield components. Seventeen varieties of camelina were planted in Kabul, Afghanistan, in 2011 and evaluated for yield.

Literature was reviewed for each of nine oilseed species. The reviewed topics included introduction and crop history; general description; climate, adaptation and soil; cultural practices, including seedbed preparation, planting date, seeding rate, seeding

depth, and fertilizer application; weed control and herbicide; disease and pest management; and harvest. The review of technology transfer included a historical perspective, concepts and definitions, components of technology transfer, and phases of the process. The oil content and oil profile of each of nine oilseed species were reviewed, with particular attention to the content of alpha-linolenic fatty acid, an omega-3 fatty acid that has purported human health benefits.

Successful transfer of agricultural technology for crops depends on matching the adaptability of the crops to the climatic conditions in the target location. This study developed adaptability estimates for nine oilseed species at eight Colorado locations. Because Afghanistan has high altitude areas similar to those in Colorado, high altitude research done in Colorado may be applicable to Afghanistan.

The base temperature and cumulative GDD requirement for each species were extracted from the literature. Long-term weather data was compiled for each location and the cumulative GDD at each location for each crop was calculated. Adaptability trials of nine species were conducted in six locations in 2010 and species were evaluated for maturity. Only camelina was predicted to reach maturity at the highest altitude (7702 feet) (2348 meters), although canola, juncea, and carinata also reached maturity because 2010 was a warm year. All species except cuphea and sesame were predicted to mature at the lowest altitude (5110 feet) (1558 meters), although cuphea also reached maturity because 2010 was a warm year.

Eight varieties of flax were planted in field trials at Fort Collins, Iliff, and Craig, Colorado, in 2011. Yield, seed weight, seeds per capsule, capsules per plant, capsules per acre, oil content, linolenic acid content, and oleic acid content were measured. Flax yield

was highly positively correlated to the number of seeds per capsules and capsules per plant, but was negatively correlated to number of capsules per acre. No significant differences for yield were found among varieties in this study. There was a significant location effect on flax oil content and linolenic acid content. Both increased with increasing altitude. This supports previous research suggesting that high altitude increases both oil content and linolenic acid content in flax. The biosynthesis of linolenic acid appeared to be favored over other fatty acids in flax. Oil content was positively correlated with linolenic acid content, while linolenic acid content was negatively correlated with oleic acid content. There was no significant correlation between oil content and seed yield.

Based on these results, growers planting flax at higher altitudes can expect higher oil content and higher linolenic acid content in flaxseed. Flax varieties should be tested locally to screen and select for high seed yield, high oil content, and high linolenic acid content. Flax breeders should breed for flax cultivars that contain high seed weight, high number of seeds per capsule, and high number of capsules per plant.

A camelina variety trial was conducted in Kabul, Afghanistan, in 2011. No significant yield differences were found among seventeen varieties. The average yield in Kabul was 975 pounds per acre (1111.5 kg per hectare). The average yield for camelina in a 2011 trial at Fort Collins, Colorado, was 953 pounds per acre (1086 .4 kg per hectare).

Flax and camelina appear to be adapted to high altitude areas in both Colorado and Afghanistan. Studies similar to this can provide valuable information to make decisions about transferring agricultural technologies to areas with climate, terrain, and

geography similar to those of Colorado. Successful transfer of agricultural technology, especially for crops, depends on conducting crop adaptability studies prior to investing financial and technical resources.

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DEDICATION

I dedicate this thesis to my grandmother, Bibi Najmai, who raised me after the early death of my mother and made sure that my father, my uncle, my brothers, and I received a good education despite the tumultuous situation in my country when I was growing up. Although she herself had no formal education, she supported and encouraged all of us to become educated in the various disciplines of interest to us. Whatever my family members and I accomplish in life is due to her influence.

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Chapter One:

Introduction

High altitude farmers around the world have a limited set of crops that are adapted to the short growing season and cold temperatures prevalent at high altitudes. Because of their short growing season requirement and cold weather tolerance, oilseed crop species are well adapted to high altitude growing conditions. In fact, high altitude climate tends to improve the oil quality of many oilseed species. Despite this suitability of oil seed crops for high altitude agriculture, little research has been published on the adaptability of particular species to particular altitudes in Colorado. Afghanistan has altitudes and environmental conditions similar to those in Colorado, suggesting that oilseed crops suited to Colorado might also be suited to Afghanistan. The purpose of this research is to investigate the suitability of several oilseed species to high altitude agriculture in Colorado and in Afghanistan, using field trials and the Growing Degree Day (GDD) concept.

Among environmental factors such as water availability and length of the growing season, the number of growing degree days has a major impact on the potential for successful cultivation of a crop species. The concept of growing degree days, developed by Reaumur proposes that the crop requires a minimum amount of heat over the growing season to develop and mature. Growing degree day requirements have not been developed for oilseed crops in Colorado, and thus research in this area is needed.

In addition, it is expected that growing degree day requirements for oilseed crops in high altitude areas of Afghanistan maybe similar to those for oilseed crops in high altitude areas of Colorado. Development of a model for predicating crop adaptability and growth potential in high altitudes of Colorado could benefit high altitude farmers in Afghanistan, where new crops are needed to diversify the cropping system and provide oil for human consumption and biofuel as well as a supply of meal for animal feed.

Like several other sectors in Afghanistan, the agriculture sector has been considerably affected by three decades of war and conflict. Besides on-going war and natural disasters, particularly extreme weather conditions and prolonged drought, poor infrastructure along with poppy cultivation and deteriorating security have left the agriculture sector extremely weak and shaken. Despite diligent efforts made by the international community to rebuild all war-affected sectors, the agriculture sector has not yet received much attention in terms of building research and extension capacity over the past decade. After the collapse of the Taliban regime, almost all agriculture assistance was focused on quick-impact projects with a greater emphasis on horticultural crops and administrative capacity building. Despite millions of dollars poured into the agriculture sector, this sector has still remained fragile and tenuous. Among the many challenges that the agriculture sector currently faces; lack of research capacity along with dysfunctional extension and outreach programs undermine the ability of Afghan agricultural scientists to develop potential crops that will help provide food security, offer an alternative to poppy cultivation and generate economic benefits in rural areas.

Transfer of technology, including knowledge and materials, from a developed area, such as Colorado, will facilitate and accelerate agriculture development in Afghanistan.

The research conducted in Colorado and in Afghanistan focuses on the following goals:

- To conduct adaptability trials to screen potential oilseed species in multiple high altitude locations of Colorado and Afghanistan
- To examine the Growing Degree Days (GDD) concept as a major factor in crop adaptability and technology transfer
- To evaluate germplasm of potential adapted species in Colorado and Afghanistan
- To introduce high altitude, high oil-content, adapted oilseed species and their varieties into Afghanistan (Technology Transfer)

Chapter Two:

Literature Review

Flax

Introduction and History

Flax, *Linum usitatissimum* L., is an oil seed crop in the family Linaceae. Evidence of use by humans dates back to about 8,000 B.C. in the Fertile Crescent (Hall et al., 2006; Vaisey-Genser and Morris, 2003). Flax is classified as a “Near East founder crop” along with emmer wheat, einkorn wheat, barley, lentil, and pea (Hancock, 1992). Flax seeds have been found next to cultivated wheat seeds in Turkey, Iran, Israel and Jordan, with an estimated date of 8,000 B.C. (Zohary and Hopf, 2000), suggesting that wild flax was utilized, although perhaps not domesticated, along with wheat. Vasey-Genser and Morris (2003) place the beginning of flax cultivation at about 7,000 B.C., while Hall et al. (2006) give a broad estimate of between 7,000 B.C. and 4,500 B.C. Anjum and Hussain (2007) report that flax was cultivated in the Middle East by Babylonians beginning around 3,000 B.C.

Flax stem fibers, the whole seed, and the oil extracted from the seed have been used for millennia. Flax fibers have been used to make cloth and paper (Flax Council of Canada, 2002; Ehrensing, 2008). The whole seed has been consumed as a cereal grain, and oil extracted from the seed has been used as cooking oil, as lamp oil, and as a medium in paint and varnish (Vaisey-Genser and Morris, 2003).

The medicinal properties of flax were recognized in ancient times (Pengilly, 2003; Vasey-Genser and Morris, 2003) and flaxseed is now making a comeback as a health food because of its lignans, high fiber content (about 28% on a dry-weight basis), and high percentage (23% on a dry-weight basis) of alpha-linolenic acid, one of the omega-3 fatty acids (Anjum and Hussain, 2007, Hall et al., 2006; Vasey-Genser and Morris, 2003). Several possible health benefits are claimed for flax, including protection against several kinds of cancer, reduction in blood cholesterol and blood glucose, and protection against coronary heart disease and stroke (Anjum and Hussain, 2007; Vasey-Genser and Morris, 2003).

The geographical origin of flax is either the Near East (Hancock, 1992) or the Indian subcontinent (Vasey-Genser and Morris, 2003). Biological diversity of the genus *Linum* is greatest in India, and flax easily could have been carried from India to the Middle East along a trade route (Vasey-Genser and Morris, 2003). In modern times flax cultivation has spread to all five continents (Hall et al., 2006). Although flax fiber is important in some countries, oil production is the predominant reason for flax cultivation today (Vasey-Genser and Morris, 2003). Data from 2002 show that the world leader in flax production is Canada, with about 33% of the worldwide total of 2 million metric tons of flaxseed. China is a distant second producer with 20%, followed by the United States, and India (Hall et al., 2006).

General Description

The flax family (class Dicotyledoneae, sub-class Rosidae, order Geraniales, family Linaceae) consists of about 300 species worldwide. The following description follows that presented by Diederichsen and Richards (2003). The flax family includes

shrubs and herbs; species with perennial, biennial, and annual life cycles; and subgroups used for oil, fiber, and forage, as well as several species cultivated for their ornamental value. In species for which the chromosomes have been counted, the somatic number ranges between $2n=16$ and $2n=80$, with $2n=18$ and $2n=30$ being the most common numbers. In cultivated flax, $2n=30$.

The taxonomy of the genus *Linum* is complex and no satisfactory system has yet emerged despite numerous attempts based on morphology, geographic origin, and winter or spring season growth habit. The flax species, *L. usitatissimum*, includes fiber-producing, oil-producing, and dual-use types of plants. The common English name for the plant is flax, but a distinction is made in Europe, where the fiber-producing types are called flax while the oil-producing types are called linseed.

The plant has an erect main shoot; the stem bears lateral branches from its basal part. In young plants, flax can develop and re-generate secondary basal sprouts if the leading shoot is injured. In fertile soils, flax tends to produce an increased number of basal shoots.

Branching in flax varies, and it depends on the type of flax and the density of planting. Flax mainly grown for seed purposes initiates secondary branches from the middle of the stem while fiber flax initiates branches only in the upper part of the stem (Diederichsen and Richards, 2003). However, when planted in a low density for seed production with plenty of available nitrogen, flax branches at the base similar to tillering in a cereal grain. However, if the plant population is very dense, this will suppress lateral branching. In fiber flax, a dense plant population with suppressed lateral branching is

preferred in order to increase the production of long fibers in the central stem (Diederichsen and Richards, 2003).

The plant height highly depends on growing conditions and the genotype, varying from 8 to 50 inches (20.3 to 127 cm) (Flax Council of Canada, 2002; Diederichsen and Richards, 2003; Ehrensing, 2008b). Flax grown for seed purposes is considerably shorter than fiber flax.

Flax has a tap root system. If good growing conditions allow, the root can penetrate 40 inches (101.6 cm) deep in to the soil (Flax Council of Canada, 2002; Berglund and Zollinger, 2007).

Flax is mainly a self-pollinated plant. However, during the flowering stage, frequent insect activities and visits may cause some cross-pollination. The inflorescence is panicle-like, with blooms occurring in clusters, and almost all the branches on the main shoot bear flowers. Flax flowers open in the early morning and drop most of their petals by noon. When the flowers open, pollination occurs (Flax Council of Canada, 2002; Diederichsen and Richards, 2003).

Although the plant undergoes one intensive flowering period, a small number of flowers may continue to appear until the seed pods ripen. During the ripening process, if soil fertility is high and moisture is available, the stem may remain green, and this may lead to a second period of “intense” flowering (Flax Council of Canada, 2002).

Flax blooms occur in clusters, which open at first light of the day (Cullis, 2007). The petals tend to drop in the early afternoon.

Flax varieties can be differentiated based on the color of different parts of their flowers. The petals vary from a dark to a very light blue or pale pink, yellow, white and

red (Flax Council of Canada, 2002; Diederichsen and Richards, 2003). Anthers can be blue or yellow and the style and filaments can be blue or colorless (Flax Council of Canada, 2002).

Seeds are produced in a boll or capsule (Flax Council of Canada, 2002; Berglund and Zollinger, 2007). The maximum number of seeds in a boll is 10; however, on average each boll contains 6 seeds (Berglund and Zollinger, 2007).

The boll has five elongated segments which are divided from each other by a wall called a septum. Each segment contains two seeds, which are separated from each other by a low partition called a “false septum”. Flax bolls usually do not open, thus, the seeds are retained (Cullis, 2007).

Flax seeds are smooth, flat and narrowed at one end (Anjum and Hussain, 2007; Flax Council of Canada, 2002). The size of seeds is about 0.1 x 0.2 x 0.06 inches (0.254 x 0.508 x 0.1524 cm) (Anjum and Hussain, 2007), but Vaisey-Genser and Morris (2003) and Diederichsen and Richards (2003) report a significant variation in seed size. Seed color mainly ranges from light to dark reddish brown or yellow, or alternately, from a reddish brown to a light yellow (Anjum and Hussain, 2007; Flax Council of Canada, 2002).

The flax seed coat consists mostly of mucilaginous material. The coat gives flax seed a shiny appearance. Mucilage absorbs water, so when the seeds get wet, they become sticky (Flax Council of Canada, 2002). The texture of flax seed is crunchy and chewy, which gives the seed a pleasant, nut-like taste (Anjum and Hussain, 2007).

Growth Stages

The Flax Council of Canada (2002) describes 12 distinct growth stages of the flax plant, based on Turner (1987) (Fig. 1). The first growing stage is cotyledon initiation and the second phase of growth is appearance of the shoot above ground. The third, fourth and fifth stages of growth include appearance of the first pair of true leaves, unfolding of the third pair of true leaves, and the stem extension, respectively. Bud initiation, first flowering and early branching, and complete flowering account for the sixth, seventh and eighth growth stages. The ninth, tenth, eleventh and twelfth growth stages account for the development of green seed capsules, brown capsules, ripe seed and mature plant, respectively.

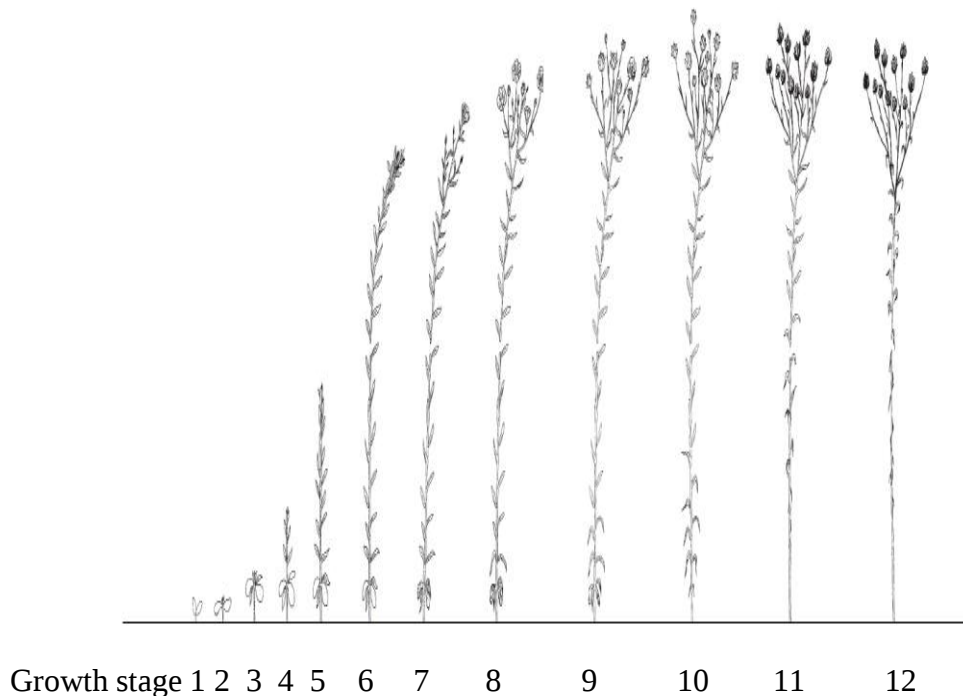


Figure 1. Flax growing stages (Turner, 1987)

Depending on growing conditions, flax requires around 90 to 110 days to mature (Flax Council of Canada, 2002; Berglund and Zollinger, 2007; Oplinger et al., 1989b).

The life cycle of flax includes vegetative, flowering and maturing phases. Flax requires 45 to 60 days to complete the vegetative stage, 15 to 25 days to flower, and 30 to 40 days to mature (Flax Council of Canada, 2002; Berglund and Zollinger, 2007; Oplinger et al., 1989b). In North Dakota, availability of moisture may extend the maturation period, and the plant maturity stage may continue until a hard frost kills the plant (Berglund and Zollinger, 2007).

Climate, Adaptation and Soil

Flax is adapted to a variety of climates across different geographic regions. Flax is cultivated as a summer annual crop in temperate climates (Diederichsen and Richards, 2003) and as a winter annual in mild climates (Ehrensing, 2008b). Flax is cultivated as both a spring and a fall crop in cool temperate regions such as the Northern Great Plains of the United States (North Dakota and Minnesota) and Southern Canada (Saskatchewan and Alberta) (Lisson and Mendham, 2000). In addition, flax is also well adapted to subtropical areas, where it is grown under short-day environments (Diederichsen and Richards, 2003). According to Diederichsen and Richards (2003) in the past, some Mediterranean, south, central and east European countries with a mild winter climate used to grow flax as a winter-annual. Flax is a day-length sensitive crop, requiring 12 to 14 hours of daylight to flower. Fiber flax tends to reach maturity earlier than oilseed flax in Northern latitudes (Diederichsen and Richards, 2003; FAO, n.d.).

Although the total annual rainfall is important, the crop benefits most from precipitation during flowering and seed filling. Abundant precipitation during these

stages is believed to increase oil content and oil quality (Ehrensing, 2008b; Oplinger et al., 1989b).

Although adapted to a variety of environmental and soil conditions, flax tends to do better in cool temperatures. Cool temperatures, particularly after the flowering stages, tend to increase yield and oil content. Cool temperatures may result in a preferred oil profile, specifically the percentage of linolenic acid (Ehrensing, 2008b). The optimum temperature requirement for growing flax varies from 60 to 75 °F (15.6 to 23.9 °C) . Flax seedlings are believed to survive in temperatures ranging from 13 to 25 °F (-10.6 to -3.9 °C) (Ehrensing, 2008b; FAO, n.d.). However, mature plants may not be able to withstand a killing winter frost (FAO, n.d.).

Flax tends to do well on well-drained silt-loam and clay-loam soils. It does poorly on sandy soil unless sufficient precipitation or irrigation is available. Flax seedlings are vulnerable to soil crusting, particularly on heavy soil. Seedling growth is retarded and stand establishment is impaired (Ehrensing, 2008b).

Cultural Practices

Fiber flax was planted in Oregon until the 1960s, when synthetic fibers mostly replaced flax in textiles. European fiber types are superior to U.S. fiber types, having twice as much fiber and greater resistance to diseases and lodging. Thus, oilseed flax is the predominant type grown in the United States and Canada today (Ehrensing, 2008b).

Most current varieties, regardless of relative maturity, are grown in both the northern Great Plains and Canada (Berglund and Zollinger, 2007). Little has been published related to cultural practices differing between the U.S. and Canadian flax cultivars.

Seed quality

In order to achieve good stand establishment, it is important to pay attention to seed quality. The flax seed coat is vulnerable to harvesting and handling damage (Oplinger et al., 1989b). The seedlings emerging from decayed seeds do not tend to be vigorous, and they are likely to grow slowly and develop seedling blights. Some of the abnormalities resulting from damaged seeds include injured root tips, broken or cracked cotyledons, split hypocotyls and twin radicles trapped inside the seed (Flax Council of Canada, 2002).

Seedbed Preparation

Flax requires a seedbed similar to small-seeded grasses, grains and legumes (Morgan et al., 2009; Oplinger et al., 1989b). A clean, moist and firm seedbed should be prepared for growing flax (Flax Council of Canada, 2002; Ehrensing, 2008b; Oplinger et al., 1989b).

When planting spring flax, it is important to perform field preparation as early as possible to maintain sufficient soil moisture for good stand establishment (Morgan et al., 2009). Planting flax as soon as the field is prepared results in less weed pressure and reasonable soil moisture (Flax Council of Canada, 2002). As an alternative way of reducing weed pressure, Morgan et al. (2009) suggest using a burndown application of herbicide to control early spring weeds prior to planting. Likewise, they also recommend applying a pre-plant and pre-emergence herbicide together.

When planting fall flax, it is important to harvest the previous crop as early as possible in order to proceed with preparation of the field in a timely manner (Morgan et al., 2009). Fall planting helps with weed control (Flax Council of Canada, 2002; Oplinger

et al., 1989b). However, in case of winter weeds in the field, such as stinkweed, flixweed, or shepherd's purse, pre-emergence application of low rates of 2,4-D or MCPA will help to control weed infestation (Flax Council of Canada, 2002).

When planting flax, it is important to pay careful attention to the planting depth. Both plowing and planting should be shallow (Flax Council of Canada, 2007; Oplinger et al., 1989b). Plowing too deep may result in moisture loss and may also increase weed pressure by bringing weed seeds to the surface where they germinate well (Flax Council of Canada, 2002). In areas where flax follows corn in rotation, however, a deeper tillage may be necessary.

Planting flax seeds in no-till fields is also a feasible option, particularly in Canada (Ehrensing, 2008b).

Planting date

Planting date plays an important role in seedling survival in the fall. Planting too early in the fall, perhaps during early August, may allow the crop to reach the bloom stage when freezing fall temperatures occur (Morgan et al., 2009). According to research conducted in Manitoba, Canada, late planting resulted in lower yields, smaller seed size and lower oil content (Flax Council of Canada, 2002). However, contrary to the recommendation for early planting, sometimes late planting may be preferred, particularly when herbicides are not available to control early spring weeds such as wild oats (Flax Council of Canada, 2002).

Avoidance of bloom damage in the spring, particularly in the high altitudes, is important. Although flax is relatively cold-resistant, particularly after branch initiation at the crown, the plant is susceptible to frost during the bloom stage. Therefore, planting too

late in the spring will result in damage to the blooms due to early fall frost (Morgan et al., 2009). However, a late planting may be necessary if high soil moisture and high soil temperature are not present in early spring (Flax Council of Canada, 2002).

Seeding Rate

Flax seeding rate varies, depending on seed size, seed color, seed germination percentage, seed treatment, seeding methods, soil nutrient status and weed pressure (Flax Council of Canada, 2002; Ehrensing, 2008b; Morgan et al, 2009).

When planting large size flax seed, the seeding rates varies between 1,800,000 and 3,240,000 seeds per acre (4,447,904 to 8,006,227 seeds per hectare) (Diederichsen and Richards, 2003; Morgan et al., 2009). For small size seeds, a lower seeding rate may be used; however, planting flax at a low seeding rate may result in increased weed pressure (Oplinger et al., 1989b). Contrary to Morgan et al. (2009), a higher seeding rate of 3,024,000 to 3,600,000 seeds per acre (7,472,479 to 8,895,808 seeds per hectare) of “good flaxseed” is sometimes recommended (Diederichsen and Richards, 2003; Oplinger et al., 1989b). However, a higher seeding rate may result in plant lodging (Flax Council of Canada, 2002). A higher seeding rate is recommended for planting yellow-coated flax seed due to lower germination. A higher seeding rate should be used when the seed is not treated to repel insects and fungal diseases (Flax Council of Canada, 2002). A seeding rate of 1,944,000 to 2,880,000 seeds per acre (4,803,736 to 7,116,646 seeds per hectare), assuming 50 to 60 percent seed emergence, will result in stand density of 25 to 48 plants per square foot (269 to 517 plants per square meter) and will achieve optimum flax yield (Flax Council of Canada, 2002; Diederichsen and Richards, 2003; Ehrensing, 2008b).

Seeding Depth

The usual planting depth for flax varies from 1 to 1 ½ inches deep (2.54 to 3.81 cm) (Flax Council of Canada, 2002; Ehrensing, 2008b; Oplinger et al., 1989b). However, according to research conducted at the University of Alberta, planting flax seed at 1 ½ inches (3.81 cm) may be too deep. They found a significant stand reduction with planting depth greater than 1.2 inches (3.05 cm) (Flax Council of Canada, 2002). In order to achieve satisfactory stand establishment, a drill equipped with a press wheel should be used to firm the soil surrounding the seeds; if the drill lacks a press wheel, a soil packer may be used to firm the soil after planting (Flax Council of Canada, 2002).

Fertilizer

A soil test is considered a crucial step prior to fertilizer application. In order to maximize flax yield, a soil test should be coupled with the yield goal and the farmer's experience related to a particular farm (Flax Council of Canada, 2002; Hardman, n.d.).

Nitrogen

Flax seedlings can be injured by fertilizer placed next to the seed. According to the Flax Council of Canada (2002), even low rates of seed-placed nitrogen fertilizer may cause serious seedling injury in the flax plant. Flax does not require an aggressive nitrogen fertilization strategy during the growing season (Franzen, 2004). Excessive nitrogen can result in plant lodging and an increased plant susceptibility to disease outbreak (Ehrensing, 2008b). Depending on soil and moisture conditions, the maximum nitrogen application rate for flax is about 80 pounds per acre (90 kg per hectare) (Franzen, 2004). If moisture is not a limiting factor, the higher end of the recommended range of nitrogen fertilizer should be used.

Phosphorus

Although seed-placed nitrogen fertilizer can damage seedlings, considerable research evidence supports application of seed-placed phosphorus (Flax Council of Canada, 2002). In Canada, some provinces recommend applying low rates of seed-placed phosphorus.

Research conducted in the United States and Canada found that phosphorus application is relatively ineffective and does not tend to increase flax yield (Flax Council of Canada, 2002). This is because mycorrhizae, which are fungi living symbiotically with plants appear to reduce flax response to phosphorus fertilizer (Franzen, 2004). However, if flax is grown following a non-mycorrhizal crop or after a fallow period when phosphorus level is relatively low, application of phosphorus can benefit flax (Franzen, 2004). If the soil test shows low phosphorus levels, it is recommended to apply 31 pounds per acre (35 kg per hectare) of broadcast phosphorus. Side-band application requires only one-fourth the amount of phosphorus needed to achieve the same level of yield that could be achieved with broadcast application (Flax Council of Canada, 2002).

Interestingly, according to Flax Council of Canada (2002), high soil phosphorus from the preceding crop in the rotation is more beneficial than phosphorus application on the current crop.

Potassium

Potassium deficiency may occur when flax is grown on sandy soils. If the soil test shows a low potassium level, a broadcast application may be made. It is recommended to avoid applications of 0-0-60 of potassium chloride if the flax is grown for seed (Franzen, 2002).

Micronutrients

Flax is considered sensitive to low levels of iron (Fe) and zinc (Zn). Under wet soil conditions in early spring, temporary iron deficiency can cause chlorosis (Flax Council of Canada, 2002; Franzen, 2004). However, with warmer and drier weather, chlorosis tends to disappear (Franzen, 2004). Foliar application of iron is ineffective because it stimulates the vegetative growth and green-up of the plant.

In flax, zinc deficiency is expressed as a condition known as “chlorotic die back”; plants with zinc deficiency are pale and the growing point may die (Franzen, 2002). Similar to the situation with iron deficiency, low rates of zinc may be applied.

Weed Control and Herbicides

Flax is generally not considered a strong weed competitor. The tolerance of flax to weeds depends on the type of flax. Flax grown for seed purposes tends to be less competitive, whereas, fiber flax seems to be quite competitive when densely planted. In contrast, when grown on wider row spacing, flax usually doesn't do well against weeds. Therefore, careful attention should be paid to weed control during early growth stages until the crop establishes itself and competes against the weeds (Ehrensing, 2008b). Weeds such as wild buckwheat and redroot pigweed can easily use soil nitrogen and can deprive flax of needed soil nutrients. They also can cause considerable losses due to dockage at the selling point (Flax Council of Canada, 2002). A bad infestation of summer weeds will also interfere with the harvesting process (Flax Council of Canada, 2002; Morgan et al., 2009).

Both summer and winter weeds can be a problem. Important winter weeds in flax include henbit (*Lamium amplexicaule*), clover (*Trifolium*), mustards (*Brassicaceae*), wild

carrot (*Daucus carota*) and several grasses; sunflower (*Helianthus annuus*), lambsquarters (*Chenopodium album*), Johnsongrass (*Sorghum halepense*) and thistles (*Asteraceae*) account for summer weeds in the United States and Canada (Flax Council of Canada, 2002; Morgan et al., 2009).

Weeds in flax can be controlled by both herbicide application and cultural practices.

Pre-emergence herbicide application may result in reduced seedling injury while it will also provide a better weed control than post-emergence applications (Flax Council of Canada, 2002).

Several cultural practices can be undertaken to considerably reduce weed competition. Among the cultural practices, tillage, weed free seeds, planting density, rotation and fertilizer application are important.

The Flax Council of Canada (2002) suggests spring tillage prior to planting flax. Early spring tillage promotes seed germination of weeds which can then be removed through either cultural practices or herbicide applications. However, early spring tillage may reduce soil moisture that is available for seed germination in upper soil layers. When tilling, special attention should be paid to tilling depth. Early spring tillage should not be deeper than 4 inches (10.2 cm). Additional tillage operations should be shallower than the first spring tillage to avoid exposing more weed seeds (Flax Council of Canada, 2002). Using weed-free seed will result in reduced weed problems in subsequent years (Flax Council of Canada, 2002). Proper crop rotation prevents buildup of weeds in later crops in the sequence. Therefore, recommended crop rotation in a flax cropping sequence should be followed (Flax Council of Canada, 2002). In Canada the following rotation

results in higher yields of flax: spring wheat (*Triticum aestivum*)/field pea (*Pisum sativum*) - flax- canola (*Brassica napus*) - spring wheat/field pea (Flax Council of Canada, 2002). In Texas, flax can be rotated with cotton (*Gossypium hirsutum*), corn (*Zea mays*), grain sorghum (*Sorghum bicolor*), or a summer legume (Morgan et al., 2009).

Because flax is vulnerable to early weed competition, planting flax as densely as possible will enhance plant competition against weeds (Flax Council of Canada, 2002).

Both pre-emergence and post-emergence herbicides are available (Table 1). Pre-emergence herbicides can be incorporated into the soil before planting or can be surface-applied after weeds emerge but before the crop emerges.

Post-emergence herbicides should be applied when weeds are in the seedling stage. Before applying post-emergence herbicides, both crop and weed growth stages should be checked to be sure that they conform to the recommendations on the herbicide label. The Flax Council of Canada (2002) recommends applying post-emergence herbicides when flax seedlings are 1 to 5 inches (2.54 to 12.7 cm) tall.

It is recommended that all post-emergent herbicides be applied well before the harvest. This ensures reduction of herbicide residue to acceptable levels when the crop is harvested (Flax Council of Canada, 2002).

Several broadleaf and grass weeds can be controlled by using appropriate herbicides. Broad leaf weeds can be controlled by using Bromoxynil, Curtail M, MCPA and Trifluralin; whereas grassy weeds can be controlled by using Poast and Select herbicides (Morgan et al., 2009). If necessary, in Canada, perennial weeds can be

removed immediately before harvest by applying glyphosate after the flax plant is ripe (Flax Council of Canada, 2002).

Table 1. Flax Herbicides (Based on Berglund and Zollinger, 2009)

Herbicide	Types of Weeds	Application Time
Aim	Small broadleaf weed	Post emergence
Assure II	Annual grasses and quack grass	Post emergence Flax: Herbicide label should be checked for pre-harvest interval (PHI)
Bromoxynil	Small broadleaf weeds	Flax: 2 to 8 inches (5.1 to 20.3 cm) tall
Bromoxynil + MCPA (Premix)	Broadleaf weeds	Post emergence
Clethodim	Annual and perennial grasses	Post emergence
Commando M Curtail M (clopyralid+MCPA)	Broadleaf weeds, including Canada thistle and perennial sowthistle	Post emergence. Flax: 2 to 6 inches tall (2.54 to 15.24 cm) Canada thistle: 4 to 6 inches (10.2 to 15.24 cm) tall
Glyphosate	Emerged grass and broadleaf weeds	Pre plant or any time prior to the crop emergence
MCPA	Broadleaf weeds	Post emergence
Poast (sethoxdim)	Annual grasses	Post emergence
Select	Grass weeds	Post emergence
Trifluralin	Grass and some broadleaf weeds	Pre-Plant Incorporated Fall

Flax is susceptible to herbicide residual effects from only a few herbicides. Flax plants affected by herbicide residual seem stunted and yellow at the growing point. The severity of injury due to herbicide residual depends on herbicide application time, rate and the soil type. Careful attention should be paid to re-cropping intervals written on herbicide labels to minimize and avoid herbicide injury (Flax Council of Canada, 2002).

Disease and Pest Management

Diseases

Diseases in flax are caused mostly by fungal pathogens as well as a few viruses and phytoplasmas. Bacteria and nematodes are not major factors in flax disease (Rashid, 2003).

Both types of flax, oilseed and fiber flax, can be infected by fungal diseases; the occurrence, severity, and the importance of disease varies significantly throughout different flax growing regions of the world (Rashid, 2003). Fusarium wilt, rust, pasmo and powdery mildew are the most important diseases of flax in the top flax producing areas of the world (Rashid, 2003; Flax Council of Canada, 2002).

Fusarium Wilt

In the past, fusarium wilt was a major concern in the United States, where resistant varieties of flax were lacking (Rashid, 2003). Currently, there are resistant flax varieties available commercially.

Fusarium wilt is caused by a seedborne and soilborne fungus called *Fusarium oxysporum* Schlechtend.: Fr.f.sp *lini*. The disease attacks plant roots, growing in water-conducting tissues and interfering with water uptake (Flax Council of Canada, 2002). The disease can easily build up in fields where flax has been continuously grown (Flax Council of Canada, 2002). There are reports of 100 percent yield losses in case of severe epidemics of disease, but these are rare (Rashid, 2003).

Rust

Rust, caused by *Melampsora lini*, is reported in all flax-growing regions of the world. In North America, the commercial varieties of flax are currently resistant, but rust

frequently develops new races to overcome the resistance developed by plant breeders (Rashid, 2003). The disease attacks leaves and causes them to dry down and drop off (Rashid, 2003). Disease development is favored by cool and moist weather, resulting in loss of both yield and quality (Rashid, 2003).

Pasmo

Pasmo is also known as spasm or *septoriosi*s. It is caused by *Septoria linicola* (Speg.) Garassini, a foliar pathogen that infects leaves, stems, and bolls. Pasmo usually causes the plant to dry and defoliate. Pasmo is widely spread in North and South America. Although, the disease starts at the seedling stages, the severity of pasmo is not generally recognized until boll setting and seed ripening. Pasmo usually causes premature ripening and weakening of the pedicels, resulting in heavy boll drop (Rashid, 2003).

Powdery Mildew

Powdery mildew is a common flax disease in Europe, Australia and Asia. In North America, the disease was not reported in Minnesota until 1997 when it spread to Western Canada (Rashid, 2003). The disease is caused by the fungus *Oidium lini* Skoric (Flax Council of Canada, 2002).

Powdery mildew usually appears as whitish powdery colonies on the leaves and causes heavy defoliation of leaves (Rashid, 2003). The result is low yield and oil quality (Flax Council of Canada, 2002).

Disease and Pest Management Summary

The following steps should be taken in order to control or reduce flax disease incidence (Symptoms and Control of Crop Diseases, n.d):

- Use disease-resistant varieties
- Rotate the field with recommended crops
- Plant disease-free seeds
- Treat seeds with fungicide
- Sow seed early
- Use good cultural practices to prevent development of disease

Insects

Insect pests of flax are few and have only minor economic impact on the crop (Wise and Soroka, 2003). Fields should be regularly scouted and insect control measures should be taken if needed.

Cutworm and grasshopper are the most important insect pests causing economic losses to flax in North America.

The larvae of many cutworm species, Lepidoptera: Noctuidae, attack flax in almost all areas of the world where flax is grown. Flax is attacked by two subterranean species of cutworms: the redbacked cutworm, *Euxoa ochrogaster* (Guen.), and the pale western cutworm, *Agrotis orthogonia* (Morr.) (Flax Council of Canada, 2002). These two species usually sever the stem at soil level (Wise and Soroka, 2003).

Army cutworms feed on foliage and cut the stem below the boll (Flax Council of Canada, 2002; Wise and Soroka, 2003). Army cutworm outbreaks have occurred in North Dakota, Alberta, and Saskatchewan (Flax Council of Canada, 2002; Glogoza et al., 2005).

Grasshoppers are a major threat in the prairie regions of North America. While the young grasshopper may attack the younger plants, the older grasshoppers can cause

more damage to the crop before harvesting. Grasshoppers chew through the more succulent portions of stem below the bolls causing large numbers of bolls to drop (Flax Council of Canada, 2002; Glogoza et al., 2005).

Harvest

There are two main approaches to harvesting flax in North America: direct combining and swathing followed by combining (Marchenkov et al., 2003). Direct combining is usually done when the crop is fairly dry and ready for harvesting, whereas swathing is usually done when the crop is still green and it requires further drying. The harvesting method in flax may depend on the height and planting time of the plants. Short straw types, are more appropriate for direct combining because the combine designed for small grain is able to handle short plants easily. On the other hand, long straw types are not easily handled by a small grain combine. Therefore, swathing will be an appropriate approach for harvesting these plants. Early-sown flax is easier to combine than late-sown flax in Canada because it has a better chance to mature under dry weather conditions (Flax Council of Canada, 2002). Although flax can be harvested with 18 percent moisture (Morgan et al., 2009), lower seed moisture, perhaps around 10 percent, is always recommended.

Flax tends to be ready for direct combining when 75 percent or more of the bolls have turned brown. Direct combining is usually associated with higher seed moisture content. After the crop is harvested, flax seed moisture content should be reduced to 10 percent by exposing the seeds to dry air with protection from the rain (Marchenkov et al., 2003).

Swathing flax is a desired method when late maturity and early fall frost are the problems. Chemical desiccation followed by swathing may accelerate “maturity” to prevent frost damage on flax seed (Marchenkov et al., 2003).

When swathing flax, it is always important to leave about 4 inches (10.2 cm) of stubble to hold the flax off the ground and help with the drying process. After exposure to a few days of dry weather, when the stems and leaves are dry and the seeds reach the desired moisture content, the flax plants may be ready to combine.

It is important to make sure that the combine adjustment is correct for threshing. During the threshing process, the seed coat of flax can easily be broken, especially if the cylinder speed is too high and the seed is dry. Combine adjustment should be done from time to time, depending on temperature, relative humidity and the condition of the plants (Flax Council of Canada, 2002).

Straw Management

Several methods of handling flax straw exist. Flax residue can be used as livestock feed, can be burned down in the field or can be chopped and spread across the field (Marchenkov et al., 2003). According to recent research, none of the methods appears to affect the yield of a succeeding crop such as wheat. However, in case of removing, burning or baling flax straw, the soil can become more vulnerable to erosion, particularly if summer fallow succeeds the flax crop. Therefore, in order to compensate for the loss of crop residue, planting a cereal crop as a following crop may be necessary. When the field is not left fallow and is continuously planted where soil is not exposed to water or wind erosion, maintaining crop residue is not of concern (Flax Council of Canada, 2002).

Storage

Flax requires more attention to storage conditions than wheat. Freshly harvested seed can maintain a high respiration rate for up to six weeks, contributing to high relative humidity, heat buildup and mold growth. Therefore, it is important to cool down flax seeds before putting them in storage (Flax Council of Canada, 2002). If green weed seeds are present, they will result in increased humidity and heat (Flax Council of Canada, 2002). Controlling broadleaf and grassy weeds and volunteer plants in the field will not only reduce heating and molding problems, but will also considerably reduce the amount of seed dockage at the selling point (Flax Council of Canada, 2002). Marchenkov et al. (2003) recommend swathing to achieve cleaner seed if the field is weedy.

Camelina

Introduction and History

Camelina sativa (L.) Crantz., also known as gold-of-pleasure, false flax, largeseed false flax, linseed dodder, leindotter, and Siberian oilseed, is a member of Brassicaceae family. In North America, it was mainly known as a weed (Fleenor, nd.; Lafferty et al., 2009; Putnam et al., 1993; Vakulabharanam, n.d.).

There are conflicting views about the origin of camelina. According to Hunter and Roth (2010), camelina is native to an area from Finland to Romania and east to the Ural Mountains; however, Putnam et al. (1993) believe that the plant is native to Central Asia and the Mediterranean.

Camelina was grown in Neolithic times. During the Bronze Age (3200 to 600 B.C.), camelina was cultivated in Europe for the first time. Camelina seeds were crushed and boiled for food, medicinal and lamp-oil purposes or camelina seeds were eaten before the crop was processed (Hunter and Roth, 2010). In the Iron Age (1200 B.C. to 400 A.D.), when the number of crop plants approximately doubled in Europe, camelina was mainly used as a plant for supplying oil (Putnam et al., 1993). Evidence also exists that camelina was planted in the Rhine River valley as early as 600 B.C. (McVay and Lamb, 2008; Putnam et al., 1993). After the Industrial Revolution, camelina oil was used as industrial oil. Camelina seeds were fed to caged birds while the straw was used as fiber (Putnam et al., 1993).

Prior to the 1940s, camelina was widely cultivated in Russia and Eastern Europe (Lafferty et al., 2009); however, after WWII, when higher-yielding crops appeared, camelina was largely replaced. Camelina's decline in Europe was mainly due to farm

subsidy programs that favored major commodity grains and oilseed crops with high yields (Hunter and Roth, 2010).

Although camelina is considered an ancient crop, little agronomic and crop improvement research has been done related to this crop. The agronomic and breeding potential of this crop has not been fully explored (Hunter and Roth, 2010; Putnam et al., 1993).

Recently, because of an increased interest in vegetable oil rich in omega-3 fatty acids, camelina production has increased (Hunter & Roth, 2010; Lafferty et al., 2009; Putnam et al., 1993). Camelina has potential as a low-cost feedstock for biodiesel production. The high- quality meal can be used in animal feed to produce high omega-3 eggs, broiler chickens, and dairy products. Camelina production can potentially be expanded in the future to meet these demands (Hunter and Roth, 2010).

Because of its high water-use efficiency and drought tolerance, greater spring-freeze tolerance, flea beetle resistance, better adaptation to marginal growing conditions, short production cycle, and ability to fit in a wheat-based crop rotation system, particularly in semiarid high plain areas, efforts are underway to produce camelina as a low-input crop in dryland areas. Montana, and other Northwestern states, as well as Alberta, Canada, are places where camelina production is taking place on large-scale dryland acreage (Ehrensing and Guy, 2008b Hunter and Roth, 2010; Lafferty et al, 2009).

General Description

Camelina can grow between 12 to 36 inches (30.5 to 91.4 cm) tall. Young plants usually form a rosette of foliage, which is close to the ground. Seedling leaves are small and are covered with hair, much like mouse-ear chickweed. The leaves are 2 to 4 inches

(5.1 to 10.2 cm)long, narrow-shaped and pointed with smooth edges (Hunter and Roth, 2010). Prior to flowering, stems elongate and become stiff and heavily branched (Grady and Nleya, 2010; Hunter and Roth, 2010).

Camelina has pale-yellow flowers that bloom in clusters at the top of the branches (Grady and Nleya, 2010). Flowers have four petals varying in color from pale-yellow to greenish-yellow (McVay and Lamb, 2008). Camelina is predominantly a self-pollinated crop that does not cross-pollinate with other crops, including other Brassicas (Lafferty et al., 2009; Vakulabharanam, n.d.).

Seed bolls produced in camelina are similar to those of flax (Ehrensing and Guy, 2009). Camelina seed pods are pear-shaped, and each one contains 8 to 10 seeds. The seedpods are more resistant to shattering than canola siliques (Grady and Nleya, 2010). Camelina seeds are very small, about ¼ inch (0.64 cm) long. The seed is oblong and rough with a ridged surface and has a pale yellow-brown color (McVay and Lamb, 2008).

Climate, Adaptation and Soil

Although usually grown as an early summer annual, some cultivars of camelina can be grown as a winter annual. Camelina is a cool-season crop, and is well-adapted to production areas in the temperate regions (Hunter and Roth, 2010).

Camelina is a short-growing season crop. Depending on soil and climate conditions, the crop matures between 85 and 100 days after planting (Fleenor, n.d.; Hunter and Roth, 2010). Unlike many spring crops, camelina can germinate at low soil temperatures, and the seedlings are very frost-tolerant (Ehrensing and Guy, 2008; Fleenor, n.d.; Hunter and Roth, 2010). The seedlings can withstand a temperature as low as 21°F (-6.1°C) (Hunter and Roth, 2010).

In addition to its frost-resistance, camelina is also a relatively drought-resistant crop. According to Grady and Nleya (2010), camelina is more drought- and frost-resistant than canola; camelina's performance under drought and stress conditions makes it a well-suited crop for low rainfall regions (Hunter and Roth, 2010). However, excessive drought and heat stress may result in reduced yield (Grady and Nleya, 2010).

Camelina can be successfully established under a variety of climatic and soil conditions. However, it does not tend to do well on heavy-clay and organic soils (Zubr, 1997) or on wet and poorly drained soils (Hunter and Roth, 2010).

Cultural Practices

Seedbed Preparation

Minimal seedbed preparation is required for planting camelina (Ehrensing and Guy, 2008). In order to out-compete early spring weeds, camelina should be planted as soon as the soil is workable. Camelina seeds are relatively smaller than those of most other oilseed crops and when planting camelina, it is important to maintain a good seed-to-soil contact in order to achieve better stand establishment (Vakulabharanam, n.d.). Lafferty et al. (2009) recommend drilling camelina seeds into a firm alfalfa-type seedbed as the most effective method of planting in the semi-arid high plain areas of the United States.

It is important to plant camelina in a field where sufficient moisture allows crop establishment. According to Lafferty et al. (2009), the most favorable results under the dryland conditions have been achieved when camelina was seeded into soils with a good moisture profile consisting of 2 to 3 feet (61 to 91 cm) of available soil moisture.

Planting Date

Because camelina is frost-resistant, it can be planted earlier than other spring crops. Early-spring planting tends to favor high yield and high oil content. According to research conducted in Idaho, when the planting date was delayed from 19 March to 19 April, yield was reduced by 25 percent (Ehrensing and Guy, 2008).

Seeding Rate and Depth

The seeding rate of camelina varies depending on soil and moisture conditions. Camelina yield, maturity and competition with weeds are influenced by stand density; therefore, seeding rate is considered highly important (Vakulabharanam, n.d.).

According to McVay and Lamb (2008), a pound of camelina contains approximately 400,000 seeds; therefore, a seeding rate of 5 pounds per acre (5.6 kg per hectare) will provide a density of 45 seeds per square foot (484 seeds per square meter). Even if all the seeds are not able to produce plants, this density would be enough to ensure an adequate stand.

In Europe, camelina is usually planted at a rate of 2,230,800 to 2,974,400 seeds per acre (5,512,436 to 7,349,914 seeds per hectare). However, according to recent trials conducted in Montana, a seeding rate of 1,115,400 to 1,859,000 seeds per acre (2,756,218 to 4,593,696 seeds per hectare) resulted in an adequate stand establishment. This low seeding rate results in a lower cost for seeding compared to canola, sunflower and flax (Enjalbert and Johnson, 2011). Since camelina seeding rate varies from field to field, depending on field conditions such as moisture, when the field condition is not favorable, a higher seeding rate might be used (Ehrensing and Guy, 2008; McVay and Lamb, 2008; Nielsen, n.d.).

Because camelina seed is relatively small, a shallow planting depth of $\frac{1}{4}$ inch (0.64 cm) is recommended (Enjalbert and Johnson, 2011; Zubr, 1997).

Fertilizer

Camelina requires low to moderate soil fertility levels (Hunter and Roth, 2010; Zubr, 1997). In order to determine the residual level of soil fertility, a soil test should be performed. Although considered a low-input crop, camelina still needs an adequate level of soil fertility to produce ideal yield (Grady and Nleya, 2010). Camelina fertility needs are similar to those of the crops in the mustard family with the same yield potential, such as canola (Putnam et al., 1993).

There are different methods of fertilizer placement in camelina. Pre-planting, post-planting or mixed application of fertilizer can be made (Hunter and Roth, 2010). McVay and Lamb (2008) suggest that broadcast application of fertilizer before or after planting does not cause any problem.

Nitrogen

Camelina response to nitrogen applications is similar to that of other crops in the mustard family. The trials conducted in Montana have shown a yield increase in response to up to 50 pounds per acre (56 kg per hectare) nitrogen application (Ehrensing and Guy, 2010). According to the recommendations from Montana, the typical nitrogen requirement is 35 to 40 pounds of nitrogen per acre (39 to 45 kg per hectare) for a field where yield ranges from 1200 to 1500 pounds per acre (1,345 to 1,681 kg per hectare). According to Lafferty et al. (2009), one pound (0.45 kg) of nitrogen is required to produce 25 pounds (11.3 kg) of camelina yield in the Great Plains. A similar recommendation from Montana urges the use of 70 to 90 pounds per acre (78.5 to 101 kg

per hectare) nitrogen for a 1500-pound per acre (1,681 kg per hectare) yield, or approximately 1 pound (0.45 kg) of nitrogen per 20 pounds (9.07 kg) of camelina seed production. However, under dryland conditions, where water is a limiting factor, farmers tend to use lower rates of nitrogen (Grady and Nleya, 2010). Unlike many other crops, in camelina, the natural, pale green color should not be confused with nitrogen deficiency (McVay and Lamb, 2008).

Phosphorous

Camelina's response to phosphorus is similar to that of other crops in the mustard family. According to fertility trials conducted in Montana, a yield response with up to 60 pounds per acre (67.25 kg per hectare) phosphorus was observed (Ehrensing and Guy, 2010). However, according to Grady and Nleya (2010), camelina has not shown any yield response to additional applications of phosphorus when soil availability is greater than 12 ppm.

Potassium

Generally, camelina doesn't tend to respond well to potassium applications; however, at a minimum the level of potassium in the soil should be maintained at 16 ppm (Grady and Nleya, 2010).

Micronutrients

Similar recommendations to those for crops in the mustard family can be made for micro nutrients in camelina, but there is no literature supporting this recommendation.

Weed Control and Herbicides

Early camelina stand establishment is important to ensure minimal weed pressure (Hunter and Roth, 2010).

It is common to plant camelina without using herbicides. Winter-seeding of camelina is a very good strategy to compete with and control early-spring weeds. When winter-seeded, camelina will germinate earlier than many spring weed species. Camelina can inhibit the growth of other plants because of its allelopathic properties. However, it is not a good competitor against winter weeds such as bindweed (*Convolvulus arvensis*), amaranth (*Amaranthus*) and kochia (*Kochia scoparia*) (Ehrensing and Guy, 2008).

Cultural practices

Cultural practices along with chemical control measures can be important ways to control weeds in camelina. A dense and uniform stand along with good chemical and mechanical control measures will result in better suppression of weed growth (McVay and Lamb, 2008).

Planting camelina as early as possible will result in minimal weed problems (Hunter and Roth, 2010). Fall planting of camelina has competitive advantages over spring planting. It is the most effective measure for spring weed control.

Although camelina seeds are very small compared to other oilseed crops, their early emergence and cold tolerance, particularly when planted at high density, provide outstanding competition with annual weeds. However, camelina tends to be not very competitive with perennial weeds (Vakulabharanam, n.d.). When planting camelina, fields with low weed pressure, especially of broadleaf species, should be selected (Grady and Nleya, 2010). Camelina should not be planted in fields infested by scentless

mayweed (*Matricaria inodora*), fat hen (*Chenopodium album*), common hemp nettle (*Galeopsis pubescens*), couch grass (*Agropyron repens*), and creeping thistle (*Cirsium arvense*) (Zubr, 1997).

Herbicides

Trifluralon can be applied before planting to control broadleaf weeds (Zubr, 1997). Camelina tends to be susceptible to broadleaf competition during rosette stage, prior to bolting, but once the crop is established, it is quite competitive (Grady and Nleya, 2010). Poast® is the only post-emergent herbicide labeled for camelina. It will control only grassy weeds, not broadleaf weeds.

Herbicide Residue

Guidelines for sensitivity of canola to soil residual herbicides should be followed for camelina. However, camelina is particularly sensitive to sulfonylurea (SU) herbicides such as Ally/ Escort (Metsulfuron), Amber (Trisulfuron), Express (Tribenuron), Atrazine (triazane) (Enjalbert and Johnson, 2011).

Camelina leaves its own herbicidal residue in the soil. According to Hunter and Roth (2010), the residual effect of herbicide in camelina is short-lived, and is fairly weak. This allelopathic effect usually does not harm crops planted following camelina (Hunter and Roth, 2010).

Disease and pest management

Diseases

Generally, camelina is considered to be a disease-resistant crop. Camelina tends to show good resistance against some of the most common pests and diseases affecting brassica oilseeds. This relatively better disease resistance is due to the production of

antimicrobial compounds in the roots (Vakulabharanam, n.d). The potential diseases that affect camelina production include sclerotinia stem rot, alternaria blight, downy mildew, powdery mildew and blackleg (Grady and Nleya, 2010).

Sclerotinia Stem Rot

Sclerotinia stem rot is caused by the fungus *Sclerotinia sclerotiorum*. The symptoms are similar to those in canola (Vakulabharanam, n.d.). Although camelina is highly susceptible to sclerotinia stem rot, no major outbreak has been reported. Sclerotinia weakens the plant stem, causing losses from lodging and early ripening. The disease is usually managed by proper crop rotation (Ehrensing and Guy, 2008).

Downy Mildew

Downy mildew is usually caused by *Perenospora parasitica*. Downy mildew is usually associated with white rust. The disease can be both localized and systemic (Vakulabharanam, n.d.). In the United States, downy mildew has been found on some trials in Montana (Hunter and Roth, 2010).

Downy mildew is a seed-born fungal disease. Seeds from infested field should not be saved for next year planting. Planting pathogen-free seeds is the most effective method of controlling the disease. Lower stand density, good air movement through the canopy, reduced irrigation, and reduced plant population will limit the spread of the fungus on camelina (McVay and Lamb, 2008).

Clubroot

Camelina is highly susceptible to clubroot. According to research in Alberta, Canada, clubroot causes similar symptoms on camelina as it does on canola. Currently,

there is no resistance against the disease; the only good prevention strategy is crop rotation (Vakulabharanam, n.d.).

Insects

Insect pests have not been a major concern in camelina; however, a few insects tend to cause damage. The use of control measures has rarely been reported (Grady and Nleya, 2010; Ehrensing and Guy, 2008). Flea beetles (*Phyllotreta cruciferae*), cabbage seed pod weevil (*Centorhynchus obstrictus*), and brassica aphid complex attack camelina, but do little economic damage (Ehrensing and Guy, 2008). Unlike canola, camelina can be quite tolerant against the flea beetle (Grady and Nleya, 2010).

Harvest

Camelina harvesting dates vary from late June to late July, depending on planting date, precipitation, temperature and harvesting method (McVay and Lamb, 2008). Unless weed population is large and affects the harvesting process, swathing is not recommended in camelina. Direct harvesting is preferred over swathing (Lafferty et al., 2009).

Camelina tends to be ready for direct harvest when the pods turn golden to golden-tan, although the lower stems may still look green. Maturity can be reached within a couple of days of the appearance of the first yellow pods in the field, depending on temperature (McVay and Lamb, 2008). Camelina should be harvested when the seed moisture is about 8 percent to ensure storage quality (Lafferty et al., 2009).

Although camelina pods are not prone to shattering, strong impacts can break them. Thus, damage from the reel batting during direct cutting should be avoided. It is important that the reel speed matches the ground speed (McVay and Lamb, 2008). In

order to ensure that the entire crop is harvested, header height should be set as high as possible. Since camelina seeds are very small, airflow should be regularly monitored and adjusted in order to remove as much inert material as possible while minimizing seed loss (McVay and Lamb, 2008).

Swathing

Swathing is generally not a preferred method of harvesting in camelina unless significant green weeds and lodging are issues. If done, swathing should start when about two-thirds of the pods have turned from green to yellow (Hunter and Roth, 2010).

Threshing

Combine setting for threshing camelina is similar to that for canola. In case of direct cutting, the speed of the combine fan must be reduced to minimize seed losses. Unlike many other Brassicas, camelina pods tightly hold their seeds, and shattering is generally not a problem (Hunter and Roth, 2010). Small opening screens designed for alfalfa are useful to separate camelina seed from the hulls (Ehrensing and Guy, 2008).

Storage

Camelina seeds can easily be damaged by high moisture conditions. The recommended storage moisture for camelina seed is 8 percent or lower. Higher seed moisture content, higher than 10 percent, will result in a “clump” of seed. So far, there has been no report of insect damage during bin storage of camelina.

Sunflower

Introduction and History

Sunflower, *Helianthus annuus* L., is a member of Compositae family. The genus *Helianthus* has about 37 species and among these about 17 are grown for ornamental purposes (Salunkhe, 1992). *Helianthus* is derived from the Greek “helios” meaning sun and “anthos” meaning flower (Weiss, 2000).

It is believed that sunflower probably originated in the region that is currently the southwestern United States and Mexico, where inhabitants used its seed as a source of food (Weiss, 2000). Evidence shows that the crop has been grown in Arizona and New Mexico for about 5,000 years (Semelczi-Kovacs, 1975 as cited in Putt, 1997).

Archaeological evidence has shown that sunflower has been used among American Indians (Putt, 1997). In a review of food plants of the North American Natives, sunflower was considered a main staple of people living from the Arctic Circle to the Tropics and from the Missouri River to the Pacific Ocean (Harvard, 1895 as cited in Putt, 1997).

In the western United States, American Indians have used wild sunflower, *Helianthus annuus* ssp., in food, in medicine, and in ceremonies (Putt, 1997). According to Heiser (1945) as cited in Putt (1997), it is believed that sunflower may have been planted by American Indians of Eastern United States as a major source of food before corn was known as a food staple. Indians ground sunflower seeds into flour to bake cakes and make mush (Putt, 1997). According to Whiting (1939) as cited in Putt (1997), the Hopi Indians, who settled in the Southwestern United States, used sunflower seeds for

different purposes. They cooked “piki” bread on a hot piki-stone. They also split the seeds and ate them as nuts (Heiser, 1945; Whiting, 1939 as cited in Putt, 1997).

Sunflower had many non-food uses among the Indians of North America as well. Sunflower seeds were used as the main source of dye in basketry, textiles, and painting the body (Whiting, 1939 as cited in Putt, 1997). The stems were used to build a “ventilated” hood used for cooking on the piki-stone. According to Jenness (1958) and Harvard (1951) as cited in Putt (1997), sunflower oil was used to smooth hair and skin.

Sunflower is considered a “camp follower” of many of the Native American tribes, who were settled in western parts of America. After they domesticated sunflower, they carried the crop eastward and southward throughout North America (Putman et al., 1990). Sunflower was introduced into Europe by early Spanish explorers (Putt, 1997). European explorers took the crop back to the Old World in the sixteenth century, and it was then re-introduced to North America by Europeans in the late nineteenth century (Weiss, 2000).

After soybean, rapeseed, and peanut, sunflower is ranked as one of the four most important annual oilseed crops of the world, grown mainly for edible oil (Putt, 1997). In the past, the former Soviet Union was the biggest producer of sunflower in the world, with about 50% of commercial sunflower production originating there. However, after the 1990s, Argentina became the world’s largest sunflower-seed exporter (Weiss, 2000). Production in Argentina declined after 2004 and major production has shifted back toward Eastern Europe (National Sunflower Association, 2012).

Sunflower is also produced in Europe, Asia and the United States. In the United States, North Dakota, South Dakota, Minnesota, and Texas are the main producers. Until

now, Europe has remained the biggest market for sunflower oil (Weiss, 2000). According to Salunkhe (1992), in 1988, the world production of sunflower was 21 million tons grown on over 15 million hectares.

Until the late eighteenth century, sunflower was grown only as an ornamental crop in Europe. Then oil types were developed from ornamental types by Russian plant breeders, who have been widely recognized for their work on sunflower (Salunkhe, 1992).

During the period of time from the 1920s to 1955, the Russian breeders were able to increase the oil content of sunflower from 28% to nearly 50% (Heiser, 1976). Development of sunflower varieties suitable for mechanized harvesting and the introduction of dwarf and high-yielding hybrid cultivars established sunflower as a key international oilseed crop (Weiss, 2000).

Sunflower is currently primarily grown for oil purposes (Salunkhe, 1992). Sunflower seeds are rich in both protein and oil, and the oil contains a high percentage of unsaturated fatty acids and high levels of fat-soluble vitamins (Salunkhe, 1992).

The oil content of sunflower varies depending on field and environmental conditions, and can rise as high as 50%. Sunflower oil mainly consists of palmitic, stearic, oleic and linoleic fatty acids. Sunflower oil has a higher amount of unsaturated fatty acids than any other oilseed crop (Salunkhe, 1992).

Oil contributes about 80% of the value of the crop; the oil is mostly used as a cooking medium, salad oil, margarine, and in the manufacturing of shortening. Inferior grades of sunflower oil are used for industrial purposes, such as soap manufacturing and in paints and varnishes (Salunkhe, 1992).

Having high iodine value and low linoleic acid content, sunflower oil could potentially be used in the manufacture of lacquers, copolymers, polyester films, and modified resin (Salunkhe, 1992). Sunflower seeds, usually fried and mixed with salt, are used for human consumption in various countries. Sunflower seeds are fed to birds as well.

General Description

Sunflower is an annual, broadleaf, and erect plant (Putman et al., 1990). It has a strong stem. The stem is circular in cross section with a diameter of 1.5 to 2.5 inches (3.81 to 6.35 cm) and sometimes as wide as 4 inches (10.2 cm). The stem tends to be round during the early growth stages, but becomes angular, woody and stiff during the later growth stages. The stems are generally branchless (Putman et al., 1990). Stem elongation varies depending on the particular type of sunflower. The dwarf types usually grow to a height of 3.5 to 7 feet (107 to 213 cm). Grain types can reach 16 feet (488 cm) (Weiss, 2000).

Sunflower has dark green leaves with occasional blue or red tinges. The leaves are alternate or occasionally opposite. Each plant has about 20 to 40 leaves (Weiss, 2000); but the number of leaves, their expansion, size and duration on a sunflower depend on environmental conditions (Schneiter, 1997). The leaves are considered phototropic, and they follow the sun's rays. The phototropic properties of the leaves tend to result in an increased light interception and possibly an increased photosynthesis (Putman et al., 1990).

Sunflower's good performance under dryland conditions is attributed to its deep "explorative" root system, which enables the plant to absorb a considerable amount of water from deep soil layers. The strong tap root develops prolific lateral extensions that

increase the surface area of the roots (Putman et al., 1990). Sunflower roots can penetrate as deep as 7 feet (213 cm), depending on soil condition and moisture availability (Angadi and Entz, 2002).

The sunflower head consists of 1,000 to 2,000 individual flowers connected by a common receptacle. The ray flowers around the circumference are sterile while disk flowers in the center are perfect, having both stamens and pistils (Putman et al., 1990). Sunflower is a cross-pollinated crop. Honey bees are the main pollinators (Putman et al., 1990; Weiss, 2000), and bee colonies tend to increase crop yield (Putman et al., 1990).

Climate, Adaptation and Soil

Sunflower is grown in different semi-arid regions of the world. Although the plant tolerates both high and low temperatures, it tends to be more tolerant in lower temperatures. Although seeds can germinate at 39 °F (3.9 °C) , better germination requires temperatures between 46 and 50 °F (7.8 and 10 °C). Temperatures less than 28 °F (-2.2 °C) may kill the maturing sunflower plants. The optimum temperature for sunflower growth varies between 70 and 78 °F (21.1 and 25.6 °C); however, the crop can tolerate a wider range of temperatures. Extremely high temperature, usually more than 90 °F (32.2 °C), leads to lower oil content (Putnam et al., 1990).

Sunflower is a fairly drought-resistant crop. According to the definition by Blum (2005), it avoids dehydration by enhanced capture of soil moisture due to its long roots. The crop is insensitive to day-length and is considered a short duration plant, requiring about 110 days from planting to harvesting (Putnam et al., 1990; Salunkhe, 1992).

The sunflower oil profile varies, depending on latitude. In high latitudes, the oil has higher linoleic acid content and the ratio of polyunsaturated to saturated fatty acids is higher, compared to oil produced in low latitudes (Putnam et al., 1990).

Although the crop tends to do well in warm-temperate regions, sunflower breeding has enabled the crop to adapt to a variety of environments (Weiss, 2000).

Sunflower is usually grown in areas and seasons where average daily temperatures vary from 70 to 85 °F (21.1 to 29.4 °C). However, the crop may withstand temperatures as low as 37 °F (2.8 °C) while still producing seeds (Weiss, 2000).

Sunflower yield performance reportedly is better at lower altitudes. However, the crop can be grown at altitudes as low as sea level and as high as 8,000 feet (2,438 meters).

The crop is cultivated from 40 S to 55 N. However, it tends to do better and has maximum production between 20 and 50 N and between 20 and 40 S (Weiss, 2000). Sunflower does well on a variety of soils. It does well on sandy to clay soils with good drainage. Sunflower has poor tolerance to salt and is less salt-tolerant than corn, wheat, rye (*Secale cereal*), sorghum, barley (*Hordeum vulgare*), and sugar beet (*Beta vulgaris*). Sunflower's salt tolerance is slightly better than that of field bean or soybean (Putnam et al., 1990).

Cultural Practices

Sunflower is usually cultivated in rotation with cereals, soybean, safflower, sorghum, and corn. Sunflower in a crop rotation sequence can control grassy weeds, reduce the number of parasitic weeds, and prevent outbreaks of pests and diseases in the field (Weiss, 2000). When used for intercropping, sunflower increases beneficial insect

activity, leading to high levels of insect pollination and consequently to increases in yield (Weiss, 2000).

Seedbed Preparation

Sunflower seems to be well adapted to large and small acreage cultural practices (Lzekor and Porter, n.d.). Appropriate seedbed preparation, which ensures a uniform and rapid seedling emergence, is required for successful stand establishment of sunflower.

Different tillage systems can be used efficiently for sunflower production (Putman et al., 1990). Sunflower may grow well under a no-till system (Lzekor and Porter, n.d.), which will require the use of labeled herbicides (Lzekor & Porter, n.d.). Sunflower doesn't tolerate water-logging. Therefore, seeding in poorly-drained soil should be avoided (Lzekor and Porter, n.d.).

Planting date

Sunflower can be planted over a wide range of dates. Generally, sunflower is planted as early as May 1 through June 10. In the southern U.S, planting any time from mid-March through early April is acceptable (Putnam et al., 1990). Since sunflower is not a photoperiod-sensitive crop, in areas where temperature is constantly high, sunflower can be planted anytime during the year (Putnam et al., 1990).

There are some potential advantages and disadvantages to early and late plantings. Early planting often results in higher yield and oil content due to more favorable temperature and moisture conditions. However, early planting tends to attract insect larvae that damage the sunflower head, requiring insect control to avoid yield losses. Later planting results in a high proportion of linoleic acid, thus improving the oil profile

(Putnam et al., 1990). But test weight is likely to decrease as a result of late planting (Putnam et al., 1990)

Seeding Rate

The desirable plant population for sunflower varies greatly depending on the type. In oil-types, a plant population of 15,000 to 25,000 plants per acre (37,066 to 61,776 seeds per hectare) is recommended; whereas for confection sunflower, 14,000 to 20,000 plants per acre (34,595 to 49,421 plants per hectare) is recommended (Lzekor and Porter, n.d.).

Seeding Depth

Unlike camelina, sesame, and mustard seeds, sunflower seed is large. An appropriate seeding depth, anywhere from 1 to 3 inches (2.54 to 7.6 cm), will maintain good soil-to-seed contact (Putnam et al., 1990). Planting sunflower too deep will result in a reduced stand. In crusting soil, a shallower depth is recommended (Putnam et al., 1990).

Fertilizer

Sunflower requires only moderate levels of N, P, K fertilizers (Putnam et al., 1990). A soil test is recommended to determine current soil fertility levels.

Sunflower stover is high in macronutrients, when returned to the soil, are available to the next crop when stover is returned to the soil (Putnam et al., 1990).

Nitrogen

Nitrogen can be applied pre-plant, side-dress, or a combination of these methods (High Plain Sunflower Production Manual, 2009). The general recommended nitrogen

rate for sunflower is 50 pounds per acre (56 kg per hectare) pre-plant and top-dress and 75 pounds per acre (84 kg per hectare) side-dress in Arkansas (Lzekor and Porter, n.d.).

Nitrogen recommendations may vary, depending on the preceding crop. For sunflower following fallow or legume sod, small grain or soybean, and corn or sugar beet, recommendations are 18, 60, and 80 to 100 pounds per acre (20.2, 67.25, and 89.7 to 112.1 kgs per hectare), respectively (Putman et al., 1990).

Excessive nitrogen application tends to decrease oil content and increase plant lodging, leading to lower yields (High Plains Sunflower Production Handbook, 2009).

Phosphorus

In fields where moisture and other environmental factors do not limit the expected yield, sunflower has shown consistent response to phosphorus application in soils testing low in phosphorus. The response in medium phosphorus soils is not as great as in lower ones (High Plains Sunflower Production Handbook, 2009).

The recommended phosphorus application rate for sunflower is about 25 to 30 pounds per acre (28 to 33.6 kg per hectare), depending on residual phosphorus in the soil, and previous crop in the rotation (Lzekor and Porter, n.d.).

Phosphorus applications can be made as pre-plant, broadcast, pre-plant-knifed, or banded at seeding (High Plains Sunflower Production Handbook, 2009).

Potassium

Potassium deficiency is less likely to be a problem than nitrogen and phosphorus deficiency. Potassium deficiency is most likely to be seen in sandy soils (High Plains Sunflower Production Handbook, 2009). If necessary, the potassium application rate in sunflower varies from 30 to 40 pounds per acre (33.6 to 44.8 kg per hectare) (Lzekor and

Porter, n.d.). Application of potassium can be made as pre-plant, broadcast or starter (High Plains Sunflower Production Handbook, 2009).

Micronutrients

Sunflower tolerates low soil iron availability (High Plains Sunflower Production Handbook, 2009). Boron deficiency is sometimes seen in sunflower, particularly on sandy and silt-loam soils (Lzekor and Porter, n.d.).

Weed Control and Herbicides

Once established, sunflower competes well with weeds (Lzekor and Porter, n.d.). Grassy weeds can be effectively managed by tillage and by applying herbicides. Several pre-plant herbicides including Prowl, Sonalan, Eptam and trifluralin can be applied to control grassy weeds (Lzekor and Porter, n.d.; Myers, 2008). In contrast, broadleaf weeds are more difficult to control by tillage and few herbicide options are available. Only two broadleaf herbicides are labeled for sunflower: Spartan and Beyond TM(Meyer, 2008).

Disease and Pest Management

Diseases

Diseases in sunflower are most often caused by fungi. The following are most important on sunflower (Putnam et al., 1990).

- Downy mildew- *Plasmopara halstedii*
- Powdery mildew- *Erysiphe cichoracearum*
- Leaf spot- *Septoria helianthi*
- Verticillium wilt- *Sclerotinia sclerotiorum*
- Rust- *Puccinia helianthi*
- Head and stem rot- *Verticillium dahlia*

- Phoma black stem- *Phoma macdonaldi*

Insects

Pest infestation in sunflower is similar to that in corn. Many insects feed on sunflower (Myers, 2008). The following are some of the most important (Putnam et al., 1990).

- Sunflower moth- *Homoeosoma electellum*
- Banded sunflower moth- *Cochylis hospes*
- Sunflower bud moth- *Suleima helianthana*
- Sunflower midge- *Contarinia schulzi*
- Sunflower headclipping weevil- *Haplorynchites aeneus*
- Sunflower beetle- *Zygogramma exclamationis*
- Sunflower maggot- *Strauzia longipennis*
- Red sunflower seed weevil- *Smicronyx fulvus*
- Gray sunflower seed weevil- *Smicronyx sordidus*
- Sunflower stem weevil- *Cylindrocopturus adspersus*

Harvest

Sunflower needs 120 to 130 days from planting to harvest (Lzekor and Porter, n.d.). Physiological maturity of sunflower takes place when the back of the head turns from green to yellow, and the bracts are turning brown (Putnam et al., 1990; Lzekor and Porter, n.d.). The seed moisture at this stage, when the head color turns yellow, has been reported to be about 35 percent (Lzekor and Porter, n.d.). Harvesting sunflower at this high moisture stage has been reported when there is a need to decrease bird damage,

lodging and seed shattering (Lzekor and Porter, n.d.). However, sunflower is often harvested long after maturity (Putnam et al., 1990).

Sunflower seed moisture should be below 12 percent for short-term storage; however, for long-term storage, the seed moisture should be below 10 percent (Putnam et al., 1990). In freezing temperature, seed storage at up to 15 percent seed moisture has been reported, but when the weather gets warmer, the seeds are likely to spoil in a few days (Putnam et al., 1990).

Safflower

Introduction and History

Safflower, *Carthamus tinctorius* L., is one of 25 species belonging to the genus *Carthamus* L. in the family of Compositae (Salunkhe, 1992; Weiss, 2000). Safflower is also known as false or bastard saffron, dyer's saffron, kardi, kusumba, cartamo and suff (Salunkhe, 1992).

Safflower is considered one of the world's oldest crops (Salunkhe, 1992). According to Johnston et al. (2002), Middle East and South Asian regions are considered as the origin for safflower. Weiss (2002) indicates an area, which is bounded by the Mediterranean and Persian Gulf, as a potential origin of safflower cultivation. Safflower is believed to have been introduced into Egypt from the Euphrates region around 2,000 BC.

Historically, safflower was grown for its flowers, which are used for dyes, medicines and flavoring purposes (Johnston et al., 2002; Salunkhe, 1992). According to Weiss (2002), the carpet weavers of the Irano-Afghanistan area used safflower petals as a source of dye from ancient times.

Safflower has been grown as a minor crop throughout different regions of the world; the annual seed production is estimated at 800,000 tons (Johnston et al., 2002). China, Kazakhstan, Argentina, Uzbekistan and the Russian Federation are considered important producers of safflower (Baydar and Gokmen, 2003).

In the United States, California accounts for 50 percent of the production of safflower, while the rest of the crop production mainly takes place in North Dakota and Montana, with very small-scale production in South Dakota, Idaho, Colorado, and

Arizona (Oelke et al., 1992). In the United States, safflower is mainly adapted to small-grain production areas in the Western Great Plains. Although safflower production in the Great Plains started as early as 1925, oil content was too low to permit extraction, so safflower was not considered a profitable oilseed crop. The Nebraska Agriculture Experiment Station developed improved varieties that contained 30 percent oil (Oelke et al., 1992).

Safflower is used for both food and non-food purposes. Food purposes include cooking and frying oil, margarine, mayonnaise, salad dressing, frozen desserts and breads. The meal is used as animal feed and the seeds are sold for birdseed. The non-food use of safflower oil is mainly in manufacturing paints, urethane resins, caulks and putties, linoleum and oil emulsion for exterior paints (Johnston et al., 2002; Salunkhe, 1992).

Safflower oil is a very rich source of various fatty acids, mainly linoleic acid. Safflower oil is considered the richest source of linoleic acid and iodine among oilseed crops. In addition, it is known as a rich source of proteins, amino acids, minerals and vitamins (Salunkhe, 1992). The meal is rich in fiber and protein, with an estimated protein content of about 25 percent. It is mainly used as a protein supplement for livestock and poultry feed (Berglund et al., 2007b).

General Description

Safflower is a spring-planted, broadleaf, thistle-like, annual herbaceous plant which has long and sharp thorns (Herdrich, 2001; Johnston et al., 2002; Oelke et al., 1992).

Depending on cultural practices, environmental conditions and variety, plant height varies from 14 inches to 60 inches (35.6 to 152.4 cm) (Herdrich, 2001; Oelke et

al., 1992; Salunkhe, 1992; Weiss, 2000). There are two types of safflower: short and tall. The taller type belongs to the Turko-Afghanistan area, whereas the shorter type comes from India (Weiss, 2000).

The strong central stem has a stiff and cylindrical shape, which is fairly thick at the base and narrowing toward the growing point (Oelke et al., 1992; Salunkhe, 1992). Safflower has simple, sessile, oblong, lanceolate and alternate leaves (Salunkhe, 1992). Like inflorescences in the Compositae family, the safflower inflorescence consists of several florets closely held together on a circular and flattened receptacle (Weiss, 2000). Although safflower is predominantly a self-pollinated crop (Baydar and Gokmen, 2003), bees and other insects can help to maximize fertilization and yield. Depending on environmental and field conditions and the variety, flowering usually takes 3 to 5 days, however, this period can sometimes be extended over 10 to 40 days (Oelke et al., 1992; Weiss, 2000).

The optimum temperature required during the flowering stage varies between 76 and 86 °F (24.4 and 30 °C). Late planting causes flowering to coincide with hot months and maturity may coincide with frost; consequently, this may result in reduced yield and lower oil content (Weiss, 2000).

The fleshy tap root system, with plentiful laterals, is able to penetrate the soil to a depth of 6 to 10 feet (183 to 305 cm). Deep root penetration gives the plant remarkable drought resistance (Herdrich, 2001; Lyon et al., 2007; Salunkhe, 1992). In addition, the deep rooting system enables the plant to benefit from nutrients from a significant volume of soil (Weiss, 2000).

Cultivated safflower, *C. tinctorius* L., has 12 pairs of chromosomes (Weiss, 2000).

Climate, Adaptation and Soil

Safflower is well adapted to the semi-arid and arid areas of the world where the rains come in winter and spring and a dry atmosphere prevails during the flowering and maturation phase (Johnston et al., 2002; Salunkhe, 1992; Yau, 2004). It is not generally recommended as a suitable crop for areas with more than 15 inches (38 cm) of rainfall per year. Reduced yields result from foliar diseases that attack the plant in humid areas (Oelke et al., 1992). Safflower is one of the most drought- and salt-tolerant oilseed crops (Baydar and Gokmen, 2003; Yau, 2004). The soil salinity tolerance of safflower is similar to that of barley (Berglund et al., 2007b; Lyon et al., 2007; Oelke et al., 1992). In California, safflower is mainly cultivated as a rain-fed crop, particularly in areas with an annual rainfall of 15 to 20 inches (30.5 to 50.8 cm).

Safflower cannot withstand frost injury after the seedling stage. It requires 110 to 140 days from planting to maturity with 120 of these days being frost-free. The total accumulation of heat to successfully harvest the crop is about 2,200 growing degree days (1,222 Celsius growing degree days) beginning when the soil temperatures reaches 41 °F (5 °C) (Armah-Agyeman et al., 2002; Herdrich, 2001; Oelke et al., 1992).

Distribution of safflower as a smallholder crop is approximately limited by latitudes of 20S and 40N; furthermore, commercial production on a large scale is concentrated in moderately low altitude, semi-arid areas where the incidence of disease is low (Weiss, 2000). Although safflower can be grown at high altitudes, the yield is not as good as at lower altitudes (Weiss, 2000).

Safflower tends to grow well on deep, well-drained, fertile soils with high water-holding capacity (Berglund et al., 2007b; Lyon et al., 2007; Oelke et al., 1992). Safflower can also tolerate coarser-textured soils with low water-holding capacity if sufficient soil moisture and rainfall is available (Berglund et al., 2007b; Oelke et al., 1992).

The crop tends to be highly susceptible to soil crusting and does not withstand low soil temperatures (Armah-Agyeman, 2002; Herdrich, 2001; Oelke, 1992).

Safflower is well-suited to growing in recharge areas; its deep tap-root system is able to benefit from surplus water during its long growing season (Berglund et al., 2007b).

After harvest, safflower leaves very little crop residue. This small amount of residue exposes the land to wind and water erosion if the fields are left fallow (Berglund et al., 2007b; Lyon et al., 2007; Oelke et al., 1992). Strip planting, reduced tillage or chemical fallow will reduce erosion (Berglund et al., 2007b; Oelke et al., 1992 ; Lyon et al., 2007).

According to Lyon et al. (2007), planting a shallow-rooted crop after safflower, such as proso millet, and leaving the land fallow during the next cropping year, is another possible alternative to reduce soil erosion.

Cultural Practices

Safflower is considered an opportunity crop in terms of its rotational potential and deep tap-root system. When planted in rotation, safflower gives dryland farmers some options for dealing with problems associated with available soil moisture, weeds, and disease control. Safflower is usually grown in rotation with small grains, legumes, or fallow (Berglund et al., 2007b; Lyon et al., 2007; Oelke et al., 1992). According to Lyon

et al. (2007), safflower usually does well when planted following wheat. Safflower should neither be followed by safflower nor be planted in rotation with crops that are susceptible to *Sclerotinia*, head rot (white mold). Crops susceptible to *Sclerotinia* are sunflower, mustard, canola, crambe, and dry bean (Berglund et al., 2007b; Oelke et al., 1992).

In a crop rotation involving safflower, a crop should be planted only if sufficient recharge of soil moisture has taken place (Berglund et al., 2007b; Oelke et al., 1992). In dry years, when the soil moisture level is very low, six years may be needed to replenish moisture in order to re-include safflower in the rotation sequence (Lyon et al., 2007).

Seedbed Preparation

Planting on crusting soils may result in low germination rate and poor stand establishment. Therefore, safflower should be planted on a moist, firm seedbed. Fall tillage will promote the germination of small grain volunteers before safflower is planted in the spring (Oelke et al., 1992).

Planting Date

Unlike camelina and flax, safflower requires relatively high soil temperatures for germination, at least 41°F (5 °C) (Berglund et al., 2007b; Lyon et al., 2007).

Although planting date varies from region to region, the optimum planting date is usually between late April and early May (Berglund et al., 2007b; Lyon et al., 2007; Oelke et al., 1992). Late planting is not recommended in safflower. According to Oelke et al. (1992), any planting date beyond mid-May in the Western Great Plains will not ensure that the crop has time to mature. Late planting can be associated with frost injury leading to lower yield and lower oil content and quality (Berglund et al., 2007b; Oelke et

al., 1992). Even if winter frost is not a concern, late planting will result in less vigorous plants. Weaker plants do not tend to withstand and survive disease and insect outbreaks (Berglund et al., 2007b; Lyon et al., 2007; Oelke et al., 1992).

Seeding Rate

When planting safflower, high quality seed with good germination should be selected. High germination ensures a good stand establishment leading to a vigorous plant population (Berglund et al., 2007b).

The seeding rate for safflower varies from 320,000 to 400,000 pure live seeds per acre (790,738 to 988,423 pure live seeds per hectare) (Oelke et al., 1992; Lyon et al., 2007; Nielsen, n.d.). However, depending on moisture availability, planting date, and row spacing, a higher seeding rate may be recommended. Berglund et al. (2007) recommend 240,000 to 480,000 pure live seeds per acre (593,054 to 1,186,108 pure live seeds per acre).

Seeding Depth

Safflower generally does not have good seed vigor. Planting depth should be from 1 to 1 ½ inches (2.54 to 3.81 cm), which should result in good stand establishment (Berglund et al., 2007b; Lyon et al., 2007; Oelke et al., 1992).

Row spacing depends on growing conditions. Planting safflower in rows spaced 6 to 10 inches (15.24 to 25.4 cm) apart is common (Berglund et al., 2007b; Oelke et al., 1992). However, Lyon et al. (2007) suggest leaving 14 to 30 inches (35.6 to 76.2 cm) between the rows. Row spacing of at least 14 inches (35.6 cm) results in good air movement, leading to lower insect and disease incidence, however, this may also increase

weed pressure, delay maturity, reduce yield and lower oil quality (Berglund et al., 2007b; Lyon et al., 2007; Oelke et al., 1992).

Fertilizer

Safflower fertilization recommendations are influenced by expected yield, previous crop in rotation, and soil moisture availability (Berglund et al., 2007b; Lyon et al., 2007; Oelke et al., 1992). Unlike small grains such as flax and camelina, safflower has a deep-rooted system that allows it to utilize deep soil nutrients that may not be readily available to other crops. Since safflower is able to utilize soil nutrients from deeper soils, it is recommended to take soil samples from 2 to 4 feet (61 to 122 cm) deep in the soil (Berglund et al., 2007b; Lyon et al., 2007; Oelke et al., 1992).

Nitrogen

Nitrogen can be the most limiting nutrient in safflower (Berglund et al., 2007b; Lyon et al., 2007; Oelke et al., 1992). The recommended rate of nitrogen fertilizer in dryland conditions varies from 30 to 60 pounds per acre (33.6 to 66.3 kg per hectare), whereas in irrigated land, the nitrogen application rate may not exceed 120 pounds per acre (134.5 kg per hectare) (Lyon et al., 2007). Berglund et al. (2007b) suggest 5 pounds (11 kg) of nitrogen for every 100 pounds (220 kg) of seeds expected to be produced. According to Oelke et al. (1992), it is usual to get higher yields if 100 to 120 pounds per acre (112.1 to 134.5 kg per hectare) nitrogen is available in the field; for a yield goal of 1,000 pounds of seed per acre (1,121 kg per hectare), a lower amount of nitrogen would be needed unless the crop is grown after another deep-rooted crop such as sunflower.

Phosphorus

In order to attain high yields and early maturity, medium to high levels of phosphorus are needed. In case of low level of phosphorus in the soil, 20 to 30 pounds per acre (22.4 to 33.6 kg per hectare) of P_2O_5 will help the crop to attain high yields and early maturity (Berglund et al., 2007b; Lyon et al., 2007; Oelke et al., 1992). However, according to Oelke et al. (1992), phosphorus application doesn't seem to produce a consistent response unless soil available phosphorus is very low.

Potassium

According to Berglund et al. (2007b) neither potassium nor phosphorus application results in increased yield unless soil levels are low. If the potassium soil test level is below 125 ppm, potassium should be applied; in case of potassium deficiency, fertilizer guidelines for wheat can also be followed (Lyon et al., 2007).

Micronutrients

Limited information is available related to micronutrients in safflower.

Weed Control and Herbicides

Safflower is highly susceptible to weed pressure due to its low branching growth form, which does not provide good ground coverage. Weeds can be a serious issue leading to low yields and harvesting problems. Safflower has a very slow early growth. Before the crop is well-established, weeds can easily take over. However, three to four weeks after planting, when the crop is relatively well-established, safflower may compete well with late-emerging weeds (Berglund et al., 2007b; Lyon et al., 2007; Oelke et al., 1992).

Broadleaf weeds, such as Kochia and Russian thistle, can considerably impact the crop. They can be controlled through a well-managed rotation sequence (Lyon et al., 2007).

The following herbicides are labeled for use in safflower to control weeds: Paraquat, Eptam (EPTC), Trifluralin, Sonalan, Metolachlor, Clethodim and sethoxydim (Poast) (Berglund et al., 2007b; Lyon et al., 2007).

Disease and Pest Management

Diseases

Diseases and pests are generally not a concern unless high humidity and precipitation occur throughout the safflower growing season (Berglund et al., 2007b; Oelke et al., 1992). Two diseases seem to be troublesome during extended rainfall and high humidity periods:

- Alternaria leaf spot, *Alternaria carthami*
- Pseudomonas bacterial blight, *Pseudomonas syringae*

In case of Alternaria incidence, plants can lose photosynthetic tissue, resulting in reduced yields. Disease-free and treated seeds are recommended to prevent disease outbreaks (Berglund et al., 2007b). The symptoms of bacterial blight are similar to those of Alternaria leaf spot (Berglund et al., 2007b; Oelke et al., 1992). The following diseases can also attack safflower: flower head rots, root rots, wilts, safflower rusts and Pythium rot (Berglund et al., 2007b; Oelke et al., 1992).

Insects

Insect damage is usually not associated with economic losses unless the stand is reduced considerably (Oelke et al., 1992). Major insects that can be found on safflower

are cutworms, seed corn maggots, and wireworms. Safflower can also be damaged by thrips, lygus bugs, grasshoppers, and sunflower moths (Oelke et al., 1992).

Harvest

Safflower should be harvested when the leaves turn brown and not much green can be observed on the bracts of the latest flowering heads. The stem should be dry, but not breakable. When hand threshed, seed should have a white color. Seed discoloration or sprouting in the head can happen if post-maturity rainfall is received; therefore, it is important to harvest safflower as soon as it is ready (Berglund et al., 2007b; Oelke et al., 1992). Safflower does not shatter; therefore, it can be direct combined (Berglund et al., 2007; Oelke et al., 1992).

Sesame

Introduction and History

Sesame (*Sesamum indicum* L.) is also known as sesamum, gingelly, beniseed, sim-sim and til (Salunkhe, 1992). Sesame is one of about 35 species belonging to the genus *Sesamum* in the family Pedaliaceae (Salunkhe, 1992).

Sesame is considered one of the older oilseed crops in the world (Oplinger et al., 1990). Central Africa, mainly Ethiopia, is believed to be the origin of sesame. However, one Indian botanist says there is reliable evidence supporting India as the country of origin (Weiss, 2000). Cultivation of sesame as an oilseed crop dates back to 2,000 B.C., when it was prized and planted in Babylon and Assyria (Oplinger et al., 1990; Thomas Jefferson Agricultural Institute, n.d.). Sesame is believed to have been grown on over 5 million acres in the Fertile Crescent in the Ancient Near East (Thomas Jefferson Agricultural Institute, n.d.). In the thirteenth century, Marco Polo praised sesame from Badakhshan, located in Northeast Afghanistan, for its excellent flavor (Weiss, 2000). Cultivation of sesame as a cash crop in Russia started in the late seventeenth century. In the 1930s, sesame was introduced into the United States, but commercial production of the crop did not begin until the 1950s (Oplinger et al., 1990; Thomas Jefferson Agricultural Institute, n.d.).

Currently, India and China are the biggest sesame-producing countries in the world (Oplinger et al., 1990; Thomas Jefferson Agricultural Institute, n.d.; Weiss, 2000). In the United States, sesame acreage is mostly concentrated in Texas and the other southwestern states, which in recent years have accounted for 10,000 to 20,000 acres (4046.86 to 8093.7 hectare) of sesame cultivation (Thomas Jefferson Agricultural

Institute, n.d.). The United States is not able to meet the domestic demand for sesame and imports about 40,000 tons of sesame seeds as well as 2,200 tons of sesame oil each year.

General Description

Cultivated sesame is usually an erect, branched annual but can also be perennial. Two types of sesame are distinguished: long-season annual and long-season perennial (Weiss, 2000). Sesame is sensitive to photoperiod, and initiation of flowering requires long days (Oplinger et al., 1990).

Sesame is usually a self-pollinated crop. However, cross pollination by insects does occur (Oplinger et al., 1990).

Climate, Adaptation and Soil

Sesame is considered a crop of the tropics and subtropics, with most cultivation occurring between 25 S and 25 N latitude. The crop doesn't seem to do well at higher altitudes. In addition to tropical and subtropical areas, some warm temperate areas such as Texas and Oklahoma in the United States are also suitable for sesame cultivation (Salunkhe, 1992). Sesame is well-adapted in areas with a long growing season and well-drained soils (Thomas Jefferson Agricultural Institute, n.d.).

High soil and air temperature are also necessary. According to Oplinger et al. (1990), commercial varieties of sesame take 90 to 120 frost-free days to mature with a daytime temperature of 72 to 79 °F (22.2 to 26.11 °C) . Growth is believed to be reduced below 68 °F and both seed germination and plant growth cease at around 50 °F (10 °C) (Oplinger et al., 1990).

Although sesame is considered a drought-tolerant crop because of its extensive root system, the crop still requires a sufficient amount of moisture for adequate stand

establishment and growth (Oplinger et al., 1990; Thomas Jefferson Agricultural Institute, n.d.). An average rainfall of 20 to 26 inches (50.8 to 66.04 cm) is required to attain reasonable yield (Oplinger et al., 1990).

Although adapted to a variety of soils, sesame does well on fertile and well-drained soils, ranging from medium texture to sandy loam (Langham and Wiemers, n.d.; Oplinger et al., 1990; Thomas Jefferson Agricultural Institute, n.d.). According to Langham and Wiemers (n.d.), sesame does not do well on heavy clay soils. According to Thomas Jefferson Agricultural Institute (n.d.), sesame has been satisfactorily established on silty clay loam, but in clayey soils crusting can be a problem. Poorly-drained soils lead to poor performance (Oplinger et al., 1990; Thomas Jefferson Agricultural Institute, n.d.). Sesame prefers neutral to slightly high soil pH, and it is not a salt tolerant crop (Langham and Wiemers, n.d.; Oplinger et al., 1990; Thomas Jefferson Agricultural Institute, n.d.).

Cultural Practices

Seedbed Preparation

Like many other crops, sesame needs a fine, moist and weed-free seedbed with a fairly high soil temperature, around 72 °F (22.2 °C). Sesame is highly susceptible to water logging, so a well-drained seedbed is needed. Soil crusting is the most serious problem in sesame stand establishment. Even a very slightly crusting soil can affect stand establishment. Because irrigation can cause crusting, irrigation after planting is usually not recommended. However, in some parts of Texas, farmers pre-irrigate their fields prior to planting sesame (Oplinger et al., 1990; Thomas Jefferson Agricultural Institute, n.d.).

Planting Date

Sesame will not germinate until the soil reaches a temperature of 72 °F (22.2 °C), which usually happens a month after the last killing frost of spring (Oplinger et al., 1990). Planting time varies significantly, depending on soil temperature at the field location. According to Thomas Jefferson Agricultural Institute (n.d.), early June is a preferred planting date for sesame in Missouri (Midwestern U.S.). Planting later than June 15 may not allow the crop to attain maturity (Thomas Jefferson Agricultural Institute, n.d.). However, Langham and Wiemers (n.d.) suggest that late plantings are acceptable because sesame planted late tends to mature in fewer days than normal.

Seeding Rate

Sesame seeds are bigger than camelina seeds but smaller than flax seeds. A seeding rate of 45,000 seeds per acre (111195 seeds per hectare) planted on 40-inch (101.6 cm) row spacing will suffice for a good stand (Langham and Wiemers, n.d.; Thomas Jefferson Agricultural Institute, n.d.). Unlike seeding other crops, sesame seeding rate is not highly critical; sesame compensates for differences in plant population by self-thinning (Thomas Jefferson Agricultural Institute, n.d.). A plant population of 6 to 18 plants per foot (20 to 60 plants per meter) of row on 30-inch (76.2 cm) row spacing is considered an adequate plant stand; a plant population of 4 to 8 plants per foot (14 to 26 plans per meter) of a row at maturity is considered a good plant population target (Thomas Jefferson Agricultural Institute, n.d.).

Seeding Depth

Sesame seed is very small and has low seedling vigor. When planting sesame, it is important to pay careful attention to seeding depth. Because of their small size, sesame

seeds don't have high energy in comparison to crops with large seeds. An appropriate seeding depth for sesame will vary from 0.75 to 1.5 inches (1.90 to 3.81 cm) (Langham and Wiemers, n.d.). At optimum soil temperature, sesame seeds will germinate 3 to 5 days after planting (Langham and Wiemers, n.d.).

Fertilizer

Like many other alternative crops, sesame requires only a moderate amount of fertilizer; however, sesame is not considered a “poor-land” crop. Applying balanced fertilizer can result in satisfactory yield on fields with low to moderate soil fertility levels (Langham and Wiemers, n.d.; Thomas Jefferson Agricultural Institute, n.d.).

The soil fertility recommendation for sesame is similar to that for millet and cotton on the same fields (Langham and Wiemers, n.d.; Oplinger et al., 1990).

Nitrogen

The amount of nitrogen applied to a sesame field depends on previous crop, current level of fertility in the soil, and available soil organic matter. Assuming an average seed yield of 1000 pounds per acre (1140 kg per hectare), the nitrogen requirement for sesame typically varies from 40 pounds per acre (45.6 kg per hectare) for soil with more than 5 percent organic matter to 80 pounds per acre (91.2 kg per hectare) for soil with less than 2 percent organic matter (Hansen and Huntroos, 2011; Langham and Wiemers, n.d.; Oplinger et al., 1990; Thomas Jefferson Agricultural Institute, n.d.). In fields where sesame follows a leguminous crop, a lower range of the recommended nitrogen rate should be applied (Thomas Jefferson Agricultural Institute, n.d.). Sesame utilizes relatively high amounts of nitrogen during the flowering stage. The

crop has been shown to respond well to foliar applications of nitrogen (Langham and Wiemers, n.d.).

Phosphorus

Application rate of phosphorus depends on the soil test. There is not much literature about the response of sesame to phosphate applications. According to Oplinger et al. (1990), in the northern mid-west U.S., 20 pounds of phosphorus per acre (22.8 kg of phosphorus per hectare)can be applied in sesame, depending on soil conditions.

Potassium

Similar to phosphorus, the response to potassium application is not known. A soil test will be the most appropriate guide to potassium fertility. According to Thomas Jefferson Agriculture Institute (n.d.), the potassium requirement of sesame is similar to that for soybean or sorghum. Oplinger et al. (1990) recommend 20 pounds per acre (22.8 kg per hectare) potassium in the northern mid-west.

Micronutrients

Little is known about the response of sesame to micronutrient applications.

Weed Control and Herbicides

Fields that are relatively weed-seed free should be selected. Sesame has slow early growth; therefore, the crop is highly vulnerable to weeds during early crop establishment (Oplinger et al., 1990). Early and shallow planting of sesame, along with shallow tillage after planting, helps the crop to compete with the weeds (Langham and Wiemers, n.d.; Oplinger et al, 1990; Thomas Jefferson Agricultural Institute, n.d.). Fields should be kept free from weed infestations of Johnsongrass, wild cucumber, sunflower and ground cherry. If mixed with these seeds, sesame will lose its economic value

(Langham and Wiemers, n.d.). Currently no herbicides are labeled for sesame; however the following herbicides can be applied to control the weeds: Treflan, Dual, Fusilade, Poast, Select and a combination of Prowl and Treflan. Sesame cannot tolerate the herbicides like Atrazine, Caparol, Paraquat, Pursuit, Roundup, Cadre, and 2, 4-D (Langham and Wiemers, n.d.).

Disease and Pest Management

Diseases

The following are the most serious diseases infecting sesame:

- Leaf spot
- Leaf and stem blight
- Fusarium wilt
- Charcoal rot
- Root rot

In order to prevent disease incidence in sesame, planting clean, treated seeds that are free of diseases is recommended (Oplinger et al., 1990).

Insects

Sesame is vulnerable to attack by several insects: aphids, thrips, gall midges, green stink bugs, red spiders, and grasshoppers, cut worms, armyworms, and boll worms (Langham and Wiemers, n.d.; Oplinger et al., 1990).

Harvest

Depending on planting date, variety, weather, and field conditions, farmers should expect to harvest sesame within a period of 90 to 150 days after the planting date. Sesame should be harvested as soon as possible after the first killing frost. When evaluating sesame for maturity, one should pay attention to leaf color and stem color. Sesame leaves

and stems change from green to yellow to reddish as the plant matures (Oplinger et al., 1990).

Sesame is susceptible to seed shattering, particularly the varieties Margo, Oro, Blanco, Dulce, and Ambia. Shattering varieties are usually swathed and then threshed, whereas non-shattering varieties can be directly combined. It should be mentioned that care should be taken when harvesting both types of sesame varieties to prevent seed loss due to the harvesting process (Oplinger et al., 1990).

Cuphea

Introduction and History

The genus *Cuphea* belongs to the family Lythraceae, which consists of about 250 herbaceous or perennial wild species (FAO, 1992; Graham, 1988 as cited in Knapp, 1990; 1988; Hirsinger, 1985; Schoellhorn, 2004). Most of the species are native to Mexico and Central and South America; however, one species, *C. viscosissima*, is believed to be native to the United States (Graham et al., 1981 as cited in Knapp, 1990).

Most of the *Cuphea* species are able to produce and store medium-chain fatty acids (MCFAs) in their seeds. Some of the MCFAs, such as capric, lauric and myristic acids, are important feedstocks in manufacturing broad-range chemical products (Gesch et al., 2002; Knapp, 1990). Lauric and capric acids have a wide range of industrial, medical and nutritional uses (Knapp, 1990). Cuphea oil is used in chewing gum, as a solvent in the candy industry, as a defoaming agent, as a booster in soap and detergent, and in cosmetics, especially lipsticks, lotions, creams, bath oils and sun screen (Berti et al., 2007). Cuphea oil is suitable for biofuel production, particularly biodiesel and jet fuels (Berti et al., 2007). Because most of the *Cuphea* species are highly attractive to nectar feeding insects and hummingbirds, cuphea has another usage at the retail level (Schoellhorn, 2004).

Due to the lack of temperate crops that can produce lauric or capric acids, the United State imports coconut and palm kernel from South Asian countries to supplement the annual needs of MCFAs. Thus, there is a definite need for an alternative crop that can produce MCFAs (Knapp, 1990).

Cuphea was originally introduced into the United States as an oilseed crop (Schoellhorn, 2004). The plant is commercially grown on a small-scale in the Midwest U.S. (Minnesota and Eastern North Dakota). The estimated area devoted to cuphea production in these states is small, for example it was approximately 750 acres (300 hectare) in 2006 (Berti et al., 2007).

Although there are 250 *Cuphea* species worldwide, only a few have shown promise for industrial and commercial production (Schoellhorn, 2004). *Cuphea* species are good sources of capric and lauric acids. However, their commercial production is limited by indeterminate flowering, seed shattering, seed dormancy, self-fertilization, and sticky hairs on stems, leaves and flowers, which cause problems during harvesting. Low germination and low stand establishment due to the small seed size, low seedling vigor, and the requirement for high soil temperature also hinder commercial production of cuphea. Late harvesting due to indeterminate growth and high seed moisture content are problems in cuphea production. Cuphea is not an efficient water user; it does not tend to withstand water shortage during the growing stage (Berti et al., 2007; Gesch et al., 2002; Knapp, 1990).

General Description

Plants are annual or perennial, 0.6 to 4 feet (23.4 to 156 cm) tall, and branching. Tubular flowers are yellow, purple, red or white. The seeds are 0.4 to 0.12 inch (1.06 to 0.30 cm) long and contain 40 to 85 percent fatty acids (Hirsinger and Knowles, 1984).

Climate, Adaptation and Soil

Cultivated cuphea is a summer annual crop (Berti et al., 2007) having various species well-adapted to temperate and sub-tropical agricultural regions (FAO, 1992;

Knapp, 1990; Sharrat and Gesch, 2002). Cuphea seems to do well under cool and moist weather early in the growing season, which promotes root and shoot development and prevents potential water stress (Sharrat and Gesch, 2002). In the Northern Corn Belt of the United States, small-scale cuphea production has been successful in a cool temperate-short-season climate (Gesch et al., 2002).

Cuphea needs relatively high soil moisture and temperature. The optimum soil temperature in which cuphea seeds germinate is 50 °F (10 °C) (Gesch et al., 2002).

There is very limited information related to growth and production of cuphea in the North Central United States (Sharrat and Gesh, 2002).

Cultural Practices

Cuphea can be grown with planting and harvesting equipment readily accessible to most farmers (Gesch et al., 2002). Cuphea is a new crop in the United States, and thus, little has been published related to cuphea production management, especially cultural practices.

Seedbed Preparation

Cuphea germination can be highly variable due to its small seed size, and seedlings tend to be weak. Seeding depth is considered one the most crucial factors in cuphea stand establishment. A well-prepared field with little excessive crop residue on the surface is desirable for good stand establishment (Gesch et al., 2002).

Planting Date

In the North Central United States, cuphea production benefits from early planting dates (Sharrat and Gesch, 2002). In West Central Minnesota, the most appropriate date

for planting cuphea varies from early to mid-May, when the soil moisture is relatively high and the soil temperature reaches 50 °F (10 °C) (Gesch et al., 2002).

Seeding Rate and Seeding Depth

Depending on field conditions and planting date, the ideal seeding rate for cuphea is approximately 3 million seeds per acre (7.4 million per hectare) (Gesch et al., 2002). Shallower seeding works best. Seeding cuphea deeper than ½ inch (1.27 cm) can lead to poor stand establishment (Gesch et al., 2002).

According to plant spacing studies in cuphea, a plant spacing of 15 to 25 inches (38.1 to 63.5 cm) with a plant population density of 400,000 to 600,000 plants per acre (988,000 to 14,820,000 seeds per hectare) will result in optimum cuphea yield (Gesch et al., 2002).

Cuphea is an indeterminate plant. Because of its potential to branch abundantly, cuphea has high yield compensation capacity. The more space provided between the plants, the greater branching takes place, resulting in higher yield (Gesch et al., 2002).

Fertilizer

Little research has been done to determine optimum soil fertility requirements for cuphea growth and development (Gesch et al., 2002).

Based on field experiments conducted in North Dakota and Minnesota, the nitrogen recommendation for cuphea production is 90 to 125 pounds per acre (102.6 to 142.5 kg per hectare) (Berti et al., 2007).

In Minnesota, the phosphorus recommendation for cuphea is about 200 pounds per acre (228 kg per hectare) of di-ammonium phosphate (Berti et al., 2007). The potassium requirement for cuphea is about 40 pounds per acre (45.6 kg per hectare). Both

of these amounts are based on the fertility requirements of other crops; little fertility research has been done on cuphea (Berti et al., 2007).

Weed Control and Herbicides

Cuphea growth and development is usually slow in the early growth stages. However, once in anthesis stage, with canopy closure, rapid growth is expected. Because cuphea grows slowly at first, controlling early-season weeds can be troublesome (Gesch et al., 2002).

Pre-plant incorporation of trifluralin or ethalfluralin, pre-emergence application of isoxaflutole, and post-emergence application of mesotrione control a broad-range of broadleaf weeds without harming cuphea seedlings (Gesch et al., 2002).

Disease and Pest Management

Little has been published related to cuphea diseases and pests. However, recently *Sclerotinia sclerotiorum* infection has been reported in Minnesota and North Dakota (Gulya et al., 2006).

Harvest

Because cuphea is an indeterminate crop, when flowering starts, it continues for nearly two months or until the plants are killed by frost. Both shattering in the earliest flowers and high seed moisture in the later flowers can cause difficulties at harvest. Cuphea is very sensitive to seed shattering. According to Gesch et al. (2002), even advanced lines of cuphea, such as PSR23, have shown substantial seed shattering.

In an experiment conducted in Minnesota, the best time for harvesting cuphea was late September to early October (Gesch et al., 2002). Although direct combining of cuphea has been done, swathing is preferred (Gesch et al., 2002). Seed moisture of 30 to

40 percent can be expected. A commercial batch-dryer designed for canola has been successfully used to complete dry down of cuphea seeds. Seed moisture should be below 10 percent for long-term seed storage (Gesch et al., 2002).

Canola

Introduction and History

Oilseed rape, *Brassica napus*, is considered the world's second largest oilseed crop, responsible for 13 percent of the world's supply of oilseed (Raymer, 2002).

Rapeseed was among the ancient crops that were domesticated by early man. Early records have shown cultivation of rapeseed in India 3,000 years ago (Frier and Roth, n.d.; Shahidi, 1990). Rapeseed reportedly was introduced into Japan and China around the time of Christ (Raymer, 2002; Shahidi, 1990). It has been grown in Europe since the 13th century (Frier and Roth, n.d.; Oplinger et al., 1989a; Shahidi, 1990).

In North America, rapeseed was introduced into Canada during the 1930s, but commercial production was not started until 1942. During World War II, when there was a large demand for industrial lubricants, rapeseed production started in western Canada to meet this demand (Frier and Roth, n.d.; Kansas Agricultural Experiment Station, 1996; Shahidi, 1990). A small amount of rapeseed also was allocated for cooking oil production because of an edible oil shortage during World War II. However, serious efforts toward breeding rapeseed as a source of edible oil were proposed in 1948 in Canada. During 1956 to 1957, the first commercial extraction of rapeseed for edible oil took place in Canada (Kansas Agricultural Experiment Station, 1996; Shahidi, 1990). In 1957, the first rapeseed variety with low-erucic acid content was developed but not released (Kansas Agricultural Experiment Station, 1996).

In the 1970s, Canadian scientists were able to use conventional breeding techniques to remove erucic acid and glucosinolate from rapeseed. Consequently, a crop

was developed which was low in saturated fatty acids, but had high protein and high-palatability meal for livestock (Kansas Agriculture Experiment Station, 1996).

In 1971, the first low erucic acid-content variety called Span was released in Canada. In two decades following Span's release, Tower, which was low in both erucic acid and glucosinolates, was released. Tower was the first variety to become a true canola (Kansas Agricultural Experiment Station, 1996).

The name canola refers to rape seeds with genetically lower erucic acid and glucosinolates (Oplinger et al., 1989a). The name canola was trademarked by the Western Canadian Oilseed Crushers Association in 1978 (Kansas Agricultural Experiment Station, 1996; Oplinger et al., 1989a; Raymer, 2002).

In order for rapeseed to be used as edible oil, it must have an erucic acid content of less than 2 percent; also, the glucosinolate content should not exceed 30 micromoles per gram (Atkinson et al., n.d.; Berglund et al., 2007a; Parsons et al., n.d.). In the United States, the Federal Drug Administration approved rapeseed oil with less than 2 percent erucic acid as safe for human consumption. Canola oil with erucic acid and glucosinolate above the tolerance levels for the edible oil is used as industrial lubricants (Kansas Agriculture Experiment Station, 1996).

Although several Brassica species have the potential to produce canola varieties, *Brassica napus* is considered the most common one in the United States (Parsons et al., n.d.). Canola is currently developed from three different Brassica species; *Brassica napus*, *Brassica rapa*, and *Brassica juncea* (Kansas Agricultural Experiment Station, 1996).

According to Ehrensing (2008a), Canada is the largest canola-producing country in the world, reaching an annual production on 12 million acres (Ehrensing, 2008a). In the United States, Minnesota and the Northern plains of North Dakota account for more than 90 percent of about 1 million acres (400,000 hectares) of canola (Berglund et al., 2007a; Ehrensing, 2008a).

Rapeseeds including canola have both food and non-food uses. While rapeseeds have been used as a major source of cooking oil in Asia and Europe, they were also used as a source of industrial lubricants and lamp oil (Kansas Agricultural Experiment Station, 1996; Shahidi, 1990). According to Shahidi (1990), ancient civilizations in Asia and along the Mediterranean region used rapeseed for illumination and cooking oil.

Because of its health benefits, edible canola has a strong consumption demand in the United States (Thomas Jefferson Agricultural Institute, n.d). Besides being grown for edible oil, canola is also widely grown as a biofuel crop (Ehrensing, 2008a). Because of its potential to provide dual-purpose products-edible oil and biofuel feedstock-canola acreage is expected to increase tremendously in all canola production regions of the United States (Berglund et al., 2007a; Ehrensing, 2008a).

General Description

The following description comes from FAO (n.d.), Frier and Roth (n.d.), and Oplinger et al. (1989a). Canola, *Brassica napus* L., along with 3,000 other related species, belongs to the family of Brassicaceae (Frier and Roth, n.d.; Oplinger et al., 1989a). The plant is an annual or biennial herb varying between 20 and 80 inches (50.8 to 203.2 cm) in height. The stem is highly branched. The basal leaves are attached to the stem by petioles while leaves attached higher on the stem are sessile. The flowers have

petals 0.4 to 0.6 inches (1.01 to 1.52 cm) long and varying in color from pale yellow to bright yellow. Plants are pollinated by wind and by insects. Many Brassica species cross-pollinate each other.

Adaptation, Climate and Soil

Canola can be planted as either a spring or a winter annual (Berglund et al., 2007a; Kansas Agricultural Experiment Station, 1996). The growing period is 85 to 160 days for spring types and 160 to 340 days for winter types. Under ideal growing conditions, winter canola has 20 to 30 percent higher yields than spring canola in Kansas (Kansas Agricultural Experiment Station, 1996), and sometimes the yield from winter-types can be as much as twice that of spring canola (Ehrensing, 2008a).

In the middle levels of the Great Plains areas of the United States, spring canola does not tend to do well. The yields of spring canola in these areas are considerably lower, attributed to reduced seed-filling periods, and increased pressure from the spring weeds and pests. Therefore sometimes spring canola production in the Great Plains areas is not recommended unless it is irrigated (Kansas Agricultural Experiment Station, 1996).

Winter canola does not seem to have high winter success in the mid Great Plains (Kansas Agricultural Experiment Station, 1996). According to Ehrensing (2008a), dry weather conditions during plant germination, late plant stand establishment, and high temperature shortly after seedling emergence are the factors that can negatively affect winter canola production.

Although canola is adapted to a wide range of climates, it prefers cool extremes of temperate zones. Canola can survive in temperatures as low as 32 °F (0 °C). Although

the crop germinates and emerges at a soil temperature of 41°F (5 °C), the optimum temperature for growth is 50 °F (10 °C) (Oplinger et al., 1989a).

Although canola can be planted on most soils, it is well adapted to clay-loam soils, with no crusting. Canola requires good field drainage, and it does not tolerate standing water and wet field conditions (Berglund et al., 2007a; Ehrensing, 2008a; Kansas Agricultural Experiment Station, 1996; Shahidi, 1990). Canola also performs well on medium-textured soils with adequate drainage (Kansas Agricultural Experiment Station; Oplinger et al., 1989a). Canola can tolerate pH of as low as 5.5 (Oplinger et al., 1989a).

Cultural Practices

Canola fits well in rotation with several crops including small grains, grass seeds and potatoes. Canola should not be planted in a rotation more than once every 4 years (Ehrensing, 2008a; Shahidi, 1991), or more than once every 3 years (Berglund et al., 2007a). If planted continuously or an alternating years, potential disease buildups and outbreaks are possible (Ehrensing, 2008a; Shahidi, 1990). Shahidi (1990) recommends not growing canola in a field where any Brassica crop was grown within the last 4 years.

Blackleg is particularly likely to occur in fields continuously or alternately planted to canola. Therefore, canola varieties that are moderately or completely resistant to blackleg should be selected, if 3 year or 4 year rotation is not possible. Alternating the planting of canola with sunflower, beans, or crambe, which are also susceptible to blackleg, should be avoided (Berglund et al., 2007a). Some of the Brassica species are cross-pollinated. Therefore, canola seed production should be isolated carefully to avoid

reduction in oil quality and to prevent transfer of genetically modified traits (Ehrensing, 2008a).

Seedbed Preparation

Because canola seeds are very small and need a shallow seedbed, good stand establishment requires a firm, fine seedbed free of weeds (Berglund et al., 2007a; Ehrensing, 2008a; Kansas Agricultural Experiment Station, 1996; Shahidi, 1990; Thomas Jefferson Agricultural Institute, n.d). As in many other crops, seed-to-soil contact is essential for rapid seedling emergence. Seeding canola into dry soil is not recommended (Berglund et al., 2007a). Canola is adapted to both no-till and tilled field conditions; however, planting on tilled fields will result in better stand establishment (Thomas Jefferson Agricultural Institute, n.d).

Crusting is a considerable challenge in stand establishment. Therefore, careful attention should be paid to avoid planting canola on crusting soils. Crusting is usually observed in too fine and packed soils (Ehrensing, 2008a).

Planting date

Canola is planted as either a spring or a fall crop, depending on variety, climate and field conditions. In general, early planting dates tend to favor early maturity and high yields.

Canola is a heat- and drought-sensitive crop, especially during the flowering and pod-filling stages, so heat and drought stress on the crop during June and July should be avoided (Frier and Roth, n.d.; Berglund et al., 2007a). Early planting also helps with the establishment of young plants, so they can withstand attacks by flea beetles (Frier and Roth, n.d.).

Spring canola should be planted between April and May, as soon as the soil temperature reaches 37- 40 °F (2.7 to 4.4 °C) to allow seeds to germinate (Frier and Roth, n.d.; Oplinger et al., 1989a). Planting spring canola after mid-May may result in considerable yield reduction. Planting spring canola in June is usually associated with severe yield loss (Berglund et al., 2007a).

Fall planting dates vary, depending on climate and field conditions. Fall planting usually takes place in late summer (Atkinson et al., n.d.; Frier and Roth, n.d.; Oplinger et al., 1989a). The planting date should be adjusted to allow plants to reach the 6 leaf stage and to develop a considerable root size before the first killing frost (Atkinson et al., n.d.; Ehrensing, 2008a; Frier and Roth, n.d.; Oplinger et al., 1989a).

Planting winter canola too early or too late is detrimental. Planting too early will lead to flowering prior to a winter killing frost; once it flowers, canola is less likely to survive winter cold. Planting too late in the fall will delay plant growth. Plants may remain small, and they are less likely to survive the winter cold (Thomas Jefferson Agricultural institute, n.d).

Seeding Rate

Depending on a particular type of canola variety, canola seed size varies significantly. Because seed size varies, major differences can be observed between seeds per pound of different canola varieties. Adjustment should be made in order to prevent too thick or thin stand. It is also recommended to plant canola according to number of seeds per acre (seeds per hectare) (Atkinson et al., n.d.; Berglund et al., 2007a).

The canola seeding rate varies, depending on planting methods, variety, spring or winter type, and soil texture (Oplinger et al., 1989a). A rule of thumb is to plant 642,500

seeds per acre (1,586,975 seeds per hectare) (Berglund et al., 2007a; Nielsen, n.d.). Under normal conditions, the usual seeding rate ranges between 514,000 and 899,500 seeds per acre (1,269,580 to 2,221,765 seeds per hectare) (Berglund et al., 2007a; Ehrensing, 2008a; Nielsen, n.d.). Oplinger et al. (1989a) suggest 514,000 to 642,500 seeds per acre (1,269,580 to 1,586,975 seeds per hectare) for drill planting, but 642,500 to 899,500 seeds per acre (1,586,975 to 2,221,765 per hectare) for broadcast planting, depending on soil texture and seed size (Nielsen, n.d.). The seeding rates for winter canola are higher, ranging up to 1,542,000 seeds per acre (3,808,740 seeds per hectare) (Ehrensing, 2008a; Nielsen, n.d.). For both winter and spring types, in case of late planting, heavier soils, or in field conditions in which reduced seed germination may be expected, a seeding rate of 1,028,000 to 1,542,000 seeds per acre (2,539,160 to 3,808,740 seeds per hectare) canola is recommended (Ehrensing, 2008a; Nielsen, n.d.). The target population density is between 4 and 10 plants per square foot (45 to 112 plants per square meter) (Kansas Agricultural Experiment Station, 1996; Oplinger et al., 1989a).

Seeding Depth

Canola stand establishment success depends on seeding depth and moisture availability. Canola requires a shallow depth because the seeds are small (Kansas Agricultural Experiment Station, 1996).

Planting canola at a depth of 0.5 to 1 inch (1.27 to 2.54 cm) results in an optimum germination, emergence, and stand (Atkinson et al., n.d.; Berglund et al., 2007a; Ehrensing, 2008a; Kansas Agricultural Experiment Station, 1996; Thomas Jefferson Agricultural Institute, n.d.).

Planting at a depth of more than 2 inches (5.08 cm) usually results in delayed emergence, reduced plant stand and late maturity (Atkinson et al., n.d.; Kansas Agricultural Experiment Station, 1996).

Fertilizer

Soil fertility tests, season, and the expected yield will determine the amount of fertilizer to apply. In irrigated areas, where yield potential is higher, an increased rate of fertilizer may have economic return (Ehrensing, 2008a), whereas in dryland fields, there may be no economic advantage.

Nitrogen

Canola can take about 7 pounds (3.15 kg) of nitrogen per 100 pounds (45 kg) of expected seed yield (Ehrensing, 2008a). The amount of nitrogen required for canola production depends on the yield potential of the crop and the amount of residual and mineralizable nitrogen in the soil (Atkinson et al., n.d.; Kansas Agricultural Experiment Station, 1996).

Both winter and spring types of canola need more nitrogen than wheat, overall. However, for winter types the fall application should be light and the spring application may be heavy.

High nitrogen application rates in the fall will lead to excessive fall growth, which may eventually result in less winter hardiness when a killing frost occurs (Kansas Agricultural Experiment Station, 1996).

For both winter and spring types, only one third of required applied nitrogen should be applied before planting. For winter types application of the remaining two thirds should be done in the spring (Kansas Agricultural Experiment Station, 1996).

Nitrogen fertilizer application can be made as broadcast, incorporated, or banded beside the seed row (Atkinson et al., n.d.).

Phosphorus

Phosphorus should be applied before or at planting time, depending on soil test level. Applying phosphorus prior to planting tends to be more effective than post-planting applications (Ehrensing, 2008a). Both spring and winter canola types benefit from phosphorus when the soil test result is less than 5 parts per million (ppm) (Ehrensing, 2008a). The range of phosphorus required for ideal canola production varies between 40 to 60 pounds per acre (45.6 to 68.4 kg per hectare), or 15 to 25 ppm (Atkinson et al., n.d.; Wysocki et al., 2007). Phosphorus can be either broadcast or row-applied (Kansas Agricultural Experiment Station, 2009).

Potassium

Canola needs a large amount of potassium. If the potassium level is lower than 75 ppm, it is necessary to supply potassium to the crop (Ehrensing, 2008a; Kansas Agricultural Experiment Station, 2009). If the soil test shows potassium less than 100 ppm, 75 pounds per acre (85.5 kg per hectare) potassium should be applied (Atkinson et al., n.d.; Wysocki et al., 2007).

Sulfur

Unlike many cereal crops, canola's demand for sulfur is very high. Because it is rich in sulfur-containing proteins, canola may need a sulfur supplement (Atkinson et al., n.d.; Kansas Agricultural Experiment Station, 1996). If the soil test shows sulfur less than 10 ppm, 10 to 40 pounds per acre (11.4 to 45.6 kg per hectare) sulfur should be supplied in a canola field (Atkinson et al., n.d.; Wysocki et al., 2007).

Micronutrients

Boron

Canola needs slightly more boron than the crops grown in rotation with it. When the soil test for boron is lower than 0.5 ppm, an application of 1 to 2 pounds of boron per acre (1.14 to 2.28 kg of boron per hectare) is recommended. Boron is toxic to canola, thus, over application should be avoided (Ehrensing, 2008a; Wysocki et al., 2007).

Weed Control and Herbicide

An effective weed management strategy that may include cultural, mechanical and chemical practices is necessary to overcome weed problems in canola. The weed control method varies, depending on the type of canola.

Winter canola tends to be more competitive with weeds than spring canola. If best management practices are followed, winter canola can out-compete most annual weeds (Kansas Agricultural Experiment Station, 1996). Unlike winter canola, spring canola is more susceptible to weed infestation, particularly if established poorly with patchy stand (Kansas Agricultural Experiment Station, 1996).

Like many other crops, canola's ability to compete against weeds depends on its growing stage. Young seedlings tend to be more sensitive to early weed competition. Therefore, weed control strategies should be focused on reducing weed competition during early seedling stages (Thomas Jefferson Agricultural Institute, n.d.). Once established, canola is competitive against most weeds (Berglund et al., 2007a).

Proper culture practices can considerably improve canola's ability to compete against both spring and winter annual weeds. Appropriate seeding date, seeding rate and

seeding depth play an important role in maintaining a dense and vigorous stand to compete well with weeds.

While annual weeds can be controlled either before or after planting, perennial weeds should be controlled a year prior to planting canola (Berglund et al., 2007a).

Planting canola where weed pressure of Brassica species is expected should be avoided (Shahidi, 1990).

Besides cultural control measures, there are many herbicides to use to control weeds in canola.

Trifluralin and Sonalan (ethalfluralin) are pre-plant incorporated herbicides labeled to control both grassy and broadleaf weeds in canola. Both control weeds such as pigweed, common lambsquarters and kochia; however, they will not provide control for wild mustard, which is one of the main weeds of canola (Berglund et al., 2007a).

Clopyralid is a post-emergence herbicide which controls small broadleaf weeds, Canada thistle, and perennial sowthistle. Clopyralid should be applied when canola is in the 2 to 6 leaf stage and prior to bolting (Berglund et al., 2007a).

Sethoxydim, known as Poast®, quizalofop, and clethodim or Select Max are other post-emergence herbicides which are used to control grassy and broadleaf weeds (Berglund et al., 2007a).

As an alternative, Roundup Ready spring and winter canola are available (Monsanto, 2011). Especially for irrigated spring canola, the higher cost of the seed is offset by higher yields (Johnson, personal communication, 2012).

Canola is susceptible to residual herbicides in soil. Planting canola should be avoided in fields where residual levels of triazine, imadazolinones, and sulfonylureas are

present (Shahidi, 1990). Canola is sensitive to several persistent herbicides including Glean, Finesse, Assert, atrazine, and triazine compounds (Ehrensing, 2008a).

Disease and Pest Management

Diseases

Diseases can be a serious issue in canola production. In order to keep the incidence of disease low, a well-managed rotation is necessary. Blackleg, white rust, staghead, downy mildew, alternaria blackspot, aster yellows and sclerotinia wilt are major diseases in canola (Berglund et al., 2007a).

Insects

Among the many insects that attack canola plants, flea beetles can cause considerable damage to newly emerged seedlings. Over-wintering populations of flea beetles can cause severe damage to canola plants through May and June. Adult flea beetles, which feed on the cotyledons and first true leaves, can cause typical shot-holed appearance. The affected seedlings usually have slow recovery and growth. In case of severe injury, seedlings may die. When the injury is moderate, the plants may suffer a reduction in vigor and stamina (Berglund et al., 2007a).

Besides flea beetles, cabbage seedpod weevil and several species of aphids, especially cabbage aphid, turnip aphid, and green peach aphid, are found on canola (Ehrensing, 2008a).

False chinch bugs are also a major problem in both spring and winter canola in Colorado (Johnson, personal communication, 2012).

Harvest

Canola seeds mature in pods from the bottom to the top of the stem. When inspecting for maturity, seed should be sampled from the lower third of the main stem (Ehrensing, 2008a). When canola reaches full maturity, seeds turn dark brown or black, and the optimum seed moisture for canola at harvest is 8 to 9 percent (Ehrensing, 2008a).

In order to attain high yield and oil quality, harvest timing is critical. Early harvest usually results in excessive green seeds, reduced oil content, and high seed moisture. Because mature and dry canola pods can open easily, shattering can cause severe yield losses if the harvest is late (Ehrensing, 2008a). Harvesting standing canola with the combine can be highly risky if the crop is fully mature. When the pods are dry and breakable, high seed losses can be expected. Swathing is used to reduce shattering losses in both spring and winter canola.

Attention should be paid to timing. It is important that 60 to 75 percent of the seeds have turned black and have no more than 30 to 40 percent moisture (Kansas Agricultural Experiment Station, 1996).

Swathing canola at the optimum stage of ripening results in reduced green seeds and reduced seed shutter losses. It also ensures the quality required for top grades and prices. If a hard fall frost is expected, swathing early can be useful in Northern United States and Canada. Swathing after frost should be avoided (Berglund et al., 2007a).

Indian mustard

Introduction and History

Brassica juncea L. Czern. and Coss., also known as Indian, Oriental or Brown mustard (Edwards et al., 2007), originated from the hybridization of *B. nigra* and *B. campestris* (Baltensperger et al., 2004; Edwards et al., 2007; Oram et al., 2005). The hybridization between these progenitors, *B. nigra* and *B. campestris*, probably took place in Southwestern Asia and India, where the natural distributions of both species overlap (Baltensperger et al., 2004).

Three ideas have been proposed for the center of the origin of *B. juncea*. According to Vavilov (1949), Central Asia, Afghanistan and adjacent regions are considered the primary center of origin of *B. juncea*; however, Central and Western China, Eastern India and Asia Minor through Iran can be secondary centers (Prakash, 1991; Duke, 1983). Contrary to Vavilov, however, Gomez-Campo and Prakash (1999) think that the center of origin of *B. juncea* is the Middle East and China. The third idea, based on the sympatric distribution of *B. juncea*'s progenitors, is that the plant could have been originated between Eastern Europe and China (Edwards et al., 2007).

B. juncea is believed to be one of the oldest domesticated plants in the world (Edwards et al., 2007; Wysocki and Crop, 2005). Indian mustard is believed to have been planted in the Indus Valley 5000 years ago (Mehra, 1968, as cited in Oram et al., 2005). *B. juncea* was described in Sumerian and Sanskrit texts as early as 3000 B.C. (Hemingway, 1995 as cited in Edwards et al., 2007). The spread of *B. juncea* to Europe as a medicinal plant happened in the Middle Ages and the plant was grown as a vegetable for human consumption (Edwards et al., 2007).

Introduction of Indian mustard into the United States is recent. A yellow-seeded variety of *B. juncea* was brought into the country from China in the 1940s. The crop continued to be widely grown due to its adaptation to mechanized harvesting (Baltensperger et al., 2004). In the 1960s, the production of mustards started in the upper Midwest U.S in states such as North and South Dakota and Minnesota.

In the mid-1980s, mustard production increased in Canada (Wysocki and Crop, 2002). Currently, Canada is considered a major exporter and is the largest producer of mustard seeds in the world. Mustard produced in Canada is mainly used for condiment purposes (Edwards et al., 2007).

India is a major producer of Indian mustard where it is grown for edible oil. Indian mustard production accounts for 80 percent of about 12 million acres (4.8 million hectare) planted to *Brassica* oilseed each year (Kumar et al., 2000; Negi et al., 2004 as cited in Edwards et al., 2007).

B. juncea is grown over much of the world. After the U.S, Canada and India, Indian mustard is also grown in China, Central Africa, Bangladesh, Japan, Nepal, Pakistan and Southern Russia north of the Caspian Sea (Duke, 1983; Edwards et al., 2007). Recently, there has been a tremendous interest in development of brown mustard as an alternative to canola in Australia (Norton et al., 2009).

Indian mustard is mainly cultivated for three important purposes: oil, spice and as vegetable. Indian mustard has been known as a spice for a long time. Indian mustard and white mustard, *Sinapis alba*, are the only two species used for condiment production purposes around the globe (Edwards et al., 2007; Callihan et al., 2000). In addition to a spice, the flour of Indian mustard is used as a salad dressing, as a sauce, and in

mayonnaise production (Skrypetz, 2003 as cited in Edwards et al., 2007). Besides grown as an oilseed crop, Indian mustard is also cultivated for its edible leaves (Callihan et al., 2000). It is also grown as forage, as green manure and as a garden crop (Wysocki and Corp, 2002).

General Description

Brown mustard is closely related to canola, turnip, and *B. rapa* (Edwards et al., 2007; Norton et al., 2009; McCaffery et al., 2009).

The plant is mainly a perennial, but it is grown as either an annual or a biennial (Duke, 1983). The following description comes from Duke (1983): *B. juncea* grows slightly more than 3.4 feet (132.6 cm) tall. The plant has long leaves, erect or angled at 90 degrees from the stem. The lower leaves have petioles and sometimes are coated with a whitish bloom.

The root varies in length from 35 to 50 inches (90 to 127 cm). *B. juncea* has $2n=36$ chromosomes (Chopra and Prakash, 1991) and is a self-pollinated crop (Shivanna, 1991).

Climate, Adaptation and Soil

Although Indian mustard is a cool season and short season crop (Edwards et al., 2007; Wysocki and Corp, 2002), it also flourishes in hot days with cool nights (Duke, 1983) and in areas with a short, warm, to hot growing season (Oram et al., 2005). Mustards including brown mustard tend to grow well at monthly average temperatures of 60 to 65 °F (15.5 to 18.33 °C).

Indian mustard is more heat and drought tolerant crop than spring canola (Baltensperger et al., 2004; McCaffery et al., 2009; Norton et al., 2009; Oram et al.,

2005; Wysocki and Corp, 2002). The crop is considered highly flexible and has shown a good response to a wide range of rainfall or supplemental irrigation (Baltensperger et al., 2004). Indian mustard has been a preferred crop in areas where water supply is inadequate or unreliable (Oram et al., 2005).

In Australia, where the average annual rainfall is less than 13 inches (330. 2 mm), Indian mustard is preferred over canola as a crop (Norton et al., 2009). Likewise, in drier regions of Russia, India, China, and Canada, where rainfall tends to fluctuate, brown mustard is given precedence (McCaffery et al., 2009; Oram et al., 2005).

Brown mustard is found as cultivated, weedy escapes, or wild forms in landscapes varying from coastal low lands to sandy beaches to plateaus and to mountains areas (Edwards et al., 2007).

Although mustards grow well on most soils, they are well-adapted to fertile, well-drained, loamy soils. *B. juncea* can also be grown in a variety of soils with good drainage (McCaffery et al., 2009; Wysocki and Corp, 2002).

Soils vulnerable to crusting can cause seedling problems. When planting *B. juncea* on acidic soils, aluminum levels should be checked and lime should be applied if necessary. Sodic soil, which usually crusts after rain, can significantly reduce plant stand; therefore, planting on sodic soil, especially if rain is expected after planting, should be avoided (McCaffery et al., 2009). Indian mustard prefers soil with a pH greater than 7.0 (McCaffery et al., 2009). *B. juncea* is susceptible to standing water, and it cannot tolerate water logging (Baltensperger et al., 2004).

Cultural Practices

Seedbed Preparation

A firm and well-packed seedbed which allows proper seeding depth and seed-to-soil contact is needed for successful stand establishment of Indian mustard with minimal weed pressure. When preparing the seedbed, excessive tillage should be avoided to reduce soil moisture loss and crusting (Baltensperger et al., 2004).

For good germination, Indian mustard slightly needs more sub-soil moisture than cereal crops. Seeding in a field with low sub-soil moisture may be risky (McCaffery, et al., 2009).

Planting date

Planting date of Indian mustard varies, depending on soil and weather conditions. In the U.S planting generally begins in March when the soil temperature reaches 40 °F (4.4 °C) or warmer (Baltensperger et al., 2004). Like many other oilseed crops, *B. juncea* benefits from early planting. Early planting allows development of a vigorous root, which enables the plant to reach deep moisture during hot and dry weather conditions. Early planting is particularly important for *B. juncea* to maximize its dry matter by mid-flowering stage while providing a solid platform for seed filling shortly after flowering (McCaffery et al., 2009).

If planted too early, *B. juncea* can grow too tall and the canopy can become rank, causing harvest problems. Planting too early can lead to frost damage at pod filling stages (McCaffery et al., 2009).

Seeding Rate

Under normal conditions, the seeding rate of *B. juncea* generally ranges from 300,000 to 600,000 seeds per acre (741,000 to 1,482,000 seeds per hectare) (Baltensperger et al., 2004). In areas where late season drought can be a problem, seeding rates of 300,000 to 500,000 seeds per acre (741,000 to 1,235,000 seeds per hectare) should be used (Baltensperger et al., 2004). In irrigated, weedy, high surface residue fields, or when broadcast, a higher rate should be used, varying from 800,000 to 1 million of seeds per acre (1,976,000 to 2,470,000 seeds per hectare) (Baltensperger et al., 2004). There are approximately 100,000 seeds per pound of (220,000 seeds per hectare) *B. juncea* (Baltensperger et al., 2004). Higher seeding rates will result in stems that are more sensitive to lodging; however, added density will result in shorter maturity time (Baltensperger et al., 2004).

Under dryland conditions, a population density of 10 to 12 plants per square foot (112 to 134 plants per square meter) is ideal, whereas, in irrigated fields, a population density of 14 to 16 plants per square Foot (156 to 178 plants per square meter) is recommended. A plant population of 2 to 4 plants per square foot (23 to 44 plants per square foot) in a weed-free field is salvageable because Indian mustard branches profusely (Baltensperger et al., 2004).

Seeding Depth

B. juncea seeds are very small. The planting depth of *B. juncea* depends on seed size, with smaller seeds being planted at shallower depth. The planting depth varies from 1/8 to 1 ½ inches (0.31 to 3.81 cm). When moisture is adequate, planting depth of ½ inch to 1 inch (1.27 to 2.54 cm) is optimal (Baltensperger et al., 2004).

Fertilizer

Adequate plant fertilization will benefit Indian mustard. In order to have a rapid stand establishment and optimum yield, sufficient plant fertilization of nitrogen, phosphorus, potassium and sulfur is essential (Baltensperger et al., 2004).

Nitrogen

Brown mustard is a heavy user of nitrogen. The plant shows a greater response to high rates of nitrogen than wheat and barley (Baltensperger et al., 2004). The demand of Indian mustard for nitrogen fertilizer depends on the current level of nitrogen fertility in the soil and the expected yields per acre. The nitrogen requirement for a yield goal of 3,500 pounds of grain per acre (3990 kg of grain per hectare) is about 150 pounds (67.5 kg) of nitrogen (Baltensperger et al., 2004). Nitrogen application method depends on soil moisture availability. When soil moisture is a limiting factor during seedling germination, in-furrow application of nitrogen should be avoided (Baltensperger et al., 2004).

Phosphorus

Brown mustard requires as much phosphorus as high-yielding wheat crops (Baltensperger et al., 2004). Depending on soil test and previous crop in the rotation with Indian mustard, the phosphate requirement of Indian mustard is about 90 to 135 pounds per acre (102.6 to 154 kg per hectare) (Duke, 1983). Phosphorus should be applied before planting (Baltensperger et al., 2004).

Potassium

The potassium requirement of Indian mustard is similar to that of high-yielding wheat. Depending on soil test results and the previous crop, in case of low levels of

potassium, Indian mustard needs around 45 to 67 pounds of potash per acre (51.3 to 76.38 kg per hectare) (Baltensperger et al., 2004).

Micronutrients

Boron deficiency, which tends to appear more in sandy and high pH soils, may occur in brown mustard fields. Indian mustard tends to be a heavier boron user than other crops in the rotation. In case of boron deficiency, a pre-plant application is recommended. The application rate of boron should be based on a soil test (Baltensperger et al., 2004).

Brown mustard is also a heavy user of sulfur and has shown a good response to sulfur applications. Sulfur is generally required for the crop to benefit from higher nitrogen application rates. Sulfur should be used in pre-plant application forms (Baltensperger et al., 2004).

Weed Control and Herbicides

When growing brown mustard, growers should pay attention to mustard's sensitivity to several broadleaf herbicides. Fields with residual triazines, imadazolinones, some sulfonylurease, picloram, and dicamba should be avoided (Baltensperger et al., 2004).

Before planting brown mustard, weeds and volunteers should be destroyed. Pre-plant tillage can control weeds and volunteers, but a combination tillage-herbicide program will control weed infestation better than tillage alone (Baltensperger et al., 2004).

Treflan/Trifluralin is registered for use on Indian mustard, but it will not control wild oats and many weedy types of mustard (Baltensperger et al., 2004).

Select or Prism may be used as post-emergence herbicide to control the grass weeds in brown mustard (Baltensperger et al., 2004).

Disease and Pest Management

Diseases

Many diseases can reduce the yield potential of brown mustard; however, a once in four year crop rotation along with the use of disease-free, certified seeds can considerably reduce disease incidence (Baltensperger et al., 2004).

Important diseases of brown mustard include: *Sclerotinia sclerotiorum* - wild mold or stem rot, Black Spot- *Alternaria brassicae* , Seed rots, seedling blights and root rots, which are caused by *Fusarium*, *Pythium sp.* and *rhizoctonia*. Stem canker or black leg, caused by *Phoma lingam*, is prevalent in Canada (Baltensperger et al., 2004).

Insects

Among many insects that can potentially damage and reduce brown mustard yield, flea beetles are most likely to cause severe damage. Cut worm, cabbage seedpod weevil, aphids, and army cut worm are also potential pests in brown mustard (Baltensperger et al., 2004).

Harvest

In North America and Europe, direct harvesting of brown mustard is a preferred method. When weeds and humidity are issues, swathing is also possible. Harvesting should not begin until the seed moisture is 10 percent; harvesting brown mustard when seed moisture is over 10 percent can cause heat damage during storage and dockage (Baltensperger et al., 2004).

Ethiopian Mustard

Introduction and History

Ethiopian mustard, *Brassica carinata* A. Braun, which is an amphidiploid, with a genome constitution of BBCC and a chromosome number of $2n=34$, is believed to have originated through natural hybridization of two diploid species of *Brassicaceae*, *Brassica nigra* and *Brassica oleracea* (Rahman and Tahir, 2010).

The natural hybridization event that produced *Brassica carinata* is believed to have taken place in Ethiopia, where the plant is used both as a leaf vegetable and an oilseed crop (Rakow and Getinet, 1998). *Brassica carinata* is grown in a wide range of areas from the United Kingdom to North Africa, the United States, and Canada. It is fairly hardy and is also well-adapted to temperate climatic zones (IENICA, 2004). Although the crop is still in an experimental stage, the current studies suggest that the crop is believed to be well-adapted to semi-arid and arid climates with mild or hot temperatures.

Brassica carinata is believed to have the potential to out yield *B. napus* under harsh climatic conditions. The major consensus behind developing *B. carinata* is to grow the crop in drier areas where most of the *Brassicaceae* tend to not do well (IENICA, 2004).

Brassica carinata is believed to be more adaptable to harsh environmental conditions because it is highly drought and heat tolerant. The crop is also believed to have good resistance against most of the *Brassicaceae* diseases (Rahman and Tahir, 2010). *Brassica carinata* is reportedly resistant to blackleg, white rust, and alternaria leaf spot, which are major diseases of *B. napus* (Warwick et al., 2006 as cited in Rahman and Tahir, 2010).

Although the crop has shown tremendous potential in terms of its environmental adaptability, production has remained limited because of its low oil and meal quality.

Brassica carinata has high levels of erucic acid in the oil and high levels of glucosinolates in the meal. Although oil and meal quality are poor, the crop has good resistance to pod shattering as well as oil suitable for biodiesel production. *Brassica carinata* generally yields lower than *B. napus*, and there is need for crop yield improvement (Rahman and Tahir, 2010).

General Description

The following description comes from FAO (n.d.):

Brassica carinata is an annual used both as a vegetable and an oilseed crop. The plant is known to achieve a height of 6 feet (234 cm). The stems are reddish-green. Unlike some of the *Brassica* family members, the plant branches profusely, from lateral buds. The leaves are alternate, non-heading, with long petioles.

Flowers are mainly light yellow and are about 15 mm across, located on short pedicels on an extended raceme. The flowers are regular, consisting of four free sepals in one series and two sets of stamens.

The fruit is a silque. The plant has large and predominantly dark, small seeds, 2 mm thick. The weight of 1,000 seeds is about 3.5 grams.

The crop requires 50 to 77 °F (10 to 25 °C) for optimal growth. However, the plant can withstand temperatures as low as 41 °F (5 °C). The amount of rainfall needed for crop establishment varies between 40 and 60 inches (1016 to 1524 mm); however, the crop can be established with an annual rainfall of as low as 30 inches (762 mm) as well.

Brassica carinata can be established on medium texture soil. The pH requirement varies from 5.5 to 8.

Brassica carinata requires about 230 days from planting to harvesting.

Oil Composition for Nine Oilseed Species

Fatty acids are major components of fats and oils (Scrimgeour, 2005; ERNA, 2008). Fatty acids are mostly attached to other molecules such as triglycerides or phospho-lipids; when not attached to other molecules, they are called “free fatty acids” (ERNA, 2008).

Fatty acids are straight hydrocarbon chains that contain a methyl (CH₃-) and a carboxyl group (-COOH) (ERNA, 2008; Scrimgeour, 2005). Fatty acids can be distinguished based on their number of carbons and double bonds (ERNA, 2008; Scrimgeour, 2005).

Although the number of carbons in a fatty acid chain varies significantly, most of the common fatty acids contain 4 to 22 carbons (Scrimgeour, 2005). There are more than 1000 fatty acids known so far, but only a handful of them are seen in substantial amount in major commercially important fats and oils (Scrimgeour, 2005).

Fatty acids with less than 16 carbons are considered short or medium chain, whereas those containing more than 18 carbons are characterized as long chain (Scrimgeour, 2005). Most commodity oils are composed of hydrocarbon chains that consist of 16 to 22 carbons with 18 carbons being the most common number (Scrimgeour, 2005). Palm kernel, coconut and cuphea are main source of medium chain

fatty acids; animal products have longer chain fatty acids; and high erucic acid content rape varieties are higher in C₂₂ monoene acids.

Classification by presence or absence of “double bonds” and the position of “double bonds” if present, yields the following list of categories:

- Saturated fatty acids
- Monounsaturated fatty acids
- Polyunsaturated fatty acids
- Omega-3 polyunsaturated fatty acids
- Omega-6 polyunsaturated fatty acids

Saturated fatty acids

Saturated fatty acids refer to fatty acids that have no “double bond” between carbons. In saturated fatty acids, the bonding positions between carbons are occupied by hydrogens (Ophardt, 2003; ERNA, 2008). Food contains high saturated fatty acids are butter and lard (Franzen-Castle and Ritter-Gooder, 2010). Fats with high saturated fatty acids are solid at room temperature (Franzen-Castle and Ritter-Gooder, 2010).

Monounsaturated fatty acids

Fats with at least one “double bond” between their carbons are called monounsaturated fatty acids (ERNA, 2008). Fatty acids with one double bond are most common in the human body, comprising more than 50 percent of all fatty acids (Baggott and Dennis, 1998). *Polyunsaturated fatty acid*

Fatty acids with two or more “double bonds” between their carbon atoms are called polyunsaturated fatty acids (Baggott and Dennis, 1998; Ophardt, 2003). Vegetable

oils, mainly canola, corn, olive, and flax, are usually higher in polyunsaturated fatty acids (Franzen-Castle and Ritter-Gooder, 2010). Unlike saturated or monounsaturated fatty acids, polyunsaturated fatty acids occur in lesser amounts yet are highly important for human health. Since some of polyunsaturated fatty acids are not produced by the human body, they are also called essential fatty acids (Baggott and Dennis, 1998). These must be provided in the diet. Polyunsaturated fatty acids are liquid at room temperature.

Among polyunsaturated fatty acids, two of them, omega-3 and omega-6, are essential for human health (Franzen-Castle and Ritter-Gooder, 2010). Since these fatty acids are not produced in the human body, they must be provided in the diet.

Omega-3 polyunsaturated fatty acids

Omega-3 polyunsaturated fatty acids have one of their “double bonds” at carbon number 3, counting from the methyl end. The main omega-3 fatty acids are alpha-linolenic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA) (ERNA, 2008).

Omega-6 polyunsaturated fatty acids

Omega-6 polyunsaturated fatty acids have one of their “double bonds” at carbon number 6, counting from the methyl end. The main omega-6 polyunsaturated fatty acids are linoleic acid (LA), gamma-linolenic acid (GLA), and arachidonic acid (AA) (ERNA, 2008). Linoleic acid accounts for more than 85 percent of dietary omega-6 fatty acids (Franzen-Castle and Ritter-Gooder, 2010).

Melting points of fatty acids

The melting point for each fatty acid depends on molecular weight and number of “double bonds”; the melting point increases with molecular weight (Ophardt, 2003), and

decreases with double bonds (Scrimgeour, 2005). The unsaturated fatty acids have lower melting points than the saturated fatty acids (Ophardt, 2003).

Table 2. Percent fatty acid content for nine oilseed species

Fatty Acid		Species								
Saturated fatty acids	Carbon ratio	Camelina ¹	Flax ²	Safflower ²	Sunflower ³	Sesame ⁴	Cuphea ⁵	Canola ³	<i>B. juncea</i> ⁶	<i>B. carinata</i> ⁶
Palmitic acid	16:0	7.8	6.86	7.59	6.05	8.24	7.0	6.19	3.9	3.1
Stearic acid	18:0	3.0	4.59	2.42	3.83	4.89	0.9	0 ^a	2.6	1.0
Unsaturated fatty acids	Carbon ratio									
Oleic acid	18:1	16.8	15.07	11.04	17.36	37.64	12.2	61.33	62.7	9.7
Linoleic acid	18:2	23.0	13.96	70.46	69.26	47.82	6.7	21.55	17.2	16.8
Linolenic acid	18:3	31.2	58.31	0.5	0	0.45	-- ^b	6.55	9.5	16.6
Erucic acid	22:1	2.8	nd ^c	nd	0	--	--	0	0.2	42.5

¹ Ehrensing and Guy, 2008

² Bozan and Temelli, 2008

³ Putnam et al., 1993

⁴ Were et al., 2006

⁵ Knothe et al., 2009

⁶ Potts et al., 1999

⁷ Cardone et al., 2003

^a Given as zero in the source

^b No data

^c Not detected

Technology Transfer

Historical Perspective of Technology Transfer:

Technology transfer is not a new phenomenon. The transfer of technology from one place to another place has historic roots in human societies throughout civilizations on earth.

The significant difference in productivity and human well-being over time and among different nations is often attributed to the “technology factor”. Regardless of its form, tangible or intellectual, and the means of transfer, either formal institutions or informal personal contacts, the “technology factor” has been instrumental in making positive differences in people’s lives (Hayami and Ruttan, 1970 as cited in Ruttan and Hayami, 1973).

Prior to the 19th century, when the concept of technology transfer did not yet formally exist, and before agricultural research and extension were institutionalized, technology transfer took place by diffusion. New crops, agricultural practices and knowledge were passed along or exchanged via personal contact among the people of various nations and continents. The diffusion of crops, animals, and agricultural practices usually took place as a result of travel, exploration and communication, which were carried out for purposes other than technology transfer (Rasmussen, 1955 as cited in Ruttan and Hayami, 1973).

According to recent cytogenetic studies of plant origin and earlier studies done by Sauer and Vavilov, diffusion of cultivated plants, domestic animals, hand tools, and husbandry practices among nations and continents was a crucial factor for increases in

production experienced by pre-historical and classical civilizations (Sauer, 1969 and Vavilov, 1949-50; Haris, 1967; Dovring, 1956 as cited in Ruttan and Hayami, 1973).

After the discovery of the Americas, the continual transfer of new crops, such as potatoes, corn and tobacco, had a remarkable impact on European agriculture (Ruttan and Hayami, 1973). This trend of diffusion continued for decades and even centuries in various nations and continents. Exotic plants, animals, equipment, and agricultural and husbandry practices were gradually introduced and adapted to local and indigenous conditions (Ruttan and Hayami, 1973).

Colonial governments along with the great trading companies, which used to work under the protection of colonial powers, showed interest in introduction of new crops with an export potential into new crop production areas. Introduction of such crops with export potential has had a tremendous influence on the location of staple production and on international trade patterns in crop and animal production (Ruttan and Hayami, 1973).

In the 19th century, when informal diffusion was shaped into a more institutionalized process, national governments formed agencies to look for and import exotic crop varieties and animal breeds (Klose, 1950 as cited in Ruttan and Hayami, 1973). Although international technology transfer was already highly institutionalized and recognized by national governments in the early 19th century, its dominant role in agricultural development has expanded after World War II. For instance, the transfer of technology from Western countries to Japan was a tremendously successful experience and has been a major factor helping Japan to achieve its current technological position in the world (Cohen, 2004).

After World War II, the United States supported several programs to enhance agricultural sciences and facilitate agricultural technology transfer in developing countries. Among these initiatives, training of international students at U.S educational institutions and provision of technical assistance to the universities of developing countries were considered a breakthrough in the field of agricultural technology transfer (Piñeiro, 2007).

In the early 1960s, the formation of International Rice Research Institute (IRRI) in the Philippines and the International Center for Wheat and Maize Improvement in Mexico institutionally strengthened the technology transfer trend. High yielding, dwarf varieties of rice and wheat from Mexico and the Philippines were introduced to Afghanistan, India, Pakistan, Indonesia and several other Asian countries (Ruttan and Hayami, 1973).

IRRI and CIMMYT, augmented by facilities in Columbia, Ethiopia, India, Indonesia, Italy, Kenya, Nigeria, Peru, Syria, and the United States, were shaped into an independent network of research institutions (Piñeiro, 2007).

Like U.S. land-grant institutions and Agricultural Experiment stations, National Agriculture Research Institutes (NARIs) enabled developing countries to conduct applied research in the field of agriculture (Piñeiro, 2007). The international transfer of crop varieties from developed countries to developing countries helped developing countries to enhance their technological base for staple production and export (Ruttan and Hayami, 1973).

What is Technology Transfer?

There is no single definition for the term “technology transfer”. The definition of technology transfer varies greatly, depending on a particular discipline (Bozeman, 2000; Zaho and Resiman, 1992).

Technology transfer is a process in which technology moves from one entity to another entity (Souder et al., 1990; Ramanathan, 1994). Autio and Laamanen (1995) define technology transfer as a goal-oriented process which tends to strengthen organizational capabilities and performances.

The FAO (1994) separates the components of technology transfer into “hardware”, “software”, “humanware”, and “orgaware”. These words equate to tangible materials (such as seed, fertilizer and insecticide), techniques and knowledge, human skills and abilities, and organizational factors, respectively. When these inter-related components are combined into a final product that is accessible to end users such as farmers, technology transfer occurs.

Components of Technology Transfer

As exemplified in the FAO definition, many researchers see technology transfer as a set of different components. Classifying and describing technologies as various components helps to understand the mechanism and process of technology transfer (Sanyang et al., 2009). Kumar et al. (1999) describe two main components of technology transfer: physical and informational. Kumar et al.’s physical components accounts for products, tools, equipment, techniques, and processes, whereas the informational component includes knowledge of management, production and marketing, quality control and skilled labor.

Identifying the components of technology transfer is important because one needs to evaluate which portion of technology is needed by the end user (Sanyang et al., 2009).

Phases of Technology Transfer

According to Ruttan and Hayami (1973), the international transfer of technology occurs in three distinct phases: material transfer, design transfer, and capacity transfer.

The first phase includes transfer of new materials or products such as plants, animals, and machines, and also the transfer of techniques which are associated with these materials or products. For example, if a tractor is the technology being transferred, tractor driving and tractor maintenance skills should also be transferred.

The second phase is marked by the transfer of certain designs and blueprints that can help the receiver of the technology to produce his own materials and products. The designs usually transferred in this phase are generally subjected to a wide range of regular tests and duplications. The focus of this phase is mainly to import exotic materials and copy their designs rather than using the original materials themselves (Ruttan and Hayami 1973). For example, the design of a tractor will be copied and more tractors will be made locally following the imported design.

The third phase, which is generally the transfer of scientific knowledge and capability, is aimed at creating the capacity to produce locally adapted technologies similar to those that exist abroad. In this phase, the focus is to produce locally adapted materials and to modify the previously transferred designs to make it more suitable to local conditions. For instance, the tractor design will be modified to suit local crops and to be made using local materials. In the third phase of technology transfer, the transfer of

scientific knowledge and capacity is usually facilitated by agricultural scientists from developed countries (Scoville, 1951 as cited in Ruttan and Hayami 1973).

Conclusion

Successful technology transfer depends on several factors: appropriate technology for the target area and users, capacity of the receiver to absorb new technology, and the existence of infrastructure to support the introduction, development and dissemination of newly introduced technology. Infrastructure includes higher educational institutions, training facilities for science and technology, research institutes, availability of skilled labor, and participation by scientists and engineers (Kumar et al., 1999). Infrastructure is generally built and maintained by national governments. It is important that the receiving country is willing to invest and provide an enabling environment to facilitate and support locally-adapted technologies. The candidate technology should be appropriate and should meet the demands of receiving country. Appropriate technology is “technically feasible, economically viable, socially acceptable, environment friendly, consistent with household endowments and relevant to the needs of farmers” (FAO, 1994).

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Chapter Three:

Crop Growing Degree Days and Oilseed Species Adaptability Trials

Introduction

Growers have traditionally used calendar days to estimate maturity of crops in particular locations. However, predicting crop potential to reach maturity based on calendar day is misleading because temperature varies from one year to another year. Historically, determination of crop adaptability in new areas was made by trial and error due to lack of a reliable method for predicting crop maturity.

An idea first proposed by Réaumur (1735) separates the estimation of time to maturity from the traditional calendar calculation and bases it instead on the concept of accumulated heat. According to this idea, plant physiological and phenological development is strongly influenced by air temperature. The accumulation of heat from crop germination to crop maturity determines the rate at which the crop will progress through the developmental stages of growth. Time to maturity can be estimated by calculating the daily average air temperature, when it is above a minimum temperature required for crop growth and below a maximum level that does not promote additional growth, and adding up these values over the growing season (McMaster and Wilhelm, 1997). The accumulation of heat above the crop's required base temperature is expressed as cumulative growing degree days (GGD).

The concept of growing degree days is now widely used in agriculture to allow farmers to predict certain events concerning their crop management and production. It

enables farmers to plan their farm activities, such as application of fertilizers and insecticides, irrigation scheduling, scouting for pests, and harvesting, in a timely manner.

Cumulative GDD is also important to identify suitable areas for introduction and establishment of new crops. Successful introduction of crops into new environments depends on availability of sufficient cumulative GDD for the crop to reach maturity.

The main goal of this study is to use cumulative GDD to predict the adaptability of certain oilseed species to high altitudes in Colorado and to investigate whether species that are adapted to high altitude environments in Colorado might be predicted to also be adapted to similar high altitudes elsewhere in the world, especially in Afghanistan.

Materials and Methods

GDD for nine oilseed species (Table 3) at eight locations (Table 4) were calculated using the growing degree day formula (McMaster and Wilhelm, 1997), where T_{max} is defined as daily maximum temperature, T_{min} as daily minimum temperature, and T_b as crop base temperature.

$$GDD = \frac{(T_{max} + T_{min})}{2} - T_b$$

Crop base temperature (Table 5) was subtracted from daily average temperature. If daily average temperature was less than crop base temperature, $\frac{(T_{max} + T_{min})}{2} < T_b$, then daily average temperature was set to zero ($\frac{(T_{max} + T_{min})}{2} = 0$). This method is used for corn and other field crops and has been widely used (Baker et al., 1986; Swanson and Wilhelm, 1996; Masoni et al., 1990).

Cumulative GDD was calculated by adding the GDD for each day to the previous day's value.

Long-term GDD was calculated from 25 to 30 years of historical weather data obtained from the Western Regional Climate Center, Historical Climate Information, located in Reno, Nevada, and Weather Source LLC. Air temperature data for 2010 were obtained from Colorado Agricultural and Metrological Network (CoAgMet), NOAA Satellite and Information Services-National Climatic Data Center, and Weather Source LLC. In 2010, nine oilseed species were planted in six locations (Table 4) varying in altitude from 5000 to 8000 feet. GDD and cumulative GDD were calculated for the 2010 trials. GDD were calculated for 2011 flax variety trials at three locations as well.

Expected adaptability of nine oilseed species at eight locations was determined based on long-term cumulative GDD in combination with the required cumulative GDD (Table 6) for each crop. Cumulative GDD was graphed for each oilseed species at each location. Expected growth interval based on beginning and ending dates of cumulative GDD was graphed for each oilseed species at each location.

Table 3. Nine tested oilseed species.

Common Name	Scientific Name	Cultivar
Flax	<i>Linum usitatissimum</i>	Golden
Camelina	<i>Camelina sativa</i>	Ligenia
Sunflower	<i>Helianthus annuus</i>	TRX 93429
Safflower	<i>Carthamus tinctorius</i>	Centennial, Montana-North Dakota
Cuphea	<i>Cuphea</i> spp	PSR23
Sesame	<i>Sesamum indicum</i>	SD 5
Canola	<i>Brassica napus</i>	V2035
Indian Mustard	<i>Brassica juncea</i>	JP 014
Ethiopian Mustard	<i>Brassica carinata</i>	BC 20375

Table 4. Eight test locations, six in 2010 and three in 2011.

Location		Elevation (Feet)	Coordinates	
City	County		Latitude N	Longitude W
Center (2010)	Rio Grande	7702 (2347.6 m)	37.7067	106.144
Oak Creek (2010)	Routt	7228 (2203.1 m)	40.1630	106.5227
Yellow Jacket (2010)	Montezuma	6900 (2103.1 m)	37.5289	108.724
Steamboat Springs (2010)	Routt	6732 (2051.9)	40.2835	106.4936
Hayden (2010)	Routt	6454 (1967.2 m)	40.499	107.181
Craig (2011)	Moffat	6128 (1867.8 m)	40.311	107.331
Fort Collins (2010- 2011)	Larimer	5110 (1557.5 m)	40.6525	105
Iliff (2011)	Logan	3835 (1168.9 m)	40.4532	103.3057

Table 5. Base temperature for nine oilseed crops.

Species	Base temperature °F (°C)	References
Camelina	39 (3.9 °C)	Gesch and Cerma (2001); Brown (1991); Enjalbert and Johnson (2011)
Flax	41(5 °C)	Foulk et al. (2005)
Canola	41(5 °C)	Grady (2002)
Indian Mustard	41(5 °C)	Singh et al. (1996)
Ethiopian Mustard	41(5 °C)	Adak and Chakravarty (2010)
Sunflower	44 (6.6 °C)	Robinson (1971); Kaya et al. (2004); Doyle (1975)
Safflower	46 (7.8 °C)	Wachsman et al. (n.d.); Armah-Agyeman et al. (2002)
Cuphea	50 (10 °C)	Gesch et al. (2002); Berti and Johnson (2008)
Sesame	61(16.1 °C)	Angus et al. (1980); Langham et al. (2009)

Table 6. Required growing degree days for nine oilseed crops

Species	Required GDD using °F (using °C)	References
Safflower	2200 (1204.4)	Oelke et al. (1992); Engel and Bergman (1997)
Cuphea	2444 (1340)	Gesch et al. (2005); Berti and Johnson (2008)
Canola	2600 (1426.6)	Miller et al. (2001)
Indian Mustard	2600 (1426.6)	Adak and Chakravarty (2010); McKenzi and Carcamo (2010)
Ethiopian Mustard	2750 (1510)	Miller et al. (2001)
Camelina	2850 (1565.5)	Estimated from base temperature and flax GDD
Flax	2900 (1593.3)	Miller et al. (2001)
Sunflower	3236 (1780)	Miller et al. (2001)
Sesame	4900 (2704.4)	Suddhiyam et al. (1992)

Results

I. Projected adaptability of nine species across eight locations of Colorado

Projected adaptability of nine oilseed species across varying altitudes of Colorado takes into account the expected cumulative GDD calculated using 25 to 30 years of temperature data. Figures 2 through 9 indicate potential adaptability of nine oilseed species in each of the study locations, based on whether the expected temperature at a location provides the required cumulative growing degree days for each species. Locations are presented in the order of higher altitude to lower altitude.

1. Center (Altitude 7702 feet (2347.6 meters))

Based on long-term temperature data, camelina is the only species that is expected to receive the required cumulative growing degree days in Center. As shown in Fig.2, canola, *B. juncea* and *B. carinata* are expected to narrowly miss achieving the required cumulative growing degree days at this location. Although their cumulative growing degree day requirement is less than that of camelina, their required base temperature (41 °F (5 °C)), is 2 °F (1.1°C) higher than for camelina. Flax, sunflower, safflower, cuphea, and sesame are not expected to achieve the required cumulative growing degree days. Flax, despite having a required base temperature of 41 °F (5 °C) similar to canola, juncea, and carinata, has a higher cumulative GDD requirement. Safflower has a higher required base temperature (46 °F (7.8 °C)), so its relatively low required cumulative GDD requirement is not expected to be met due to its higher required base temperature. Sunflower has a 2 °F (1.1°C) lower required base temperature than safflower, but it has a much higher cumulative GDD requirement. Although cuphea has a low cumulative GDD requirement, it has a very high required base temperature and is not expected to

meet the required cumulative GDD. Sesame has both a high required base temperature and a high cumulative GDD requirement. Sesame starts accumulating GDD later in the growing season; therefore, the expectation is that it has insufficient time to acquire the required cumulative GDD to reach maturity.

2. Oak Creek (Altitude 7228 feet (2347.6 meters))

Based on long-term temperature data, camelina, canola, juncea, and carinata are expected to achieve the required cumulative GDD to reach maturity in Oak Creek, as shown in Fig3. Flax, sunflower, safflower, cuphea and sesame are not expected to achieve the required cumulative GDD. Although flax has a required base temperature similar to that of canola (41 °F (5 °C)), it has a higher cumulative GDD requirement than canola, juncea, and carinata. Sunflower is not expected to achieve the required cumulative GDD because it has both a higher required base temperature and a higher cumulative GDD requirement. Safflower and cuphea, despite having lower cumulative GDD requirements (2200 and 2400 using °F) (using °C 1204.4 and 1315.5) than those of camelina and canola (using °F 2850 and 2600) (using °C 1566 and 1427), are not expected to achieve the required cumulative GDD due their higher required base temperatures (46 and 50 °F) (7.8 and 10 °C). Sesame has both a high required base temperature and a high cumulative GDD requirement. The high required base temperature does not allow sesame to accumulate GDD early in the growing season; therefore, it does not have sufficient time to acquire the required cumulative GDD to reach maturity.

3. Yellow Jacket (Altitude 6900 feet (2103.1 meters))

As shown in Fig. 4, camelina, canola, juncea, flax, safflower, and sunflower are expected to achieve the required cumulative GDD to reach maturity in Yellow Jacket. Cuphea and sesame are not expected to achieve the required cumulative GDD. Although cuphea has a considerably lower cumulative GDD requirement (using °F 2444) (using °C 1340) than that of sunflower (using °F 3236) (using °C 1780), due to its slightly higher required base temperature (2 °F (1.1 °C) higher than sunflower, it is expected to fall short of achieving the required cumulative GDD. Likewise, sesame is not expected to reach maturity because it has a high required base temperature and a high cumulative GDD requirement.

4. Steamboat Springs (Altitude 6732 feet (2046.5 meters))

As shown in Fig. 5, none of the nine oilseed species is expected to achieve the required cumulative GDD to reach maturity in Steamboat Springs. According to long-term temperature data for Steamboat Springs, species start accumulating GDD later in the growing season; therefore, there is insufficient time for oilseed species to meet the required cumulative GDD.

5. Hayden (Altitude 6454 feet (1967.2 meters))

As shown in Fig. 6, camelina, canola, juncea, carinata and safflower are expected to achieve the required cumulative GDD to reach maturity in Hayden. Sunflower, which has a 2 °F (1.1 °C) lower required base temperature than safflower, is not expected to achieve the required cumulative GDD to mature because of its high cumulative GDD requirement. Cuphea, which has a relatively lower cumulative GDD requirement, is not expected to achieve the required cumulative GDD due to its high required base

temperature. Sesame is not expected to achieve the required cumulative GDD due to its high required base temperature as well as its high cumulative GDD requirement.

6. Craig (Altitude 6128 feet (1867.8 meters))

As shown in Fig. 7, based on long-term temperature data, camelina, canola, juncea, carinata, and flax are expected to achieve the required cumulative GDD to reach maturity in Craig. Although camelina has a higher required cumulative GDD, it is expected to meet the required cumulative GDD because of its lower base temperature. Likewise, canola, juncea, carinata, and flax, which have a 2 °F (1.1 °C) higher required base temperature than camelina, are nevertheless expected to reach maturity because they have a lower cumulative GDD requirement than camelina. Sunflower, safflower, cuphea, and sesame are not expected to attain the required cumulative GDD. Sunflower has a required base temperature several degrees higher than those of camelina (39 °F) (3.8 °C) and canola (41°F) (5 °C) as well as a higher required cumulative GDD; whereas, safflower, which has a considerably lower cumulative GDD requirement than those of camelina, canola, juncea, carinata, and sunflower, has a 2 °F higher base temperature. Due to its higher base temperature, the crop is expected to fall short of meeting the required cumulative GDD. Likewise, cuphea, which has a considerably lower cumulative GDD requirement, is not expected to achieve the required cumulative GDD due to its higher base temperature (50 °F) (10 °C). Sesame, which has both a high required base temperature and a high cumulative GDD requirement, is expected to fail to meet the required GDD.

7. Fort Collins (Altitude 5110 feet (1557.5 meters))

As shown in Fig. 8, based on long-term temperature data, camelina, canola, juncea, carinata, flax, sunflower, and safflower are expected to achieve the required cumulative GDD necessary for maturity in Fort Collins. Although cuphea has a lower cumulative GDD requirement, it is not expected to achieve the required cumulative GDD to mature because it has a high required base temperature. Like cuphea, sesame is not expected to reach maturity due to its high required base temperature as well as its high cumulative GDD requirement.

8. Iliff (Altitude 3835 feet (1168.9 meters))

As seen in Fig. 9, according to long-term temperature data, camelina, canola, juncea, carinata, flax, sunflower, safflower, and cuphea are expected to achieve the required cumulative GDD to attain maturity in Iliff. The required cumulative GDD expected to be achieved by most of the species at the location are well above the required GDD for maturity. Therefore, the species are well-adapted to this particular location. Sesame, unlike the other species, is not expected to achieve the required cumulative GDD to mature. Because it has the highest required base temperature among all the species, the crop starts accumulating GDD later in the growing season. Due to insufficient time to acquire the needed GDD, the plant is expected to fall short of meeting the requirement and is not expected to reach maturity. Iliff, with a relatively low altitude, is suitable for growing all the oilseed species in this experiment, except sesame.

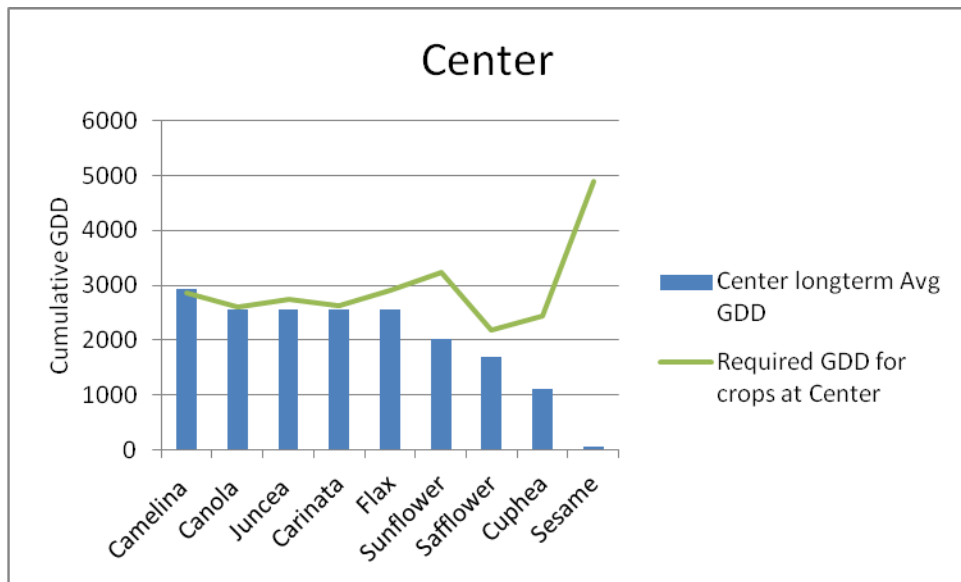


Fig. 2. Expected adaptability of nine oilseed species in Center, Colorado, based on long-term temperature data.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

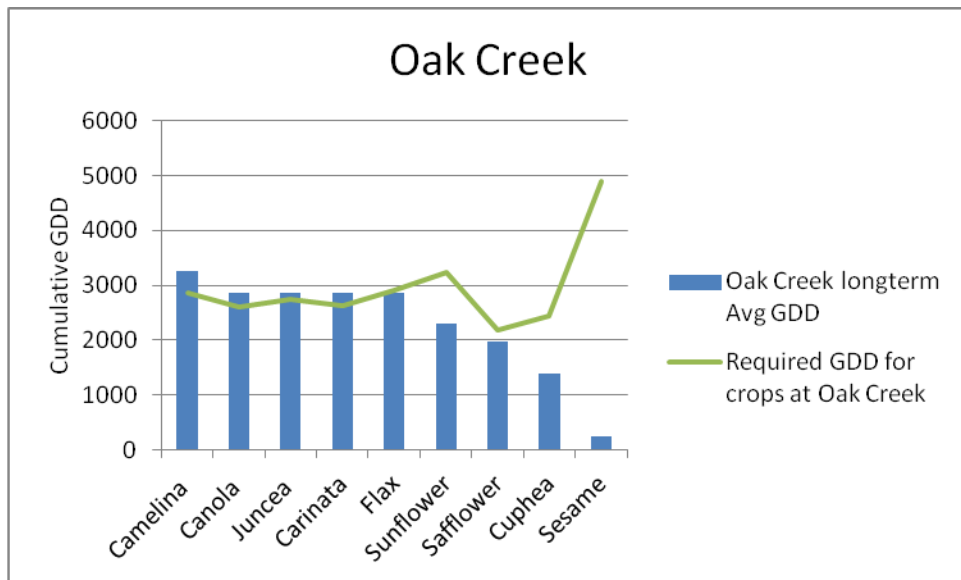


Fig. 3. Expected adaptability of nine oilseed species in Oak Creek, Colorado, based on long-term temperature data.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

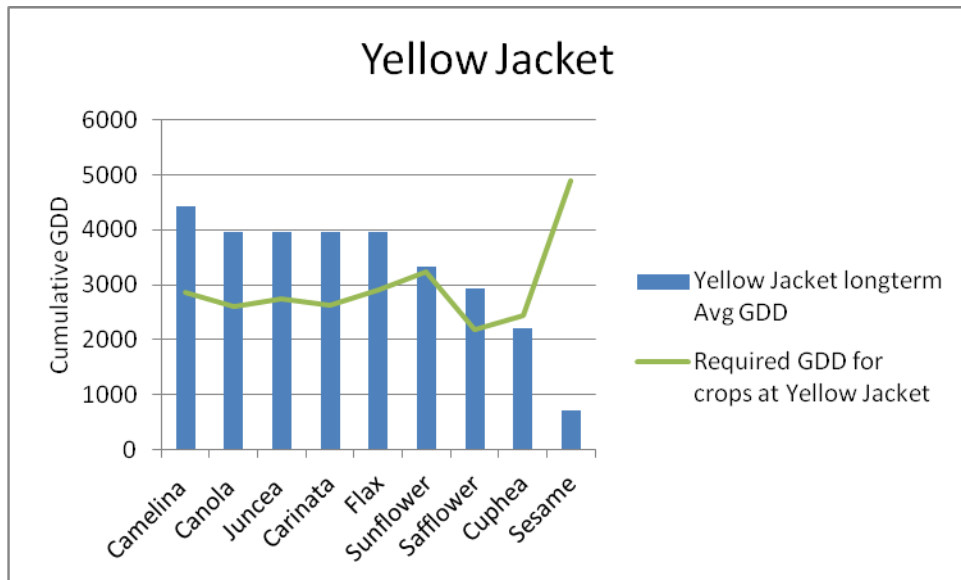


Fig. 4. Expected adaptability of nine oilseed species in Yellow Jacket, Colorado, based on long-term temperature data.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

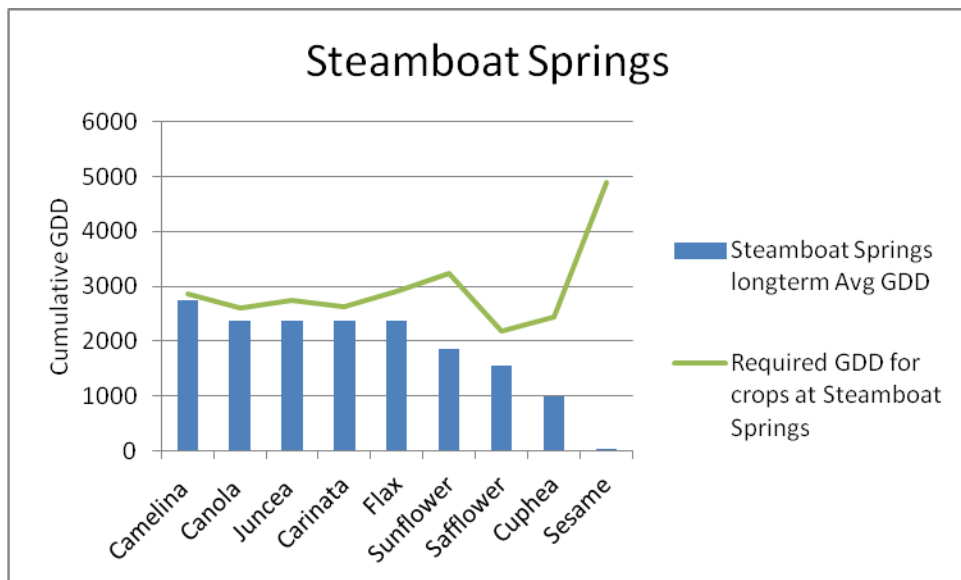


Fig. 5. Expected adaptability of nine oilseed species in Steamboat Springs, Colorado, based on long-term temperature data.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

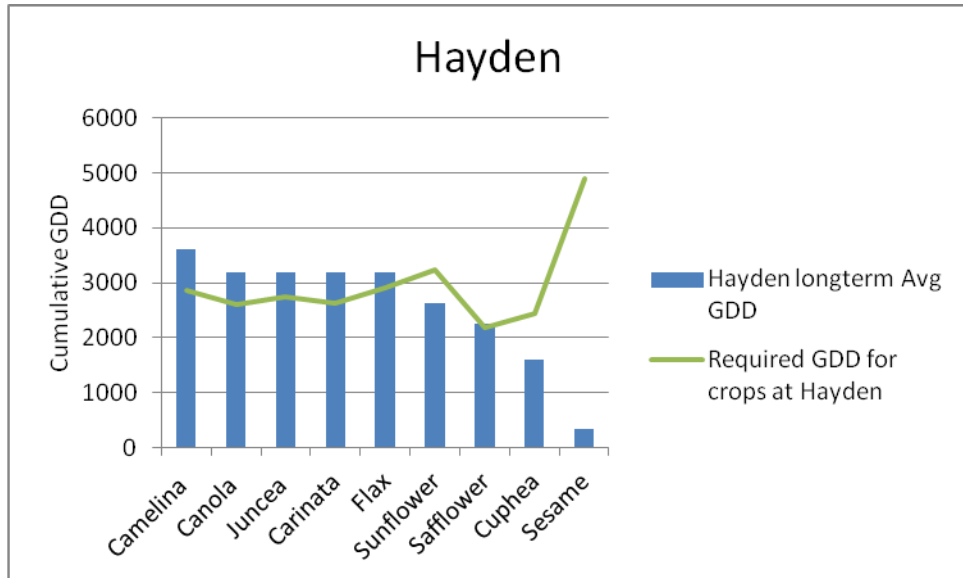


Fig. 6. Expected adaptability of nine oilseed species in Hayden, Colorado, based on long-term temperature data.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

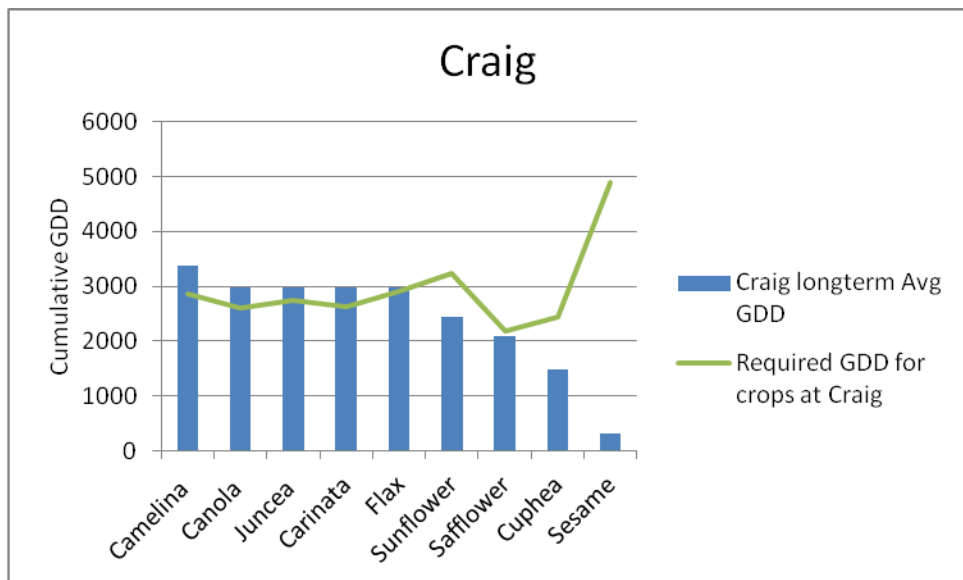


Fig.7. Expected adaptability of nine oilseed species in Craig, Colorado, based on long-term temperature data.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

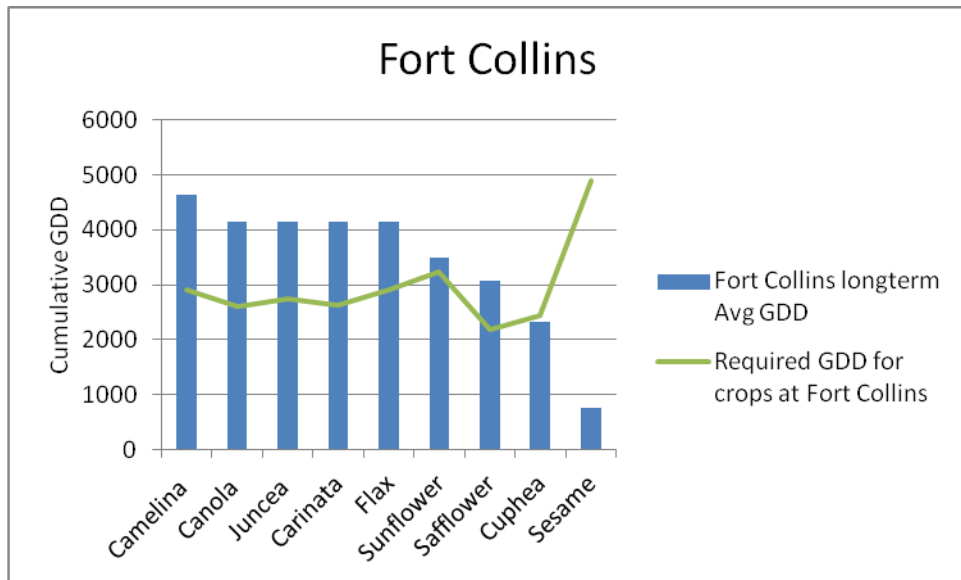


Fig. 8. Expected adaptability of nine oilseed species in Fort Collins, Colorado, based on long-term temperature data.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

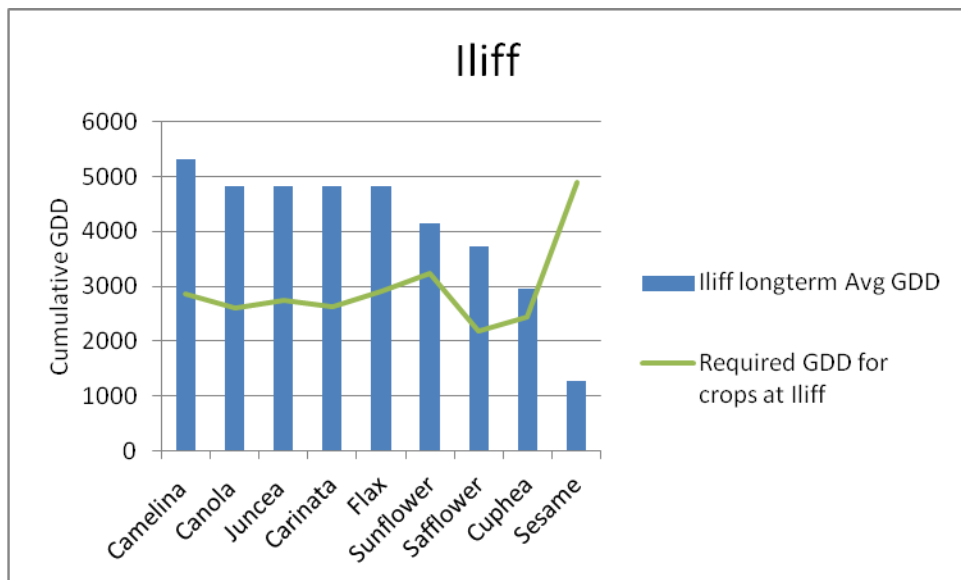


Fig.9. Expected adaptability of nine oilseed species in Iliff, Colorado, based on long-term temperature data.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

II. Projected suitability of each oilseed species across several locations in Colorado

Suitability of each oilseed species is projected based on long-term calculated growing degree days in several locations of Colorado. Figs. 10 through 18 show the expected cumulative GDD, the actual 2010 cumulative GDD, and the required cumulative GDD for all crops at each of eight locations.

1. Flax

As seen in Fig. 10, flax is suitable to grow in Iliff, Fort Collins, Craig, Hayden, and Yellow Jacket. Flax is not expected to acquire the required cumulative GDD to reach maturity in locations above 6700 feet (2042.1 meters) altitude (Steamboat Springs, Oak Creek, and Center) except Yellow Jacket. Despite its high altitude (6900 feet) (2103.1 meters), Yellow Jacket has an extended growing season, so many crops will mature there that will not mature in relatively lower altitude areas such as Steamboat Springs (6732 feet) (2051.9 meters).

2. Camelina

As shown in Fig. 11, based on long-term temperature data, camelina is expected to achieve the target cumulative GDD to reach maturity in Iliff, Fort Collins, Craig, Hayden, Yellow Jacket, and Oak Creek. Those areas with lower altitudes, such as Iliff and Fort Collins, would allow camelina to accumulate the highest cumulative GDD. Camelina is expected not to attain the required cumulative GDD to reach maturity in the Steamboat Springs area. Camelina has a 2 ° F (1.1 °C) lower required base temperature than those of flax, canola, juncea, and carinta. Although it has a higher cumulative GDD requirement than flax, due

to its lower base temperature, camelina is expected to achieve the required cumulative GDD in seven of the eight locations.

3. Sunflower

As seen in Fig. 12, sunflower is expected to achieve the required cumulative GDD only in Iliff, Fort Collins, and Yellow Jacket. Sunflower has a high required base temperature (44 °F) (6.6 °C), 3 °F (1.65 °C) higher than that of flax and 5 °F (2.75 °C) higher than that of camelina, and a higher cumulative GDD requirement. The relatively higher required base temperature and the higher cumulative GDD requirement suggest that sunflower will not meet the required cumulative GDD to reach maturity in Craig, Hayden, Oak Creek, and Center.

4. Canola

Although canola has a higher required base temperature than camelina (2 °F (1.1 °C) higher than camelina), it is expected to achieve the required cumulative GDD in as many locations as camelina, as shown in Fig. 13. Canola requires 250 fewer cumulative GDD (121 fewer using °C) than camelina. The lower GDD requirement meant that canola is expected to meet the target GDD to reach maturity in Iliff, Fort Collins, Craig, Hayden, Yellow Jacket, and Oak Creek. Canola is not expected to achieve the cumulative GDD requirement in Steamboat Springs and Center locations, both of which are high altitude areas.

5. Juncea

Juncea has a similar required base temperature and about the same cumulative GDD requirement as canola. As shown in Fig. 14, juncea is expected

to achieve the required cumulative GDD to reach maturity at the same locations as canola (Ilf, Fort Collins, Craig, Hayden, Yellow Jacket, and Oak Creek).

6. Carinata

As seen in Fig. 15, based on long-term temperature data, carinata is expected to achieve the required GDD in Ilf, Fort Collins, Craig, Hayden, and Yellow Jacket. Because carinata is closely related to juncea and has a similar required base temperature and a cumulative GDD requirement, it has shown a similar adaptability pattern to that of juncea and canola. Carinata is not expected to meet the cumulative GDD requirement in Steamboat Springs and Center.

7. Safflower

As seen in Fig. 16, based on long-term temperature data, safflower is expected to meet the required GDD to reach maturity in Ilf, Fort Collins, Hayden, and Yellow Jacket. Although safflower has the lowest cumulative GDD requirement among the nine tested species, it is expected to achieve the required cumulative GDD in only four locations. Safflower, unlike camelina, canola and sunflower, has a relatively high required base temperature (46 °F) (7.8 °C).

8. Cuphea

As seen in Fig. 17, based on long-term temperature data, cuphea is expected to achieve the cumulative GDD requirement only in Ilf. Although it has a lower GDD requirement than those of camelina, flax, canola, and sunflower, due to its high required base temperature (50 °F) (10 °C), it is not expected to accumulate enough GDD to reach maturity in Fort Collins, Craig, Hayden, Steamboat Springs, Yellow Jacket, Oak Creek, and Center locations.

9. Sesame

As shown in Fig. 18, sesame is not expected to achieve the required cumulative GDD in any of the eight locations. Sesame has both a high required base temperature and a high cumulative GDD requirement. Because these eight locations across various altitudes of Colorado do not allow sesame to mature, the crop has potential only in lower altitude areas with higher temperatures and a longer growing season.

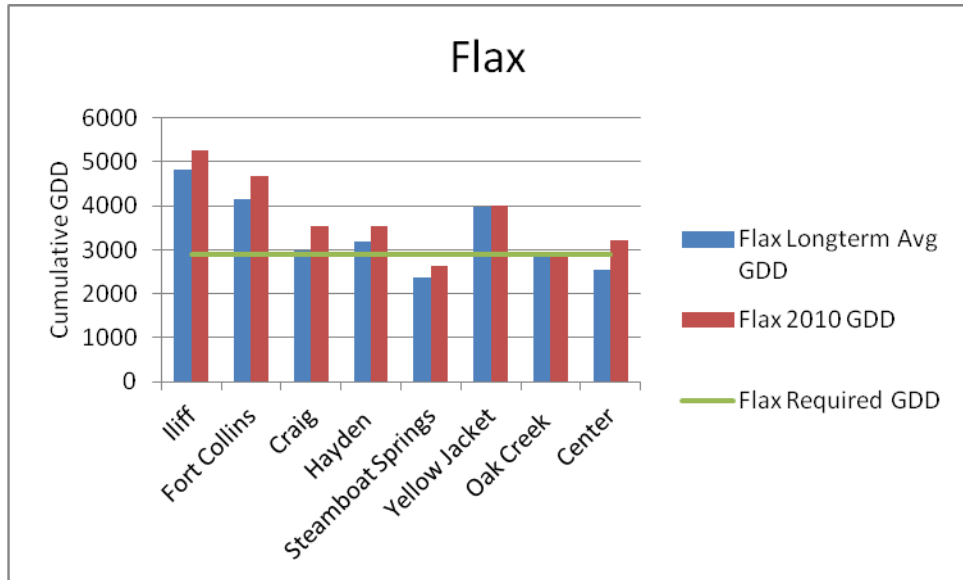


Fig. 10. Expected suitability of flax in eight Colorado locations, based on long-term temperature data.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

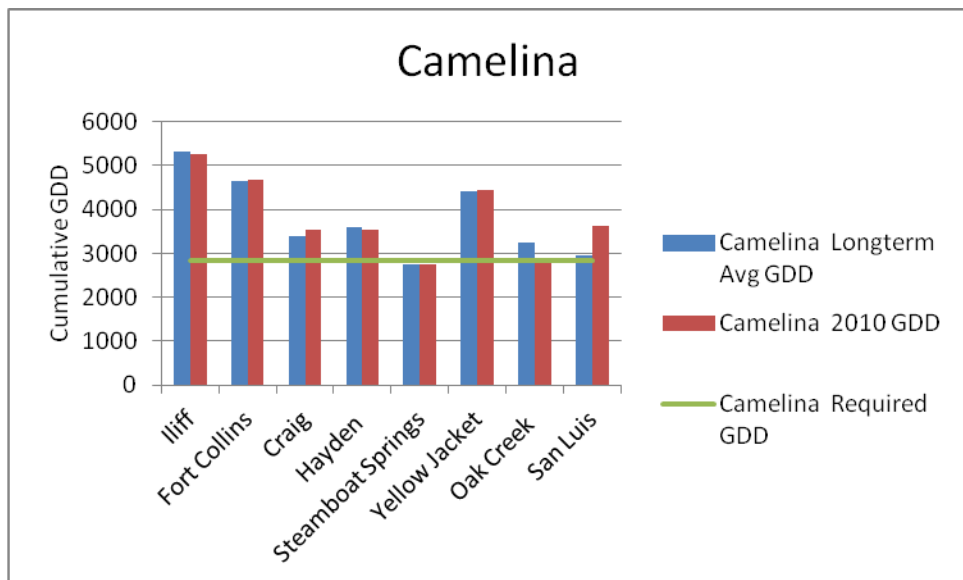


Fig. 11. Expected suitability of camelina in eight Colorado locations, based on long-term temperature data.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

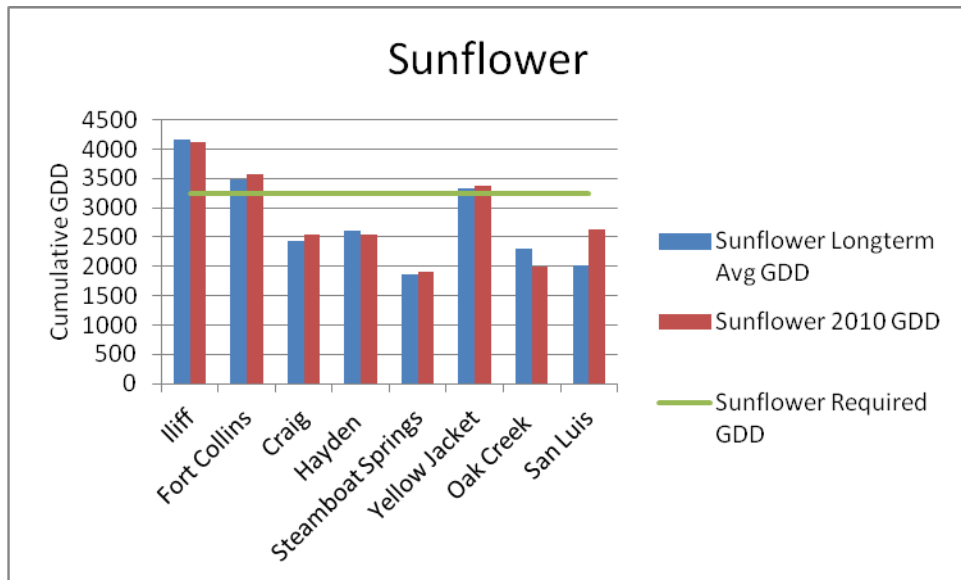


Fig. 12. Expected suitability of sunflower in eight Colorado locations, based on long-term temperature data.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

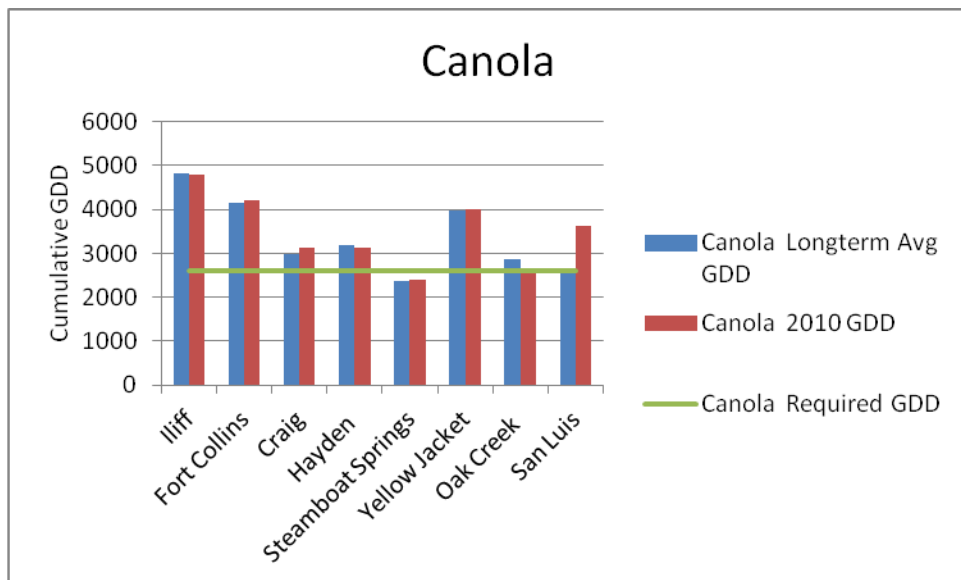


Fig. 13. Expected suitability of canola in eight Colorado locations, based on long-term temperature data.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

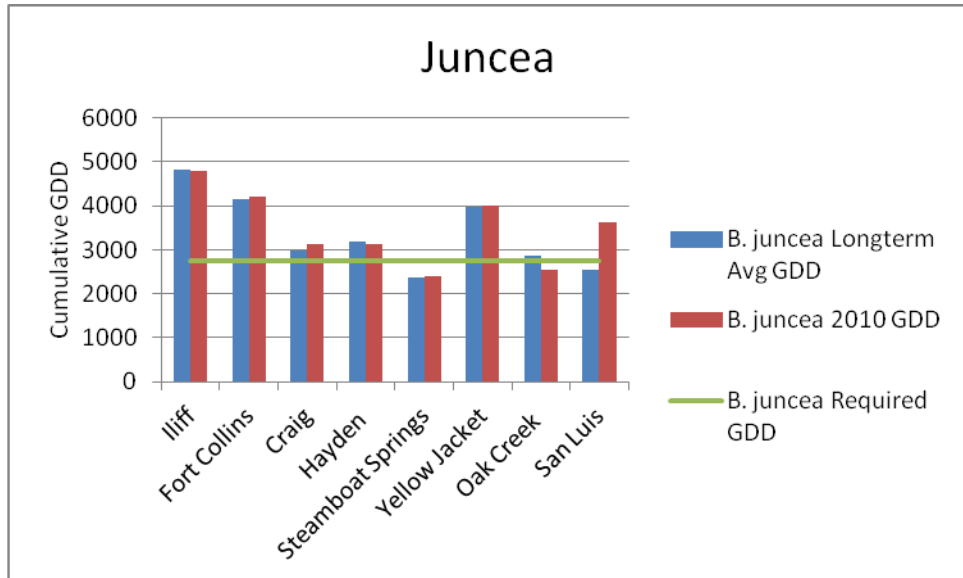


Fig. 14. Expected suitability of juncea in eight Colorado locations, based on long-term temperature data.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

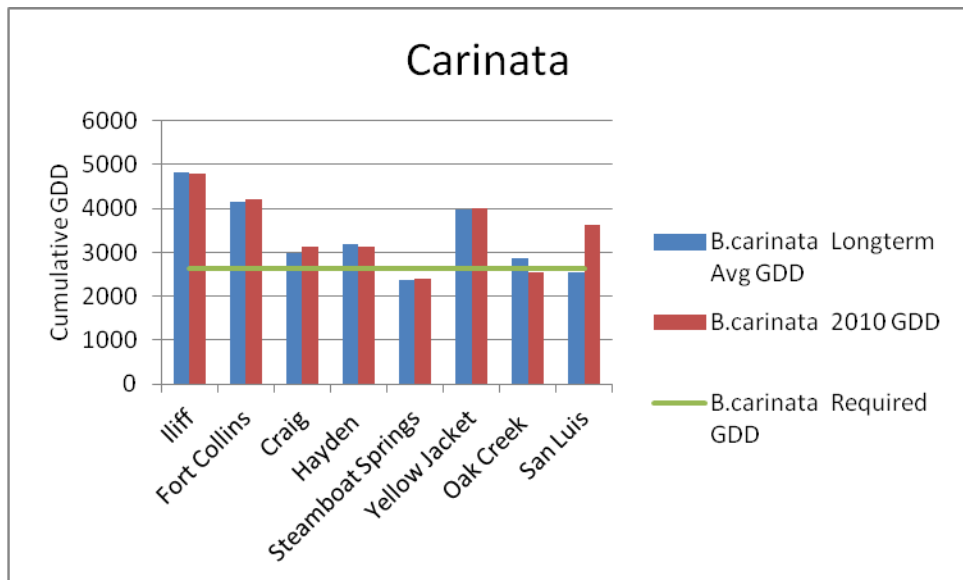


Fig. 15. Expected suitability of carinata in eight Colorado locations, based on long-term temperature data.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

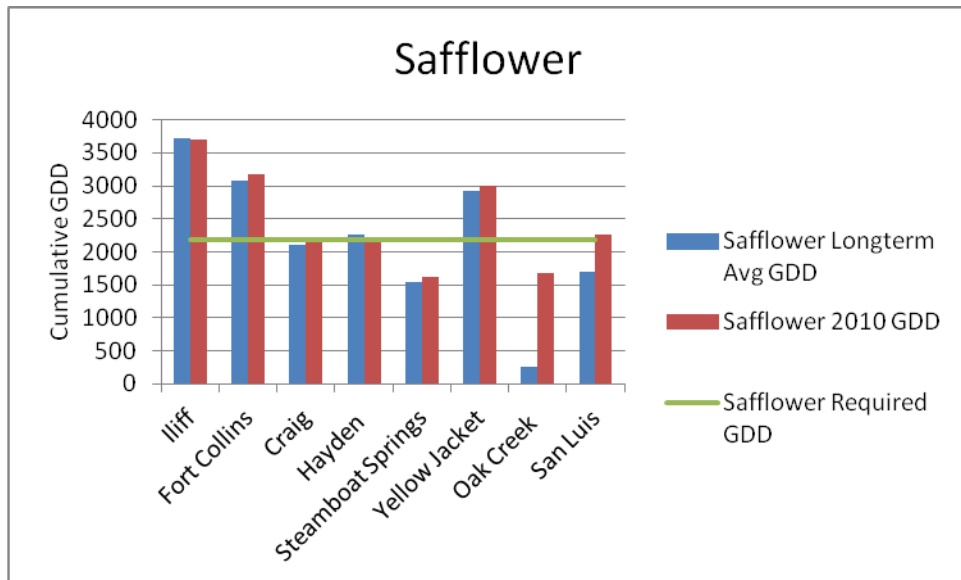


Fig.16. Expected suitability of safflower in eight Colorado locations, based on long-term temperature data.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

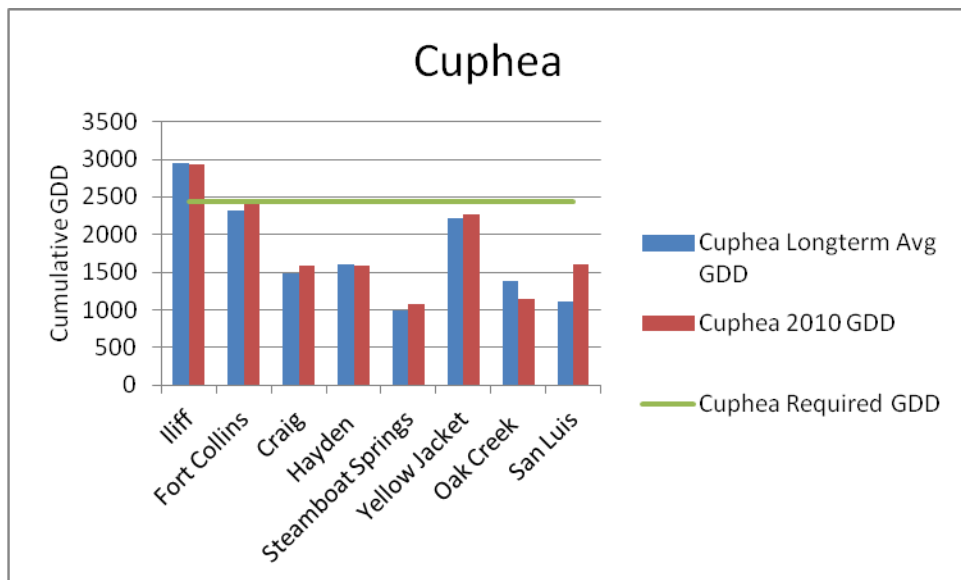


Fig.17. Expected suitability of cuphea in eight Colorado locations, based on long-term temperature data.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

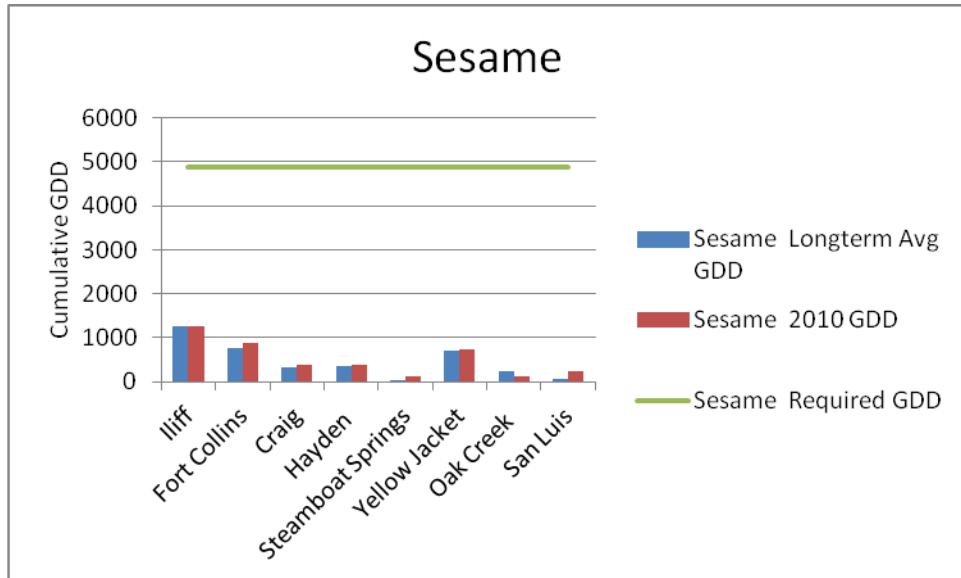


Fig.18. Expected suitability of sesame in eight Colorado locations, based on long-term temperature data.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

III. Cumulative growing degree days for nine oilseed species in a location

Figs. 19 through 26 show the cumulative GDDs on the Y axis plotted against calendar dates on the X axis for 9 oilseed species at locations around Colorado. These graphs are based on 25 to 30 years of daily weather data.

IV. Expectation and actual 2010 results of crop maturity in six locations in Colorado

Table 7 shows the expectation based on long-term temperature data and the actual 2010 results for crop maturity at six locations in Colorado.

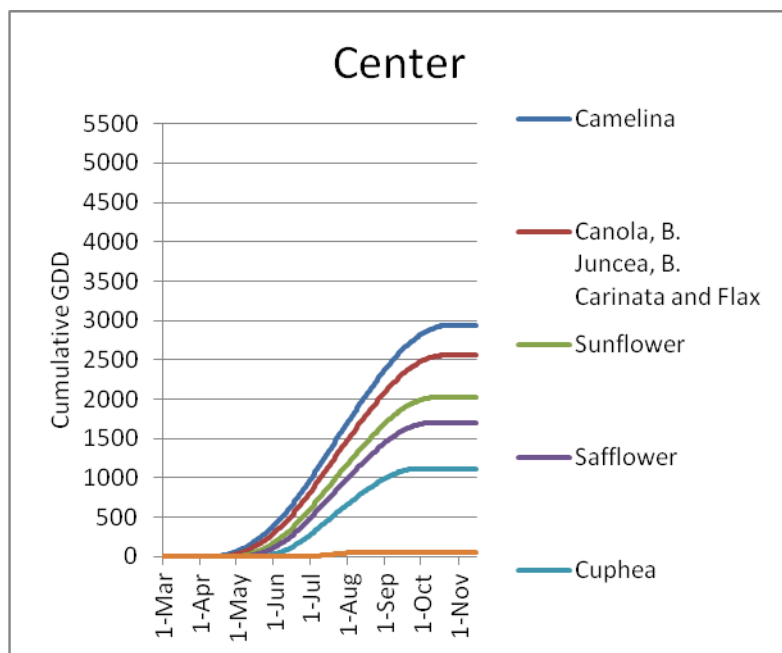


Fig. 19. Cumulative GDD of nine oilseed species in Center, based on long-term temperature data.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

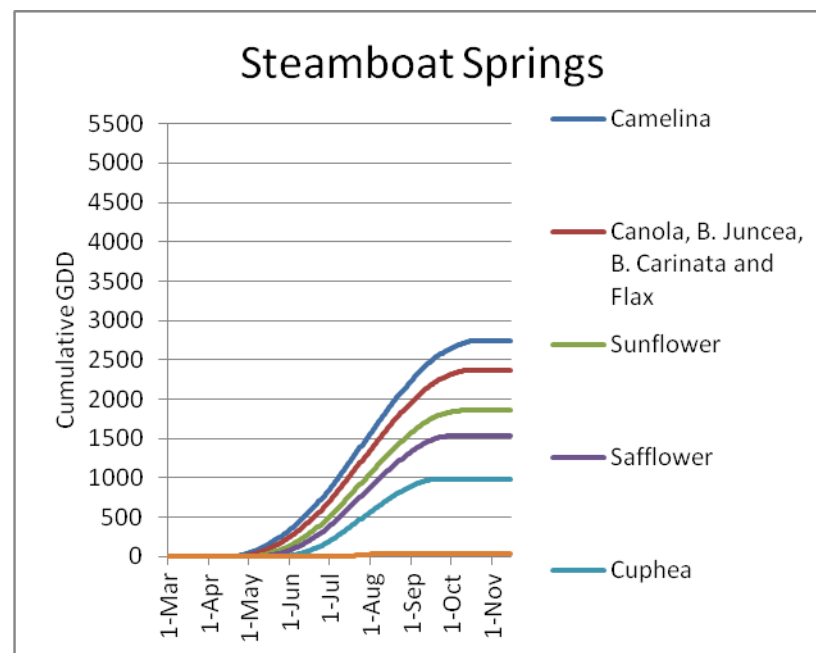


Fig. 20. Cumulative GDD of nine oilseed species in Steamboat Springs, based on long-term temperature data.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

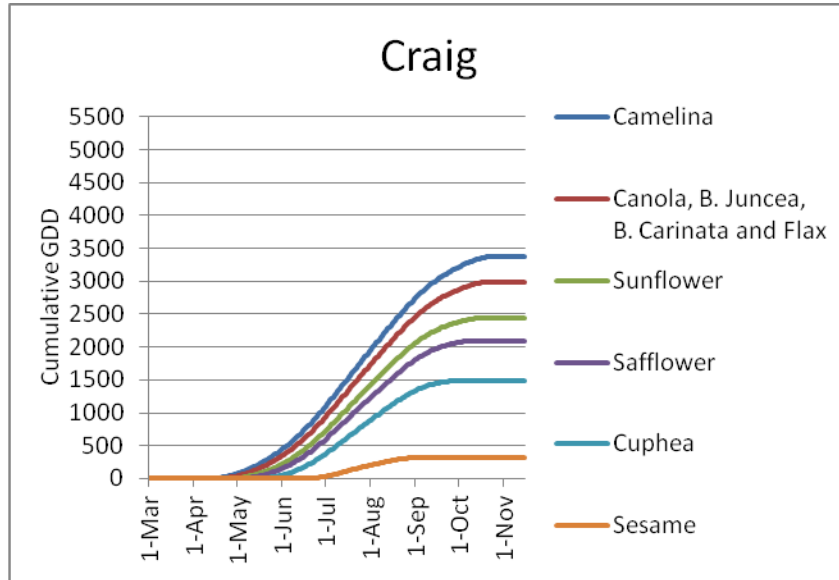


Fig. 21. Cumulative GDD of nine oilseed species in Craig based on long-term temperature data.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

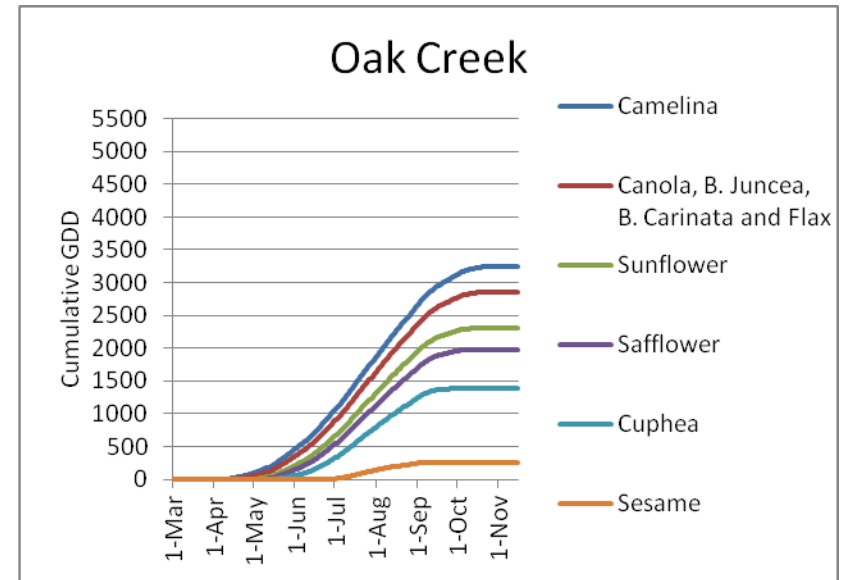


Fig. 22. Cumulative GDD of nine oilseed species in Oak Creek, based on long-term temperature data.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

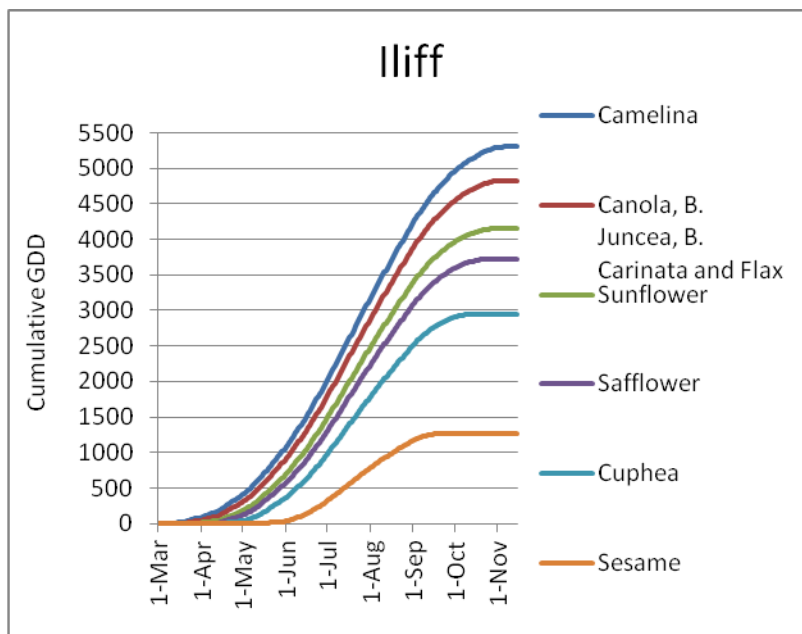


Fig. 23. Cumulative GDD of nine oilseed species in Iliff, based on long-term temperature data.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

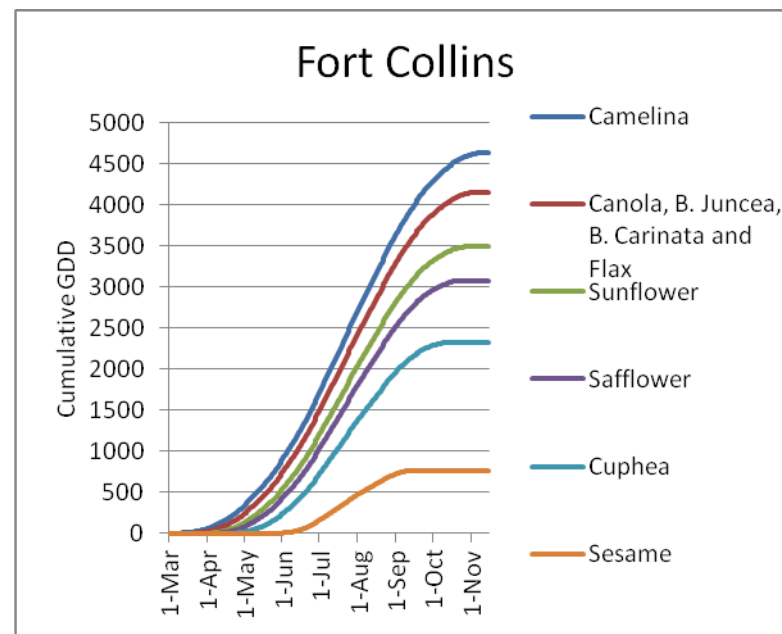


Fig. 24 . Cumulative GDD of nine oilseed species in Fort Collins, based on long-term temperature data.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

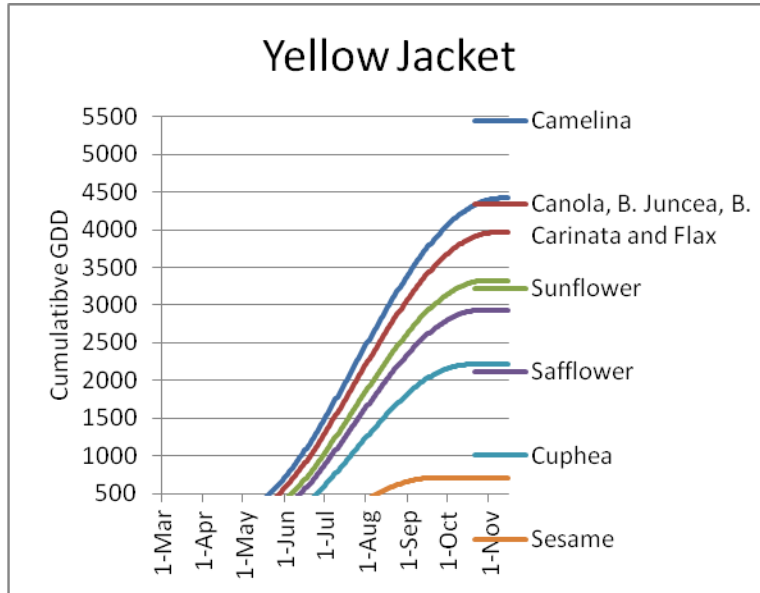


Fig. 25. Cumulative GDD of nine oilseed species in Yellow Jacket, based on long-term temperature data.

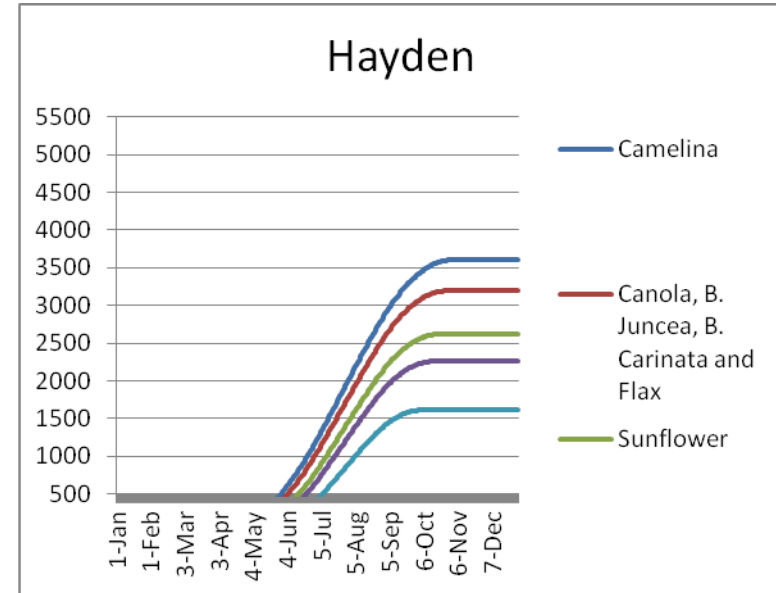


Fig. 26. Cumulative GDD of nine oilseed species in Hayden, based on long-term temperature data.

Table 7. Expected suitability and 2010 results for nine oilseed species at six locations in Colorado.

Location and Results		Species							
		Camelina	Canola	Juncea	Carinata	Flax	Sunflower	Cuphea	Sesame
Center	Expected	Mature	Not mature	Not mature	Not mature	Not mature	Not mature	Not mature	Not mature
	2010	Mature	Mature	Mature	Mature	Mature	Not mature	Not mature	Not mature
Oak Creek	Expected	Mature	Mature	Mature	Mature	Not mature	Not mature	Not mature	Not mature
	2010	Mature	Not mature	Not mature	Not mature	Mature	Not mature	Not mature	Not mature
Yellow Jacket	Expected	Mature	Mature	Mature	Mature	Mature	Mature	Not mature	Not mature
	2010	Mature	Mature	Mature	Mature	Mature	Mature	Not mature	Not mature
Steamboat Springs	Expected	Mature	Not mature	Not mature	Not mature	Not mature	Not mature	Not mature	Not mature
	2010	Mature	Not mature	Not mature	Not mature	Not mature	Not mature	Not mature	Not mature
Hayden	Expected	Mature	Mature	Mature	Mature	Mature	Not mature	Not mature	Not mature
	2010	Hailed out	Hailed out	Hailed out	Hailed out	Hailed out	Hailed out	Hailed out	Not mature
Fort Collins	Expected	Mature	Mature	Mature	Mature	Mature	Mature	Not mature	Not mature
	2010	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Not mature

V. Growing interval for nine oilseed species at each location in Colorado

Figs. 27 through 34 show the expected interval when temperatures are suitable for growth of each oilseed species at a particular location based on long-term temperature data.

VI. Growing interval for each oilseed species at eight different locations in Colorado

Figs. 35 through 40 show the expected interval when temperatures are suitable for growth of an oilseed species at eight different locations.

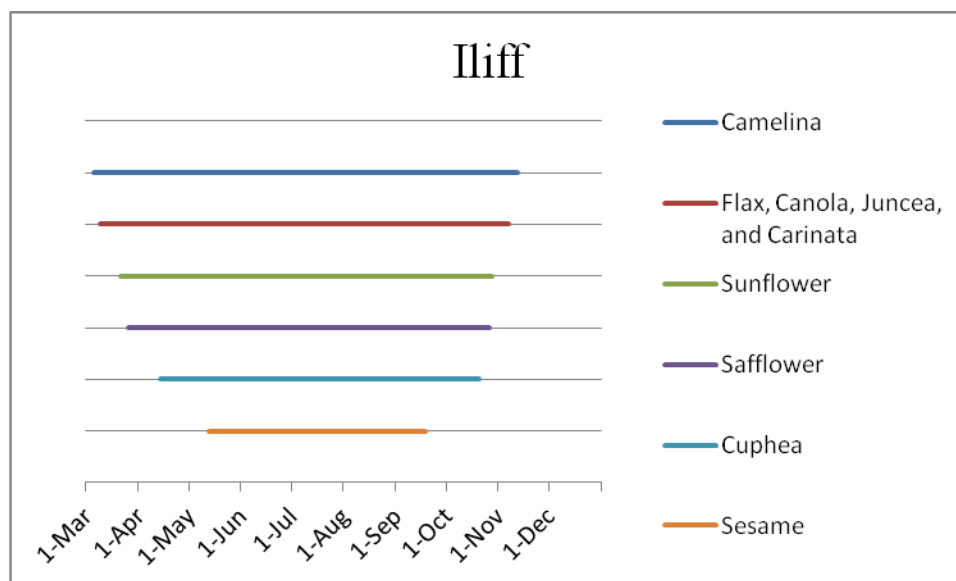


Fig. 27. Expected starting and ending dates for accumulation of GDD for nine oilseed species in Iliff, based on long-term temperature data.

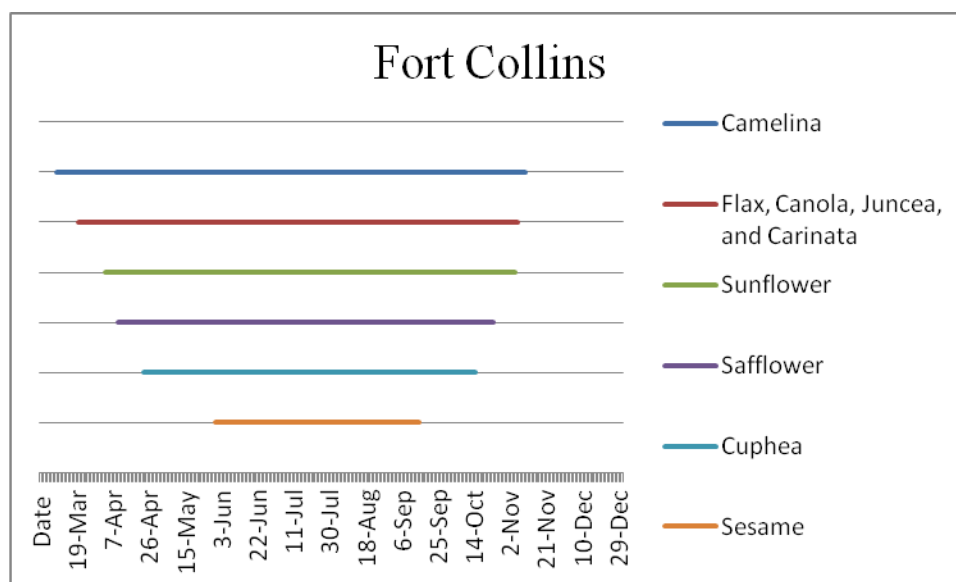


Fig. 28. Expected starting and ending dates for accumulation of GDD for nine oilseed species in Fort Collins, based on long-term temperature data.

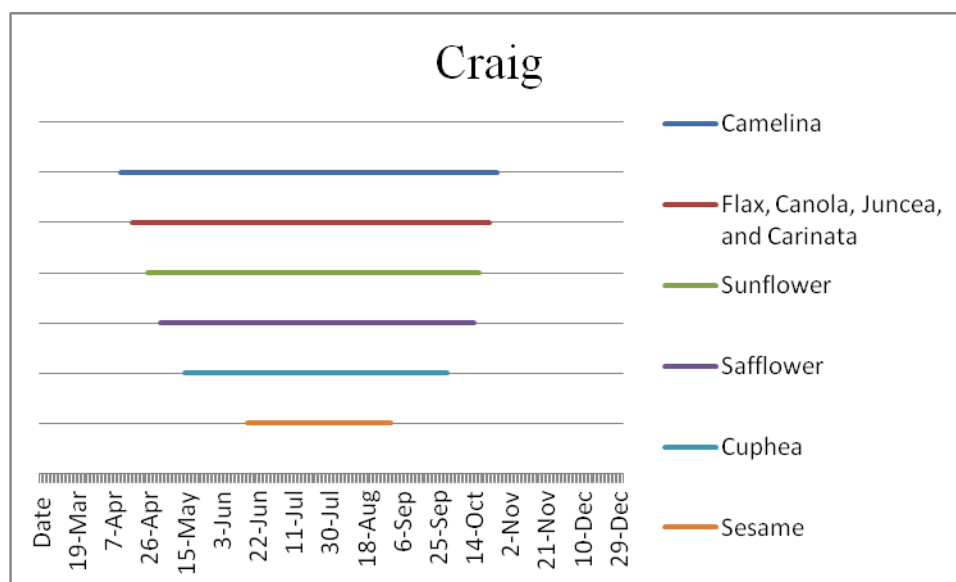


Fig. 29. Expected starting and ending dates for accumulation of GDD for nine oilseed species in Craig, based on long-term temperature data.

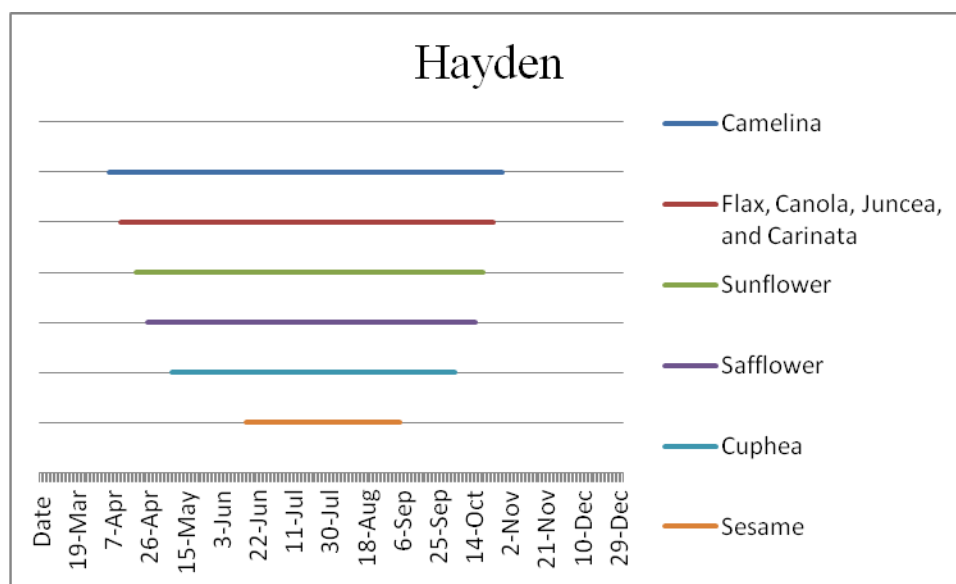


Fig. 30. Expected starting and ending dates for accumulation of GDD for nine oilseed species in Hayden, based on long-term temperature data.

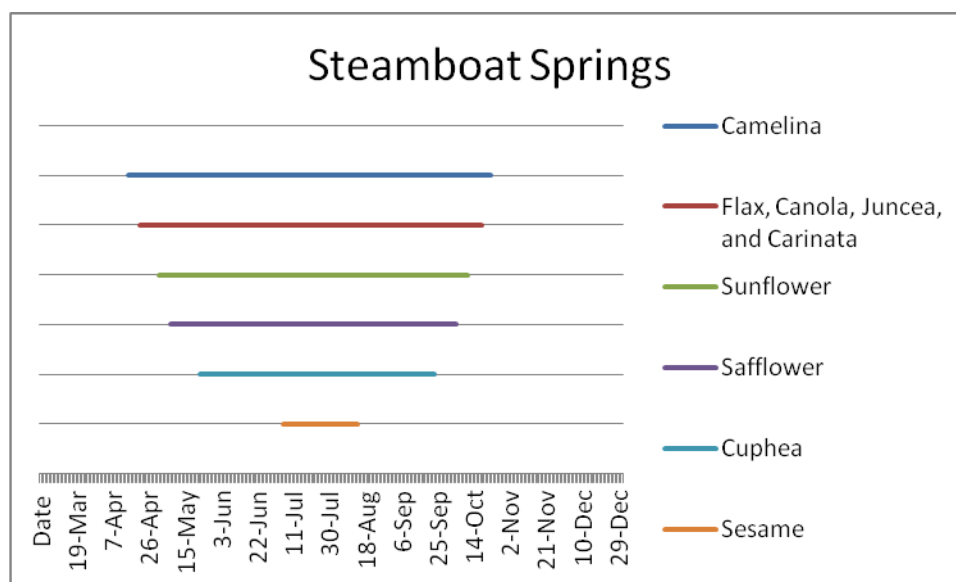


Fig. 31. Expected starting and ending dates for accumulation of GDD for nine oilseed species in Steamboat Springs, based on long-term temperature data.

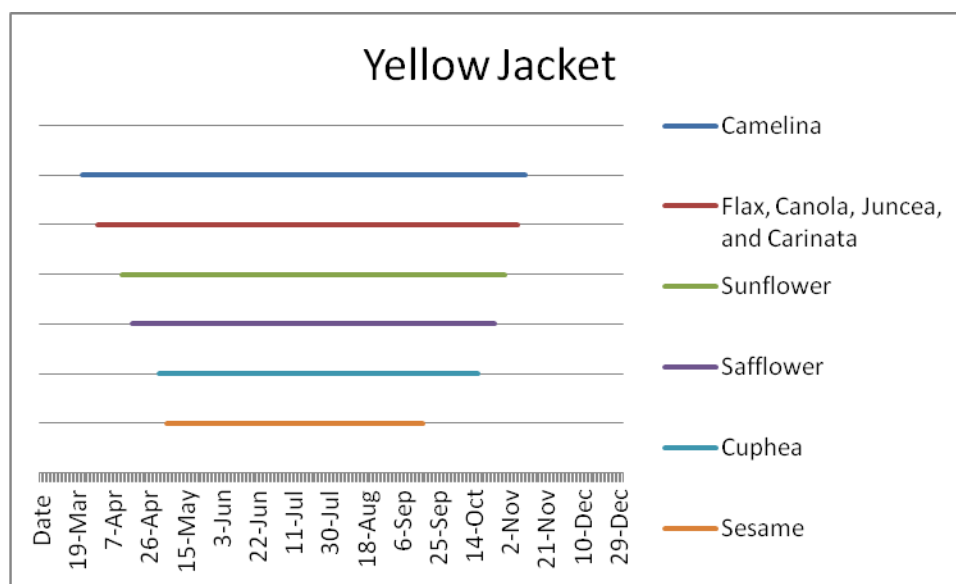


Fig. 32. Expected starting and ending dates for accumulation of GDD for nine oilseed species in Yellow Jacket, based on long-term temperature data.

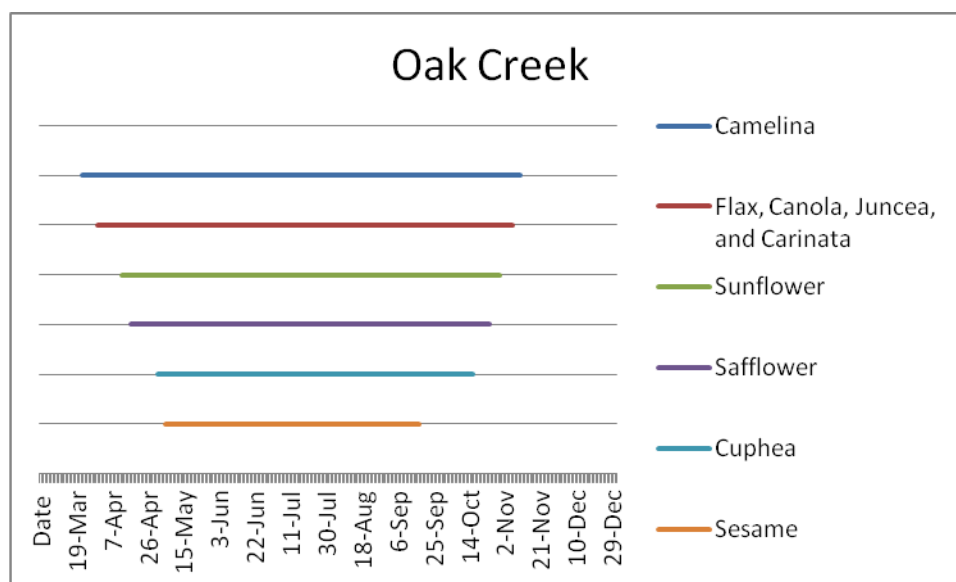


Fig. 33. Expected starting and ending dates for accumulation of GDD for nine oilseed species in Oak Creek, based on long-term temperature data.

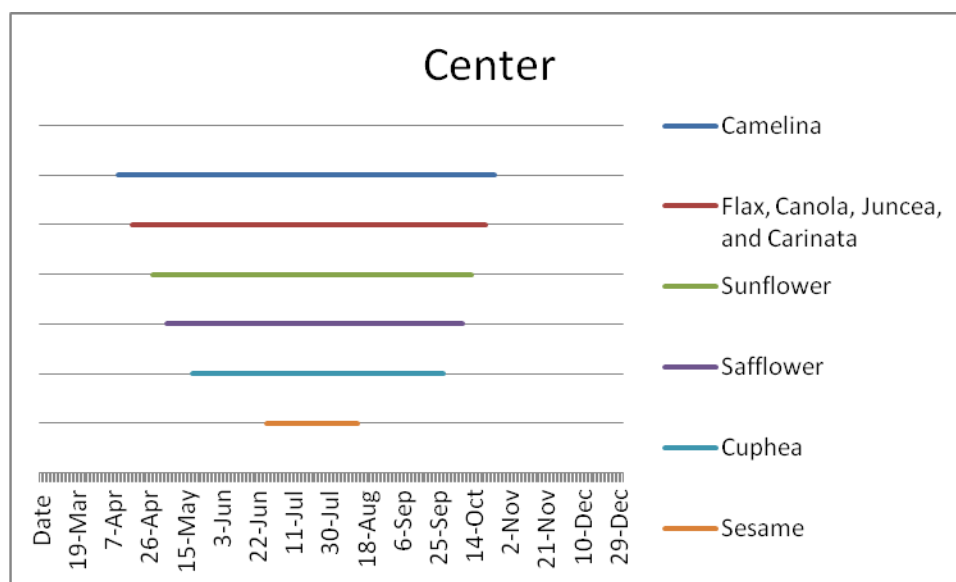


Fig. 34. Expected starting and ending dates for accumulation of GDD for nine oilseed species in Center, based on long-term temperature data.

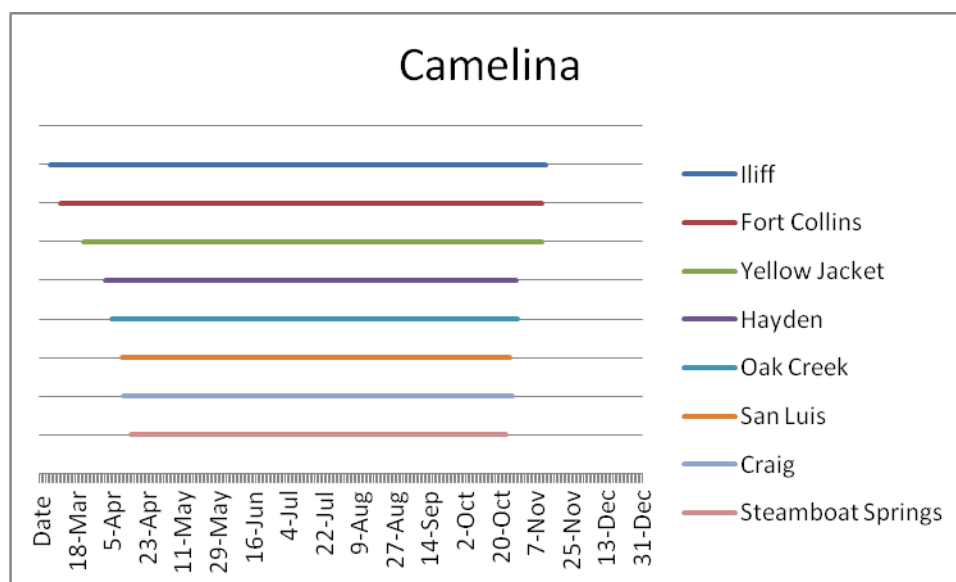


Fig. 35. Expected starting and ending dates for accumulation of GDD camelina in eight Colorado locations, based on long-term temperature data.

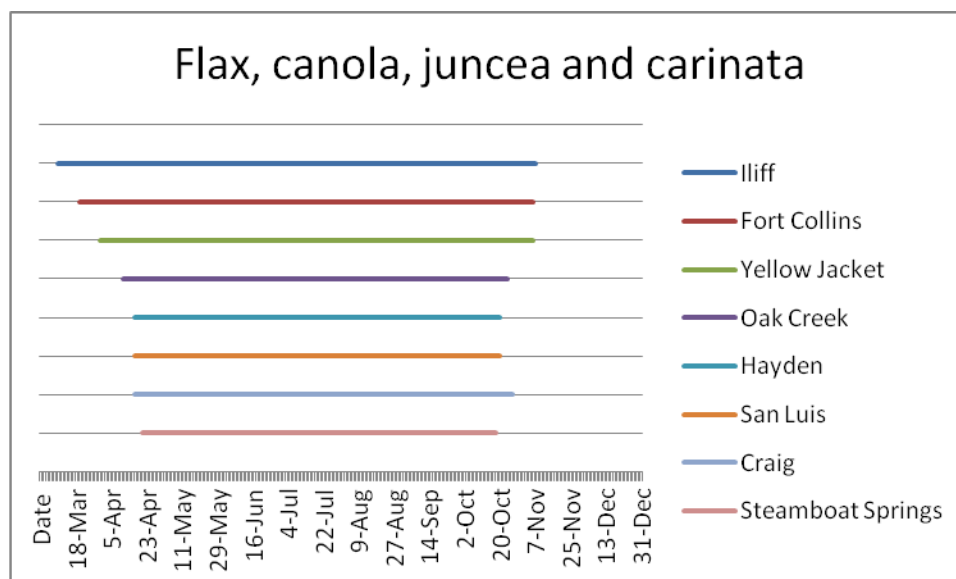


Fig. 36. Expected starting and ending dates for accumulation of GDD flax, canola, juncea, and carinata in eight Colorado locations, based on long-term temperature data.

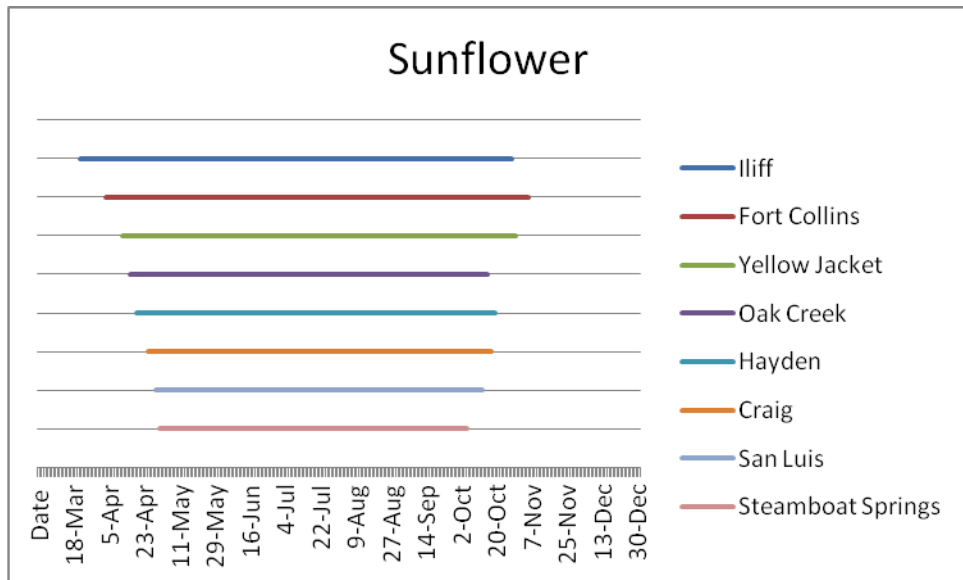


Fig. 37. Expected starting and ending dates for accumulation of GDD sunflower in eight Colorado locations, based on long-term temperature data.

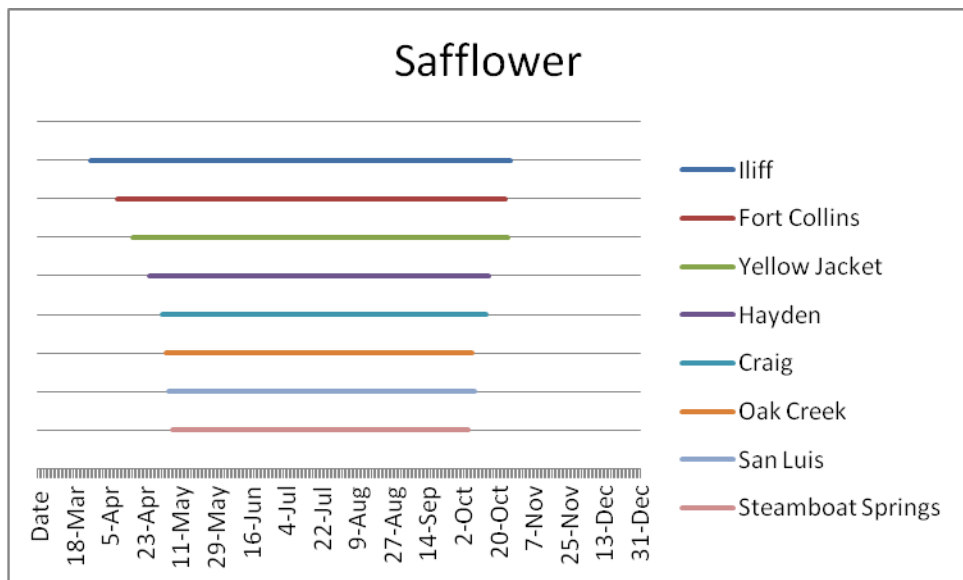


Fig. 38. Expected starting and ending dates for accumulation of GDD sunflower in eight Colorado locations, based on long-term temperature data.

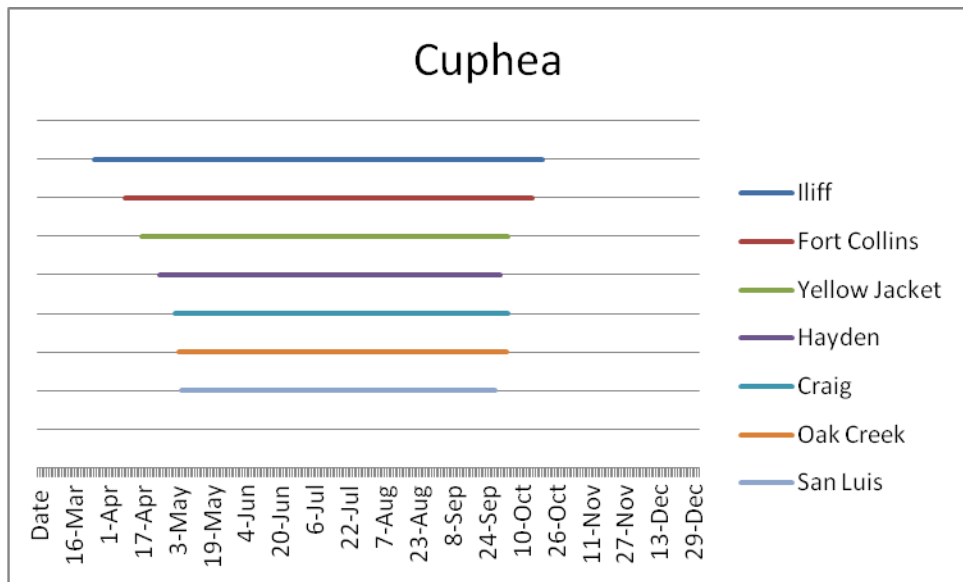


Fig. 39. Expected starting and ending dates for accumulation of GDD cuphea in eight Colorado locations, based on long-term temperature data.

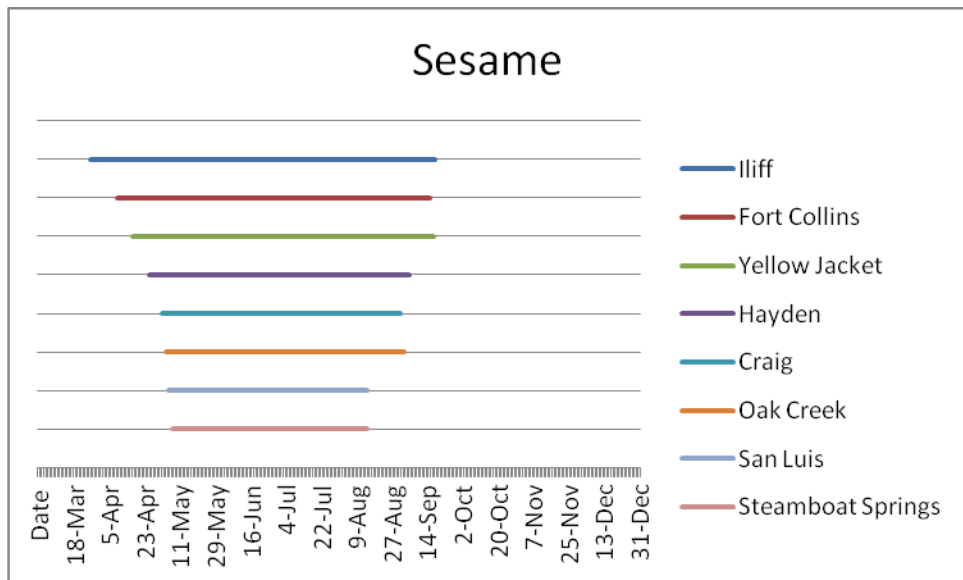


Fig. 40. Expected starting and ending dates for accumulation of GDD sesame in eight Colorado locations, based on long-term temperature data.

Discussion and Conclusion

The cumulative GDD based on long-term air temperature indicates the potential growth interval for each of the nine oilseed species in specific locations in Colorado. Species with relatively lower required base temperature start accumulating growing degree days earlier than those with higher required base temperature. Species with higher required base temperature, for instance cuphea and sesame, start accumulating GDD later in the growing season. These species require higher air and soil temperatures for seed germination and rapid growth. Oilseed species with lower required base temperature and a low cumulative GDD requirement give growers flexibility in terms of crop planting dates because there is a broad window of time for the crop to accumulate the necessary GDD, whereas high required base temperature crops have a very narrow window in which to accumulate the required GDD. When planting higher required base temperature oilseed species, growers should time planting to ensure that the crop has the opportunity to utilize the maximum available GDD at a particular location during the growing season.

As shown in Figs. 10 through 17, 2010 had a higher cumulative GDD than the long-term cumulative GDD calculated for each species at a particular location. Crops that would not be expected to reach maturity based on the long-term temperature data did mature in 2010. Table 7 shows the expectations and 2010 field results in terms of species adaptability and maturity at six locations in Colorado. Since 2010 was a relatively warmer year, it is not concluded that some of the study species, which matured at some of the higher altitude locations, would normally be suitable for planting. Temperature fluctuates each year, therefore, growers should base their growing decisions on long-term

temperature data because it provides more reliable estimate of crop establishment success and failure.

In addition to required base temperature, cumulative GDD requirement, and altitude, the length of the growing season appears to be an important factor in adaptability of an oilseed crop. As shown in Fig. 32, all of the crops had extended growing seasons at Yellow Jacket despite the relatively high altitude at this location. The longer growing season allowed them to accumulate the required GDD to reach maturity, whereas Steamboat Springs, at nearly the same altitude, did not have a growing season long enough for plants to reach maturity.

Other factors also play a role in the grower's crop selection. Disease and pest resistance, oil quality and meal quality, and historical presence in the national culture should be taken into consideration. Camelina and flax were chosen for the 2011 variety trials because of their disease resistance and oil quality. Camelina and flax are resistant to flea beetle, a severe pest problem in Colorado, during early crop establishment. Flax and camelina have the highest percentage of Omega-3 oil, which is beneficial to human health.

Based on long-term temperature data and calculated GDD, it can be concluded that the lower required base temperature crops, such as camelina, canola, flax, *B. juncea*, and *B. carinata*, are adapted in seven of the eight study locations in Colorado. Steamboat Springs is the only location in this study where these crops are not adapted. Sunflower and safflower, which both have relatively high required base temperatures, would be adapted at a subset of these study locations. Safflower is expected to reach maturity in Iliff, Fort Collins, Yellow Jacket, and Hayden. Sunflower is expected to reach maturity in

Iliff, Fort Collins, and Yellow Jacket. Cuphea and sesame, which have the highest required base temperatures (cuphea 50 °F (10 °C) and sesame 61°F (16.1 °C)), are not suitable for growing in most of these locations. Cuphea is expected to mature only in Iliff, which has the highest temperature and the lowest altitude among the eight study locations. Sesame does not accumulate enough GDD to mature at any of these eight study locations.

Based on these results, it is recommended that growers choose crops with lower base temperature requirement and lower cumulative GDD requirement in higher altitudes to allow the crops to reach maturity before the temperature drops below the crop base temperature requirement. Crops that require higher base temperature and higher cumulative GDD can be chosen for areas with lower altitude and warmer temperature, and with a longer growing season, to allow the plants to accumulate the required GDD to reach maturity.

Studies similar to this one can provide valuable information to make decisions about transferring agricultural technologies to other areas with similar climate, terrain, and geography. Crop adaptability is a key factor in successful agricultural technology transfer and GDD is one of the most important indicators of crop adaptability. When transferring agricultural technologies, especially introducing new crops, it is important to conduct an adaptability study prior to investing considerable financial and technical resources. In order to calculate GDD in a target location to predict crop adaptability, it is important to have weather stations in areas of both the technology donor and the technology receiver.

Although Afghanistan currently lacks weather stations that could collect temperature data for a preliminary review of potential oilseed species similar to this study, the results of this research can be used as a preliminary assessment of oilseed species that might be adaptable to Afghanistan in areas with altitudes similar to those in Colorado.

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Chapter Four:

Flax Variety Trials

Introduction

Flaxseed is considered an important health food because it has a high percentage of alpha-linolenic acid (omega-3) in the oil, and a high fiber and lignin content in the seed. Because of these attributes, a short growing season requirement, and cold tolerance, flax can be a viable alternative crop in high altitude cropping systems. Recent research (Ayerza, 2011) shows that high altitude may increase linolenic acid content in oilseed crops.

Although flax seems to be a suitable crop for high altitude farming, no research has been conducted on this crop in high altitude areas of Colorado. High altitude farmers in Colorado may be interested in growing flax, but they know little about cultivars that are locally adapted, screened, and tested for high yield, high oil content, and high linolenic acid (omega-3) content.

Improvement of traits related to seed yield, oil content, and oil quality in flax breeding is considered key. Potential correlations among these traits in conjunction with environmental factors, which influence these traits, could provide valuable information to breeders for flax improvement in high altitude areas.

In 2011, a flax variety trial was conducted in three different environments of Colorado varying in elevation from 3000 to 7000 feet (914 to 2134 meters). The main objective of this study was to screen cultivars in order to identify high yielding, high oil content, and high alpha linolenic acid (omega-3) content flax cultivars that are adapted to

different areas of Colorado. Also, flax yield components were studied to see if breeders might benefit from this information.

Materials and Methods

Experimental design

The descriptions of eight flax varieties planted in a randomized complete block design with three replications at Fort Collins, Iliff, and Craig locations in Colorado in 2011 are shown in Table 8.

Planting and growing conditions

Before planting, each field was treated with pre-plant Sonalan® herbicide at a rate of 2 pints per acre (2.34 liters per hectare). Plot size was 6 feet (183 cm) wide x 20 feet (610 cm) long, consisting of four rows with 30 inches (76.2 cm) distance between rows. The seeding rate was 40 pounds per acre (45.6 kg per hectare) . The experiment was planted on properly tilled and leveled, moist soil. The planting dates for Fort Collins, Iliff, and Craig were March 25, April 20, and May 12, respectively. The experimental plots at Fort Collins, Iliff, and Craig were irrigated, limited irrigation, and dryland, respectively. No experimental plot was fertilized at any of the locations.

Stand establishment at both Iliff and Craig was better than at Fort Collins, which was patchy and thin due to poor germination. No major insect or disease incidence at any location was recorded throughout the growing season. Plants at Iliff were shorter than those at Fort Collins and Craig.

Experimental plots were harvested at Fort Collins, Iliff, and Craig on 15 August, 18 August, and 2 September, respectively. At Fort Collins and Iliff, the two middle rows

were harvested with sickles. The harvested plots were threshed by hand and air dried for seed yield results. At Craig, full plots were harvested by a plot grain combine.

Yield components

At maturity, three flax plants were randomly selected from each plot to collect and count the number of capsules per plant. Collected capsules were hand-threshed. Thirty seeds from each plot were counted and weighed to estimate seed weight, seeds per capsule, and capsules per acre.

Oil content and oil profile

After harvest, 5 g of air-dried clean flax seed from each replication of each variety at each location were sent to the Bio-Oils Research Center at the National Center for Agricultural Utilization Research, Agriculture Research Service, United States Department of Agriculture at Peoria, Illinois, for analysis of oil content and oil profile. Total oil content was analyzed by pulsed nuclear magnetic resonance (NMR). Oil profile was determined by fatty acid methyl ester (FAMES) analysis on an HP 6890 gas chromatograph equipped with a reversed phase capillary column SP 2380.

Statistical analysis

Proc CORR and Proc GLM in the software program Statistical Analysis Software (SAS) version 9.2 (SAS, 2010) were used to analyze the data. One analysis of variance (ANOVA) was done for the six varieties that were grown in all locations. A second ANOVA was done for all eight varieties grown at Fort Collins and Craig. Locations were also analyzed separately. Correlations among all pairs of traits were calculated based on entry means for each location.

Results

Monthly GDD for each location are shown in Fig. 41. Total GDD for each location are shown in Fig. 42. Monthly precipitation for each location is shown in Fig. 43. Total precipitation for each location is shown in Fig. 44. Mean temperature for each location is shown in Fig. 45.

The stand establishment was poor at Fort Collins because of soil crusting. The plants at Iliff were short, possibly because of herbicide injury. The pre-plant herbicide Sonalan was applied two weeks before the seeds were planted. The recommended interval between herbicide application and planting is at least three weeks. At Craig, the capsules did not fill as well as at Fort Collins. This may have been caused by heat stress, possibly during the seed filling stage. The trial at Craig was planted later than at Fort Collins and Iliff. The late planting may have exposed the plants to summer heat.

Correlation among seed yield and yield components

Correlations among yield and four components of yield for six varieties are shown in Table 9. Seeds per capsule was positively correlated with capsules per plant and seed yield but was negatively correlated with capsules per acre. Capsules per plant was positively correlated with seed yield. Capsules per acre was negatively correlated with seed yield. No other components were related to seed yield. The analysis for all eight varieties is shown in Appendix A. Correlations for each location separately are shown in appendices E, F, and G.

Analysis of variance of yield and yield components

In a combined analysis of variance for yield and four yield components, there was a significant location effect for seed weight, seeds per capsules, capsules per plant, and

capsules per acre. No significant variety by environment interaction was found except for capsules per acre. There were no differences among varieties York, Neche, Omega, and Nekoma for capsules per acre at all locations. However, Carter and Golden were significantly different from York, Neche, Omega, and Nekoma for capsules per acre.

Location-specific ANOVA showed no significant differences among varieties for yield and yield components except for seed weight at Iliff. At Iliff, seed weight of Omega was significantly higher than seed weight of Neche, York, Nekoma, and Carter, but seed weight of Omega was not significantly different from that of Golden. Seed weight of Golden was not significantly different from those of Neche, York, Nekoma, and Carter.

Only six varieties were tested for the Iliff environment versus eight varieties at Fort Collins and Craig. The data for two varieties (CDC and Vimy) at Fort Collins and Craig locations were excluded in order to perform a combined analysis of variance across all three locations. Mean values for five traits of six varieties are shown in in Table 10,s along with the significance levels from the ANOVA. The means for all eight varieties are shown in Appendix B.

Correlation among oil content and oil profile traits

Correlations among oil content and oil quality traits for six varieties are shown in Table 9. Oil content was negatively correlated to oleic acid content and positively correlated to linolenic acid content. Oleic acid content was negatively correlated to linolenic acid content. The analysis for all eight varieties is shown in Appendix A.

Analysis of variance of oil content and oil profile traits

In a combined analysis of variance for oil content and oil quality traits, location was significant for oil content, oleic acid content, and linolenic acid content. Craig had

the highest oil content, with Fort Collins second and Iliff lowest. Oleic acid content was highest at Iliff, intermediate at Fort Collins, and lowest at Craig. Linolenic acid content was highest at Craig, intermediate at Fort Collins, and lowest at Iliff.

Variety by environment interaction was significant for oleic acid content and linolenic acid content. For oil content, oleic acid content and linolenic acid content, analysis of variance was done for each location separately.

There were significant differences among varieties for linolenic acid content at both Fort Collins and Iliff. The variety Carter at Fort Collins had significantly higher linolenic acid content than Nekoma, York, and Neche. Carter was not significantly different from Golden and Omega. Golden was significantly different from York and Neche. The varieties Golden, Carter, Neche, Nekoma, and York at Iliff were not significantly different from each other, but these varieties all had significantly higher linolenic acid content than Omega.

There were significant differences among varieties for oleic acid content only at Iliff. The variety Omega at Iliff was not significantly different from York, but had significantly higher oleic acid content than Neche, Carter, Nekoma, and Golden. York, Neche, Carter, and Nekoma were significantly different from Golden.

Only six varieties were tested for the Iliff environment versus eight varieties at Fort Collins and Craig. The data for oil content and oil quality traits for two varieties (CDC and Vimy) at Fort Collins and Craig locations were excluded in order to perform a combined analysis of variance at all three locations. Mean values for oil content and oil quality traits for six varieties are shown in Table 11, along with the significance levels

from the ANOVA. The means for all eight varieties are shown in Appendix C.

Correlations for each location separately are shown in appendices E, F, and G.

Correlation among yield traits and oil traits

Correlations among yield traits and oil traits for six varieties are shown in Table 9. Both total oil content and linolenic acid content were negatively correlated to capsules per acre. Neither oil content nor linolenic acid content was significantly correlated to seed yield. However, oleic acid content was positively correlated to capsules per acre. No other significant correlations were found between oil content, oil composition, seed yield, and yield component traits. The analysis for all eight varieties is shown in Appendix A.

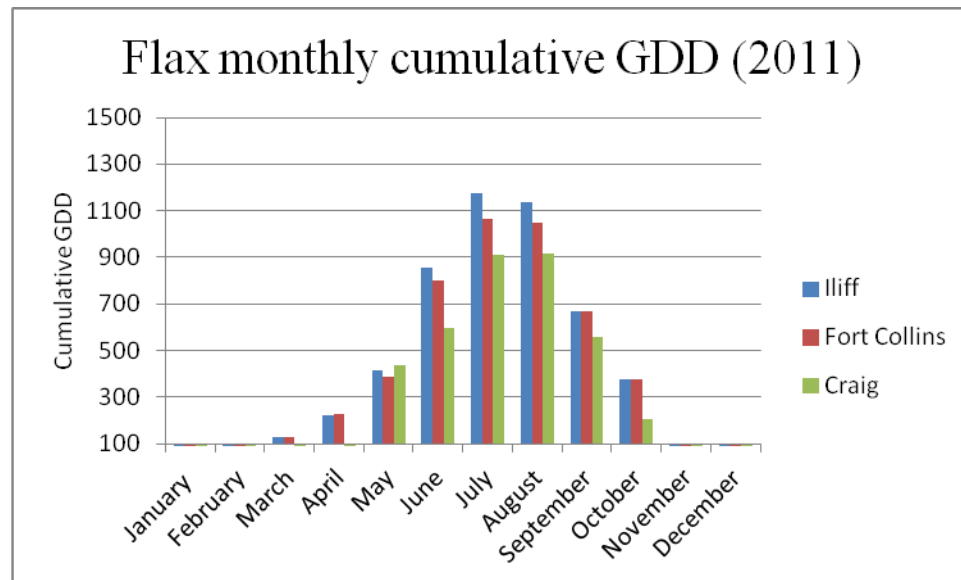


Fig. 41. Flax monthly cumulative GDD for three environments during 2011.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

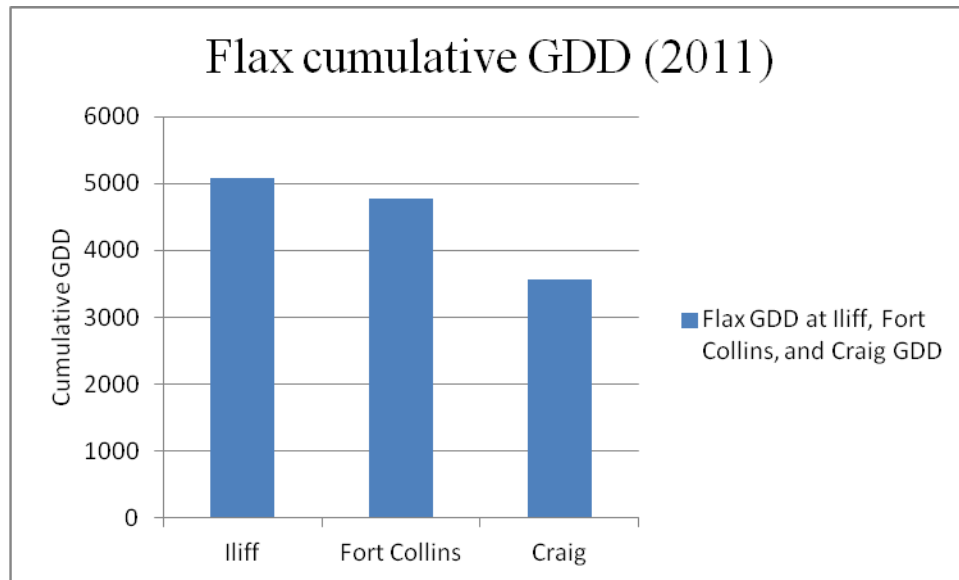


Fig. 42. Total flax cumulative GDD during 2011.
 $GDD \times 5/9 = GDD \text{ using } ^\circ C$

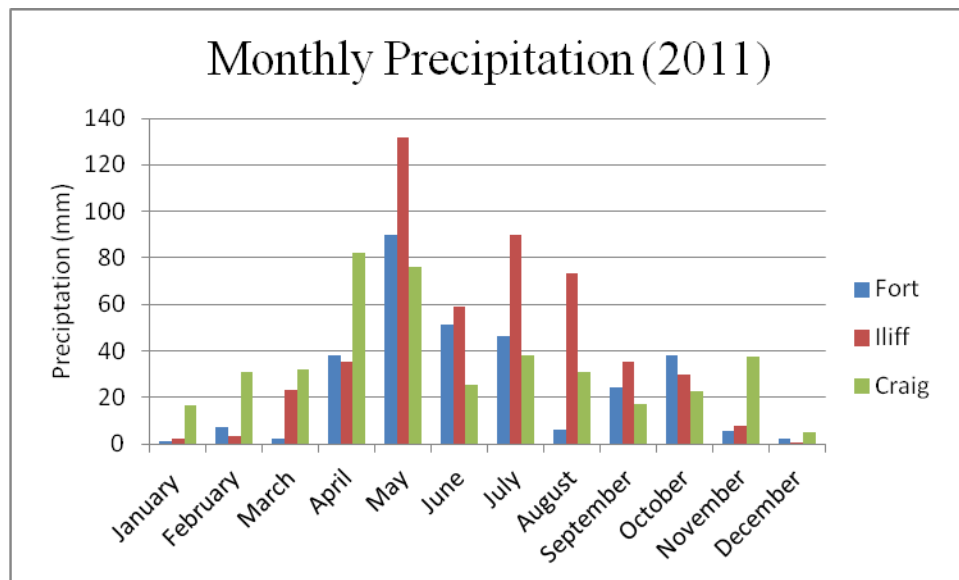


Fig. 43. Monthly precipitation at Fort Collins, Iliff, and Craig during 2011.

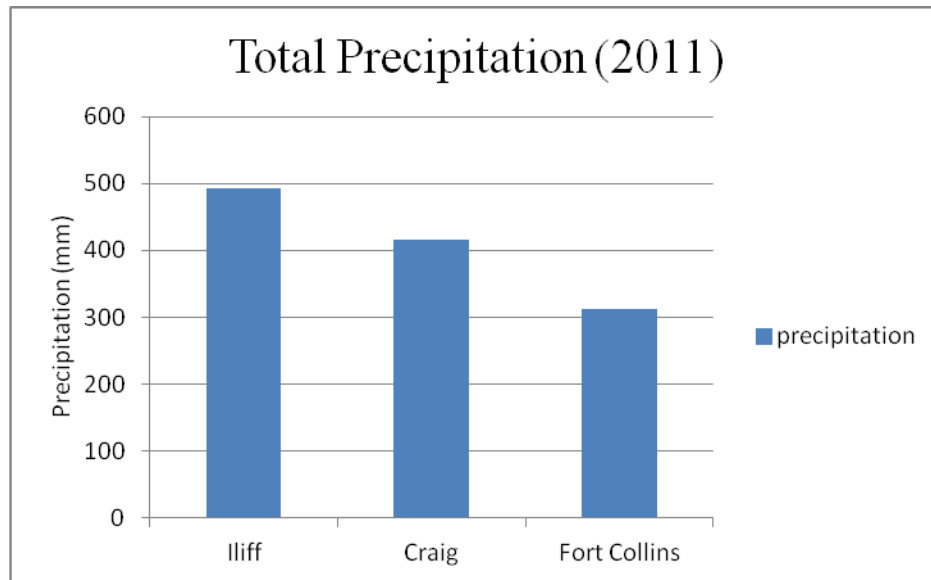


Fig.44. Total precipitation in three environments during 2011.

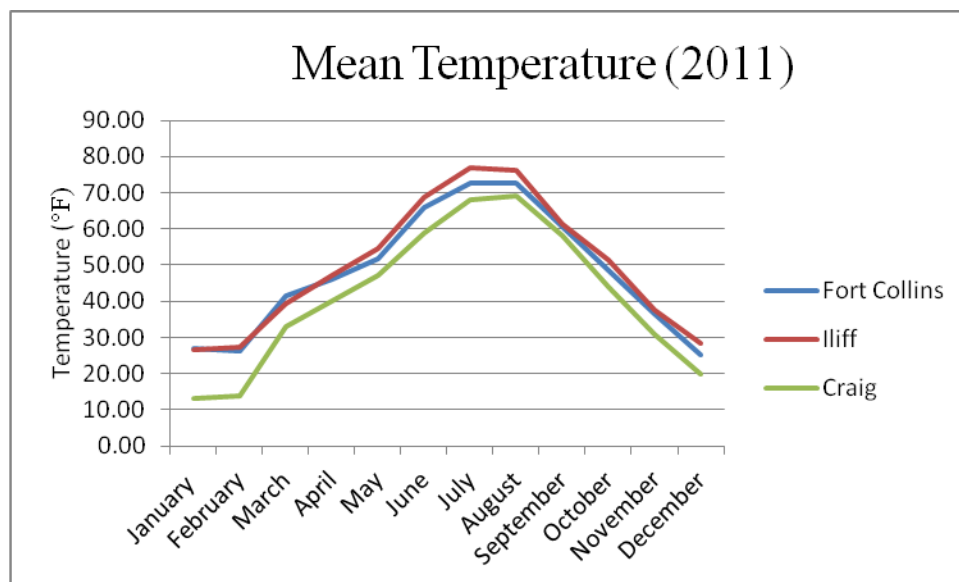


Fig.45. Mean temperature at Fort Collins, Iliff, and Craig during 2011.
 $^{\circ}\text{C} = (^{\circ}\text{F} - 32) \times 5/9$

Table 8. Flax varieties, types, and sources

Variety	Seed Color	Maturity	Source
Carter	Yellow	Full-season	North Dakota State University (NDSU)
CDC Normandy ¹	Brown	Mid	Plant Gene Resources of Canada, Agriculture and Agri-Food ,Canada
Golden	Yellow	Mid	Great Plains Flax, Littleton, Colorado.
Neché	Brown	Full-season	NDSU
Nekoma	Brown	Late	NDSU
Omega	Yellow	Medium-early	NDSU
Vimy ¹	Brown	Mid	Plant Gene Resources of Canada, Agriculture and Agri-Food ,Canada
York	Brown	Full-season	NDSU

¹Not planted at Iliff.

Table 9. Correlations between five yield traits and six oil traits based on mean values for six varieties of flax at Fort Collins, Iliff, and Craig.

	Seed weight (g) 10 ⁻³	Seeds per capsule	Capsules per plant	Capsules per acre	Seed yield (lb per acre)	Oil content (%)	Palmitic acid (%)	Stearic acid (%)	Oleic acid (%)	Linoleic acid (%)	Linolenic acid (%)
Seed weight (g)											
Seeds per capsule	0.01378										
Capsules per plant	0.27376	0.81946 *** ^a									
Capsules per acre	0.19947	-0.75713***	-0.3975								
Seed yield (lb per acre)	0.18056	0.87737***	0.88349***	-0.4759*							
Oil content (%)	-0.16955	0.28545	-0.05601	-0.78636***	0.06406						
Palmitic acid (%)	0.29978	-0.57048*	-0.54361	0.32626	-0.54362*	-0.01455					
Stearic acid (%)	0.24875	-0.16147	0.20361	0.54921*	0.19806	-0.51849*	-0.08118				
Oleic acid (%)	0.1525	0.09251	0.45231	0.51969*	0.3813	-0.83629***	-0.20443	0.66595**			
Linoleic acid (%)	-0.60026**	-0.19154	-0.20262	0.06893	-0.21441	0.03984	-0.47996	0.05345	-0.0525		
Linolenic acid (%)	-0.10379	-0.00583	-0.38291	-0.57616*	-0.31705	0.82845***	0.21659	-0.75056***	-0.98473***	-0.07489	

^a Probability * <0.05, ** <0.01, *** <0.001

There were 6 samples at each location, with total sample size of 18. Samples at each location were averaged over replications.

Table 10. Mean value of seed weight, seeds per capsule, capsules per plant, capsules per acre, and seed yield for six varieties of flax in three environments.

Variety	Environments															Mean component value over environments				
	Craig					Fort Collins					Iliff									
	Components					Components					Components									
	Seed wt (g) x 10 ⁻³	Seeds per caps	Caps per plant	Caps per acre	Yield ^a (lb ac ⁻¹)	Seed wt (g) x 10 ⁻³	Seeds per caps	Caps per plant	Caps per acre	Yield (lb ac ⁻¹)	Seed wt (g) x 10 ⁻³	Seeds per caps	Caps per plant	Caps per acre	Yield (lb ac ⁻¹)	Seed wt (g) x 10 ⁻³	seeds per caps	Caps per plant	Caps per acre	yield (lb ac ⁻¹)
Carter	4.83	9.31	11.0 0	4528281	389	4.97	25.37	27.33	2936488	808	3.04	6.84	13.67	8293009	363	4.28	13.84	17.33	5252593	520
Golden	4.58	8.51	9.22	4616023	374	4.78	28.75	32.22	2186799	656	3.59	8.27	11.44	8146842	508	4.32	15.18	17.63	4983221	513
Neché	4.62	9.37	9.67	4509906	417	5.33	25.50	29.78	3384849	1001	3.20	6.29	13.22	11109087	461	4.38	13.72	17.56	6334614	626
Nekoma	4.56	7.34	11.2 2	5609943	416	4.41	25.87	32.22	3848545	903	3.04	8.91	10.78	8961054	476	4.00	14.04	18.07	6139847	598
Omega	4.51	8.47	10.1 1	5788720	466	5.40	23.94	46.33	3122774	875	4.11	5.16	19.89	9863737	466	4.67	12.52	25.44	6258410	602
York	4.33	12.45	7.44	3376851	379	4.99	28.27	35.89	2849663	885	1.10	4.10	21.44	12962779	518	3.47	14.94	21.60	6396431	594
Mean over varieties	4.57	9.24	9.78	4738287	412	4.98	26.28	33.97	3054853	855	3.01	6.60	15.07	9889418	465					
LSD _{0.05}	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.7	NS	NS	NS	NS	0.3	1.99	3.87	2010000	94

^a Pounds per acre x 1.14 equals kg per hectare

Table 11. Mean values of oil content, linolenic acid content, and seed yield for six varieties of flax in three environments.

Variety	Environments												Mean values of oil traits and seed yield over environments			
	Craig				Fort Collins				Iliff							
	Oil traits and seed yield				Oil traits and seed yield				Oil traits and seed yield							
	Oil content (%)	Oleic acid (%)	Linolenic acid (%)	Yield ^a (lb ac ⁻¹)	Oil content (%)	Oleic acid (%)	Linolenic acid (%)	Yield (lb ac ⁻¹)	Oil content (%)	Oleic acid (%)	Linolenic acid (%)	Yield (lb ac ⁻¹)	Oil content	Oleic acid	Linolenic acid	Yield (lb ac ⁻¹)
Carter	42.1	20.4	53.3	389	40.7	23.4	50.7	808	31.2	25.6	47.4	363	38.0	23.1	50.5	520
Golden	44.3	19.7	53.5	374	40.2	23.1	50.4	656	36.3	24.6	48.5	508	40.3	22.5	50.8	513
Nече	43.9	19.5	53.6	417	40.8	25.7	47.2	1001	33.0	26.1	46.8	461	39.2	23.8	49.2	626
Nekoma	44.3	20.1	52.6	416	40.1	24.5	48.2	903	32.4	25.4	46.5	476	38.9	23.3	49.1	598
Omega	43.2	20.3	52.4	466	40.4	24.5	48.7	875	34.5	28.6	43.2	466	39.4	24.5	48.1	602
York	43.3	19.5	54.7	379	37.2	25.9	47.9	885	29.3	27.1	46.0	518	36.6	24.2	49.5	594
Mean over varieties	43.5	19.9	53.4	407	39.9	24.5	48.9	855	32.8	26.2	46.4	465				
LSD _{0.05}	NS	NS	NS	NS	NS	NS	2.3	NS	NS	1.9	2.7	NS	1.5	0.8	1.4	94

^a Pounds per acre x 1.14 equals kg per hectare

Discussion

Correlation among seed yield and yield components

The highly positive and significant correlation found in this study between number of seeds per capsule and seed yield suggests that flax cultivars with higher seeds per capsule will result in higher seed yield. However, Copur et al. (2006) found a non-significant positive correlation between these two traits in a flax study grown in Turkey.

The correlation between number of seeds per capsule and number of capsules per plant was highly positive and significant. This result suggests that when number of capsules per plant increases, seeds per capsule will also increase, resulting in higher seed yield. Copur et al. (2006) found a positive but non-significant correlation between seeds per capsule and number of capsules per plant.

A negative correlation was found between seeds per capsule and number of capsules per acre. Capsules per acre was also negatively correlated with seed yield, perhaps related to a poor stand at one location. These results suggest that fewer capsules per acre with higher number of seeds per capsule result in higher seed yield. These results also suggest that a trade-off exists between number of seeds per capsule and number of capsules per acre. As seeds per capsule increase, capsules per acre decrease.

The correlation between capsules per plant and seed yield was positive and highly significant. This result parallels the results of studies conducted by Copur et al. (2006), Gauraha and Rao (2011), Adugna and Labuschagne (2003), and Rahimi et al. (2001), all of whom found a significant positive correlation between capsules per plant and seed yield.

Our study found no significant correlation between seed weight and any other yield component. In contrast to this study, Gauraha and Rao (2011), Adugna and Labuschagne (2003), Tadesse et al. (2009), and Copur et al. (2006) found a positive correlation between seed weight and seed yield in flax.

In addition to a correlation between seed weight and seed yield, Copur et al. (2006) also found a positive significant correlation between seed weight and number of capsules per plant and a significant negative correlation between seed weight and number of seed per capsule.

Analysis of variance of yield and yield components

In the combined analysis of variance for all three environments, variation due to location was significant. Therefore, the analysis of variance for seed yield and four yield components was done separately.

Due to differences in length of growing season, accumulation of GDD, mean temperature and total amount of precipitation throughout the growing season, and altitude, significant difference in seed yield and yield component traits among the locations was not surprising.

Although variety yields did not significantly differ within each study location, over all mean yield at Fort Collins was significantly higher than at Iliff and Craig.

Fort Collins, which had the lowest number of capsules per acre, had the highest number of seeds per capsule and the highest seed weight among all the locations. Fewer capsules but higher number of seeds per capsule and better seed weight make Fort Collins the highest yielding location. The thinner stand at Fort Collins may have contributed to this result. Fewer plants per acre may have made more resources available on a per plant

basis. It can also be suggested that a trade-off exists among the yield component traits of flax. As one trait increases, another may decrease.

Although Iliff had the highest number of capsules per acre, the capsules contained fewer seeds and the seed weight was also significantly lower than at the other two locations. The lower yield at Iliff compared to Fort Collins is attributed to lower number of seeds per capsule and lower seed weight.

Although yield at Craig was similar to that Iliff, Craig had a significantly higher number of seeds per capsule and significantly higher seed weight than at Iliff. Yield at Craig was significantly lower than at Fort Collins, attributable to the significantly lower number of seeds per capsule, significantly lower capsules per plant, and significantly lower seed weight.

Correlation among oil content and oil profile traits

Oil content was positively correlated to linolenic acid content in this study. Adugna and Labuschagne (2003) and Rahimi et al. (2011) found no significant correlation between oil content and linolenic acid.

A negative significant correlation between oil content and oleic acid content was found in this study. In contrast, Rahimi et al. (2011) found a positive and significant correlation between oil content and oleic acid.

In our study, these correlations suggest that the biosynthesis of linolenic acid is favored over other fatty acids. Linolenic acid, which is an important polyunsaturated fatty acid, is considerably higher in flax than other less desirable fatty acids for the human diet. The importance of flax oil is its high linolenic-omega-3 oil content. Based on these

findings, when oil content increases, linolenic acid content increases as well.

Monounsaturated oleic acid decreases when oil content increases.

In addition, there is a very strong negative significant correlation between linolenic acid (18:3) content and oleic acid (18:2) content. The strong negative correlation found in this study is supported by the study conducted by Adugna and Labuschagne (2003). They found a similar strong negative correlation between these two traits. The strong negative correlation between these two traits suggests a trade-off between compositions of these two important fatty acids. When oleic acid increases, linolenic acid decreases and when linolenic increases, oleic acid decreases. This can be thought of as degree of unsaturation. When conditions favor the formation of higher energy double bonds (18:3), oleic acid (18:2) decreases. Flax cultivars with lower oleic acid and higher linolenic acid content (omega-3) are desirable.

Analysis of variance of oil content and oil profile traits

Oil content, oil quality, and seed yield are the most important traits in flax production and flax improvement and breeding programs. Flax oil content ranges from 40 to 50 percent of seed weight, depending on flax cultivar and under optimum growing conditions. In our study, the oil content ranged from 32 to 43 percent. The percentages of various fatty acids are important oil quality traits in oil. Flax bred for human consumption is a rich source of alpha linolenic acid (ALA, omega-3). ALA content in flax varies from 50 to 70 percent of total oil content.

Mean oil content and oil quality traits differed across three locations. As shown in Table B, Craig, which is the highest altitude among all the test locations, had significantly higher mean oil content and mean linolenic acid content than Fort Collins,

which had significantly higher mean oil content and mean linolenic acid content than Iliff. This suggests that high altitude (or some climatic variable related to altitude) improves both total oil content and linolenic acid content. No significant correlation was found between seed yield and oil content or linolenic acid content.

As shown in Table B, Craig had significantly higher linolenic acid content and significantly lower oleic acid content than the other two locations. Iliff had significantly lower linolenic acid content and significantly higher oleic acid content than the other two locations. Fort Collins had intermediate levels of both kinds of fatty acids, significantly different from both of the other two locations. These findings support the negative correlation between linolenic acid content and oleic acid content.

There were significant differences among varieties for linolenic acid content at both Fort Collins and Iliff. Carter, Golden, and Omega were the top varieties for linolenic acid content at Fort Collins. But Omega had significantly lower linolenic acid content than all other varieties at Iliff. Because linolenic acid is the most important fatty acid that has economic value in flax oil, above mentioned varieties can be selected at this particular location in order to get higher linolenic acid content.

At single locations, there were significant differences among varieties for oleic acid content only at Iliff. Omega was one of the two highest varieties for oleic acid content at Iliff, consistent with its low linolenic acid content. Because there is a significant negative correlation between linolenic acid content and oleic acid content, the varieties that have high oleic acid content have lower linolenic acid.

Correlation among yield traits and oil traits

Both total oil content and linolenic acid content were negatively correlated to capsules per acre. These results are consistent with the significant negative correlation of total seed yield to capsules per acre. These results suggest that flax plants with fewer capsules have a higher number of seeds per capsule, which results in higher oil content and higher linolenic acid content. In contrast, oleic acid content was positively correlated to capsules per acre, consistent with the finding that fewer capsules per acre is correlated with higher yield, higher oil content, and higher linolenic acid content.

Neither oil content nor linolenic acid content was significantly correlated to seed yield. This result suggests that oil content is not influenced by flax seed yield. If a flax cultivar has low seed yield, it can still have high oil content and linolenic acid content. Contrary to some of the results for yield components and oil quality traits, our study found no compensation or trade-off between oil content, linolenic acid content, and seed yield. In a flax improvement and breeding program, if yield is targeted for further improvement, oil quality and oil content may still remain stable.

Conclusions

Yield and yield components

Flax yield is highly positively correlated to the number of seeds per capsule and capsules per plant. In contrast, yield is negatively correlated to number of capsules per acre. There may be a trade-off between components of yield.

No significant differences for yield were found among varieties in this study.

Oil content and oil quality

There is a significant location effect on flax oil content and linolenic oil content. Craig had the highest oil content and linolenic acid content, Fort Collins had intermediate levels, and Iliff had the lowest levels. This suggests that high altitude, or a factor related to high altitude, increases both oil content and linolenic acid content in flax.

Our study suggests that selection for higher oil content will achieve higher levels of linolenic acid (omega-3) as well.

The biosynthesis of linolenic acid is favored over other fatty acids in flax. The positive correlation of oil content and linolenic acid content adds to the economic value of flax oil as a source of omega-3 oil in a diet.

There is no significant correlation between oil content and seed yield, suggesting that cultivars with low seed yield may still have higher oil content and high linolenic acid content.

Recommendations

- Flax breeders should breed for flax cultivars that contain high seed weight, high number of seeds per capsule, and high number of capsules per plant.
- Flax breeders may be able to breed for higher oil content without compromising seed yield.
- Flax breeders can breed for high linolenic acid content cultivars while keeping oleic acid content low.
- Growers planting flax at higher altitudes can expect higher oil content and higher linolenic acid content in flaxseed.

- Flax varieties should be tested locally to screen and select for high seed yield, high oil content, and high linolenic acid content.
- This study should be repeated in more environments.

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APPENDICES

Appendix A. Correlations among four yield traits and six oil traits based on mean values for eight varieties of flax in three environments.

	Seed weight (g) 10 ⁻³	Seeds per capsule	Capsules per acre	Seed yield (lb per acre)	Oil content (%)	Palmitic acid (%)	Stearic acid (%)	Oleic acid (%)	Linoleic acid (%)	Linolenic acid (%)
Seed weight (g)										
Seeds per capsule	0.04081									
Capsules per acre	0.17556	-0.74328**** ^a								
Seed yield (lb per acre)	0.18955	0.90142****	-0.49038*							
Oil content (%)	-0.16263	0.20516	-0.75396****	-0.00006						
Palmitic acid (%)	0.25124	-0.30504	0.08398	-0.29294	0.15158					
Stearic acid (%)	0.21133	-0.26452	0.56255**	0.01808	-0.44984*	-0.11436				
Oleic acid (%)	0.14924	0.28579	0.35094	0.51738*	-0.77534	-0.21036	0.34921			
Linoleic acid (%)	-0.45137*	-0.39855	0.23607	-0.41175	0.01326	-0.43315*	0.33008	-0.30512		
Linolenic acid (%)	-0.11034	-0.1504	-0.47792*	-0.4184	0.81895****	0.24449	-0.54522**	-0.96714****	0.09528	

^a Probability * <0.05, ** <0.01, **** <0.001

There were 6 samples at each location, with total sample size of 18. Samples at each location were averaged over replications.

Appendix B. Mean value of seed weight, seeds per capsule, capsules per plant, capsules per acre, and seed yield for eight varieties of flax in three environments.

Variety	Environments														
	Craig					Fort Collins					Iliff				
	Components					Components					Components				
	Seed wt (g) x 10 ⁻³	Seeds per caps	Caps per plant	Caps per acre	Yield ^a (lb ac ⁻¹)	Seed wt (g) x 10 ⁻³	Seeds per caps	Caps per plant	Caps per acre	Yield (lb ac ⁻¹)	Seed wt (g) x 10 ⁻³	Seeds per caps	Caps per plant	Caps per acre	Yield (lb ac ⁻¹)
Carter	4.83	9.31	11.00	4528281	389	4.97	25.37	27.33	2936488	808	3.04	6.84	13.67	8293009	363
CDC	4.67	10.07	9.56	4835907	453	4.76	27.20	47.78	3090733	880	---	---	---	---	---
Golden	4.58	8.51	9.22	4616023	374	4.78	28.75	32.22	2186799	656	3.59	8.27	11.44	8146842	508
Neché	4.62	9.37	9.67	4509906	417	5.33	25.50	29.78	3384849	1001	3.20	6.29	13.22	11109087	461
Nekoma	4.56	7.34	11.22	5609943	416	4.41	25.87	32.22	3848545	903	3.04	8.91	10.78	8961054	476
Omega	4.51	8.47	10.11	5788720	466	5.40	23.94	46.33	3122774	875	4.11	5.16	19.89	9863737	466
Vimy	4.59	9.62	10.11	4293768	402	5.33	26.96	37.00	2893207	911	---	---	---	---	---
York	4.33	12.45	7.44	3376851	379	4.99	28.27	35.89	2849663	885	1.10	4.10	21.44	12962779	518
Mean over varieties	4.59	9.34	9.79	4694925	412	5.00	26.48	36.06	3039132	865	3.01	6.60	15.07	9889418	465
LSD _{0.05}	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.7	NS	NS	NS	NS

^a Pounds per acre x 1.14 equals kg per hectare

Appendix C. Mean values of oil content, linolenic acid content, and seed yield for eight varieties of flax in three environments.

Variety	Environments											
	Craig				Fort Collins				Iliff			
	Oil traits and seed yield				Oil traits and seed yield				Oil traits and seed yield			
	Oil content (%)	Oleic acid (%)	Linolenic acid (%)	Yield ^a (lb ac ⁻¹)	Oil content (%)	Oleic acid (%)	Linolenic acid (%)	Yield (lb ac ⁻¹)	Oil content (%)	Oleic acid (%)	Linolenic acid (%)	Yield (lb ac ⁻¹)
Carter	42.1	20.4	53.3	389	40.7	23.4	50.7	808	31.2	25.6	47.4	363
CDC	42.9	20.6	53.1	453	37.9	29.3	46.3	880	---	---	---	---
Golden	44.3	19.7	53.5	374	40.2	23.1	50.4	656	36.3	24.6	48.5	508
Nече	43.9	19.5	53.6	417	40.8	25.7	47.2	1001	33.0	26.1	46.8	461
Nekoma	44.3	20.1	52.6	416	40.1	24.5	48.2	903	32.4	25.4	46.5	476
Omega	43.2	20.3	52.4	466	40.4	24.5	48.7	875	34.5	28.6	43.2	466
Vimy	43.3	19.9	52.7	402	40.4	25.8	48.2	911	---	---	---	---
York	43.3	19.5	54.7	379	37.2	25.9	47.9	885	29.3	27.1	46.0	518
Mean over varieties	43.4	20.0	53.3	412	39.7	25.3	48.4	865	32.8	26.2	46.4	465
LSD _{0.05}	NS	NS	NS	NS	NS	2.36	2.20	NS	NS	1.94	2.69	NS

^a Pounds per acre x 1.14 equals kg per hectare

Appendix D. Camelina variety trial yield at Kabul, Afghanistan, in 2011.

Variety	Mean yield over reps (lb acre ⁻¹) ^a
Blaine Creek	696.114553
BSX G22	830.474658
BSX G37	957.137503
BSX G72	1064.85549
BSX G74	909.542538
Celina	867.767808
Cheyne	1156.17496
Licalla	718.551555
Ligena	1075.81499
Lindo	1004.92163
SSD 10	902.761966
SSD 138	1114.31293
SSD 177	1185.71119
SSD 186	1008.76298
SSD 87	1232.66739
Suneson	1068.76959
Yellowstone	787.914196
Average yield over varieties	975.426818

^a Pounds per acre x 1.14 equals kg per hectare

Appendix E. Correlations between five yield traits and six oil traits based on mean values for six varieties of flax at Fort Collins.

	Seed weight (g) 10 ⁻³	Seeds per capsule	Capsules per plant	Capsules per acre	Seed yield (lb per acre)	Oil content (%)	Palmitic acid (%)	Stearic acid (%)	Oleic acid (%)	Linoleic acid (%)	Linolenic acid (%)
Seed weight (g)											
Seeds per capsule	-0.38621										
Capsules per plant	0.16399	-0.0961									
Capsules per acre	-0.17006	-0.60461	0.01								
Seed yield (lb per acre)	0.35612	-0.46664	0.11967	0.76215 ^{*a}							
Oil content (%)	0.29157	-0.54416	-0.45427	0.10205	-0.04253						
Palmitic acid (%)	0.57918	0.25473	0.05626	-0.29057	0.27225	0.03717					
Stearic acid (%)	0.15838	-0.28837	-0.25506	0.52999	0.52824	0.12608	-0.1864				
Oleic acid (%)	0.00669	0.15849	0.63273	0.2327	0.50011	-0.62739	0.34328	-0.24508			
Linoleic acid (%)	-0.15649	-0.3571	-0.4874	0.14846	-0.27368	0.61958	-0.61885	0.49219	-0.85723 ^{**}		
Linolenic acid (%)	-0.07819	0.00738	-0.53129	-0.49809	-0.74318 [*]	0.48951	-0.26684	-0.1946	-0.89425 ^{**}	0.60564	

^a Probability * <0.05, ** <0.01, *** <0.001

There were 6 samples at a location. Samples at each location were averaged over replications.

Appendix F. Correlations between five yield traits and six oil traits based on mean values for six varieties of flax at Craig.

	Seed weight (g) 10 ⁻³	Seeds per capsule	Capsules per plant	Capsules per acre	Seed yield (lb per acre)	Oil content (%)	Palmitic acid (%)	Stearic acid (%)	Oleic acid (%)	Linoleic acid (%)	Linolenic acid (%)
Seed weight (g)											
Seeds per capsule	-0.40948										
Capsules per plant	0.70081	-0.82104* ^a									
Capsules per acre	0.25701	-0.85964**	0.71694*								
Seed yield (lb per acre)	0.07568	-0.28091	0.29517	0.68922							
Oil content (%)	-0.4476	-0.38469	-0.09585	0.18852	-0.14655						
Palmitic acid (%)	0.06585	0.52249	-0.31697	-0.40861	0.17401	-0.48635					
Stearic acid (%)	0.25986	-0.73709*	0.63194	0.59107	0.26105	0.22901	0.06588				
Oleic acid (%)	0.57495	-0.32516	0.58235	0.57075	0.61414	-0.5609	0.08358	0.15013			
Linoleic acid (%)	-0.12355	-0.80671*	0.54121	0.7212*	0.27416	0.66955	-0.52808	0.69741	-0.05857		
Linolenic acid (%)	-0.38828	0.79762*	-0.8098*	-0.84987**	-0.60034	-0.01424	0.04097	-0.83654**	-0.61908	-0.65074	

^a Probability * <0.05, ** <0.01, *** <0.001

There were 6 samples at a location. Samples at each location were averaged over replications.

Appendix G. Correlations between five yield traits and six oil traits based on mean values for six varieties of flax at Iliff.

	Seed weight (g) 10 ⁻³	Seeds per capsule	Capsules per plant	Capsules per acre	Seed yield (lb per acre)	Oil content (%)	Palmitic acid (%)	Stearic acid (%)	Oleic acid (%)	Linoleic acid (%)	Linolenic acid (%)
Seed weight (g)											
Seeds per capsule	-0.71921										
Capsules per plant	0.76258	-0.94398** ^a									
Capsules per acre	0.81076	-0.79169	0.71089								
Seed yield (lb per acre)	0.5152	-0.1215	0.23855	0.45904							
Oil content (%)	-0.62828	0.48941	-0.42926	-0.60444	0.18012						
Palmitic acid (%)	0.68057	-0.91536*	0.76973	0.72024	0.03917	-0.46998					
Stearic acid (%)	0.36647	-0.43644	0.55972	0.58852	0.43503	-0.23304	0.07516				
Oleic acid (%)	0.38354	-0.79711	0.86503*	0.52498	0.08732	-0.19813	0.50871	0.73964			
Linoleic acid (%)	-0.83664*	0.76542	-0.63825	-0.91404*	-0.45391	0.51171	-0.84371*	-0.24062	-0.31369		
Linolenic acid (%)	-0.20339	0.58723	-0.70798	-0.36548	-0.0733	0.09857	-0.22935	-0.82682*	-0.95349**	0.0724	

^a Probability * <0.05, ** <0.01, *** <0.001

There were 6 samples at a location. Samples at each location were averaged over replications.