Chapter 7
Changing Climate Scenario: Perspectives of *Camelina sativa* as Low-Input Biofuel and Oilseed Crop

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Abstract High population shifts and climate change are putting thrust on the food industry, especially edible oil production. Monoculture of high-input crops certainly affects the crop yield and soil health. The import of edible oil is increasing in the major part of the world, putting some burden on the national exchequer of the countries. The current oil crops are unable to meet the deficit to address the problems; a crop with distinct features must be incorporated in the cropping system.

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[*Camelina sativa* (L.) Crantz], a unique profiled biodiesel crop, is famous as gold of pleasure, and its oil is famous as a golden liquid. Camelina oil is an outstanding feedstock for the bio-based industry since its unique composition allows multiple applications. It is a rich source of oil >43%, which comprises a huge amount of unsaturated fatty acids, which accounts for 90%, containing 30–40% of alpha-linolenic acid and 15–25% of linoleic acid. The revival of this unique oilseed crop was based on (a) numerous inherent promising physiognomies, vigorous agronomic characteristics, eye-catching oil profile, genetic continuity with *Arabidopsis*, and the comfort of genetic remodeling by floral dip; (b) the investment in camelina which is understood as it merits serious considerations as potential biodiesel and oilseed and which shares a big role toward the sustainability along with increasing the diversity and production of plant oils; and (c) a univocal and descriptive portrayal of the different growth stages of camelina which will be used as an important apparatus for agronomy and research. In this review, the extended BBCH (Biologische Bundesanstalt, Bundessortenamt, and Chemische Industrie) scale was used to describe the phenological stages. The best use of camelina in the industrial sector as a drop-in product of packing materials, coatings, and adhesions can be achieved by further research to enlarge the camelina market.

Keywords Agronomic aspects · Industrial products · and biodiesel · BBCH scale · *Camelina sativa* · Diversification · Morpho-phenology · Attainable yield potential

7.1 Introduction

Agriculture productivity has many major challenges including increasing resource depletion, ever-growing cost pressure (Iqbal et al. 2021a), ongoing structural change, and increasingly adverse impacts of climate change (IPPC 2011). Oil crops are high-value agricultural commodities used in refined edible oil products, and with the rising global population, the demand for high-quality seed oils continues to grow (Gupta 2015). Despite numerous efforts to enhance the productivity of oil crops, there is still a huge gap between the demand and supply of oil in the bio-based and edible oil markets extracted from different oilseed crops (Iqbal et al. 2021b). Sustainable oil crops produce high amount of edible oil which could be used in human nutrition and the feedstock could be used in animal feed. Most extensively grown oilseed crops, i.e., rapeseed (*Brassica napus* L.), soybean (*Glycine max* L.), and sunflower (*Helianthus annuus* L.), mainly retrieve the economic values of their oil related to its quality. Having even, or at least predictable, oil quality would

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characterize an added value for emerging oilseed crops, such as camelina, which has a huge potential in the bio-based market under the eyes of its unique fatty acid profile, as it permits a plethora of numerous applications (Berti et al. 2016). The introduction of a new crop in the existing cropping system to enhance productivity and profitability is directly associated with crop diversification. This is a vital part of the process of structural transformation of the economy of the country. The improvement in the productivity of oilseed crops in the country is the need of the hour. The introduction of the latest technologies brings crop diversification, which results in a positive shift in the area under oilseed crops (Abro 2012). These efforts were fruitful, but still, there is a huge gap between the demand-supply of edible oil in the country. *Camelina sativa* is a golden crop, which is a success story due to its salient features, i.e., environmentally sustainable source of energy (Chaturvedi et al. 2017). The introduction, adoption, and implementation of new technology always need special attention due to certain factors such as economic situation of the farmers. So, it is a challenge to penetrate a new crop into the rural market and agriculture infrastructure. Furthermore, the adoption of the new crop must be superior in a particular section, plus it must have the ability to be a value-added commodity which can give early and handsome returns to the stakeholders. This will also help in resolving the problems associated with monotonous crop rotation and also will enhance the systems health and productivity. To overcome these problems, there should be an alternative solution like another oilseed crop that can compete in the production race and maintains the quality of edible oil and other purposes. In this scenario, *C. sativa* may be used as a commercial, sustainable, and terrestrial source of longer-chain fatty acids and for human food and as aquaculture feedstock (Righini et al. 2019).

C. sativa is a rediscovered oilseed crop that belongs to the family Brassicaceae (Righini et al. 2016); originated from Finland, Northern Europe; and spread around the globe (Schillinger 2019). This crop has gained tremendous attention from stakeholders and re-emerged as an important oilseed crop. It has numerous attributes that give it unique status among other oilseed crops. For instance, it can be grown successfully under suboptimal growth condition and has been reported to perform well under water-deficit environment than major oilseed crop, e.g., rapeseed (*Brassica napus* L.) (Zubr 1997; Gugel and Falk 2006). It requires low inputs compared to other crops (Righini et al. 2019) that makes *C. sativa* the best fit on less fertile and moisture-deficient lands. Its oil has comparatively low glucosinolate content than other members of the Brassicaceae family, making it relatively better option to use its oil in different feed formations (Matthäus and Zubr 2000b).

Biodiesel production from vegetable oils is a great alternative to conventional petroleum-biodiesel due to its remarkable environmentally safe quality. It has a huge market as it can be used in agricultural machinery, automobiles, power generation, and the stationary power sector (Xue et al. 2011). Almost 95% of the world's biodiesel is produced from vegetable oils like canola, sunflower, and soybean (Gui et al. 2008). In recent years, the demand for *C. sativa* has increased due to its ability to grow with few inputs, and its oil can be utilized for a nonfood purpose (Putnam et al. 1993). The fatty acids pattern in *C. sativa* is very particular with the characterization of 30–40% linolenic acid (C18:3), almost 4% of erucic acid, and 15% of eicosenic acid (C20:1) (Budin et al. 1995), making it highly suitable for drying oil, which is used to form environment-friendly paints and coatings (Zaleckas et al. 2012; Kasetaite et al. 2014). Despite its ability to be grown as an alternate oilseed crop for semiarid regions, *C. sativa* remains underexploited due to the limited attention of researchers despite its unique agronomic and industrial potential. The present review describes the agronomic potential of *C. sativa* provided under semiarid conditions as an alternate oilseed crop. It further underscores the industrial potential of *C. sativa* and its nutritive values. Moreover, it also discusses the challenges and projections for future research to ensure the economic feasibility of *C. sativa* production.

7.2 Oilseed and Biofuel Crops Under Changing Climate

The climate change is characterized by various indicators and manifests itself as global warming, CO_2 enrichment of the atmosphere, ozone depletion, melting of glaciers, and permafrosts resulting in rising of sea level and changing of weather patterns (Abbas et al. 2021a; Iqbal et al. 2021a, b; Siddiqui et al. 2019). The net impacts of climate change include erratic rainfalls, emergence of drought spells of varying intensity and duration along with disruption of modern cropping systems with respect to sowing time, and emergence of new insect pest of food and nonfood crops (Iqbal et al. 2020). Besides food and oilseed crops, biofuel crops have also been seriously affected by changing climatic scenario in a direct or an indirect way (Abbas et al. 2021b; Iqbal et al. 2020). The direct influence of climate change and global warming has been significantly adverse for most of C3 crops compared to C4 crops (Iqbal et al. 2020). The indirect impact of changing climate on biofuel crops might be attributed to lesser area available for cultivating nonfood crops owing to uncertain and highly variable productivity of food crops especially wheat, rice, maize, etc. Currently, intensive research is being undertaken to develop strategies for reducing CO_2 emission into the atmosphere, while bioenergy may serve as one of the promising substitutes of the fossil fuels (Somerville et al. 2010). For instance, the USA is using the starch component from 40% of maize for the production of ethanol having consumption in transportation sector. However, optimum amount of fertilizer needs to be applied in addition to field preparation for growing biofuel crops such as maize that ultimately requisite fossil fuel consumption, thus tempering carbon savings strives (Hossain et al. 2020).

Recently, researchers are striving to develop liquid fuel (ethanol) from lignocellulose of crops like camelina that hold potential to mitigate adverse effects of climate change through lesser use of fertilizers and tillage, avoiding numerous disadvantages associated with traditional biofuel crops such as corn which require intensive management and contribute to greenhouse gases emission into the atmosphere. The biofuel term encompasses grown fuels like corn ethanol that might be utilized in transportation sector instead of fossil fuels (like petroleum products). In addition, biofuel term is also used for any fuel synthesized from various types of plant materials belonging to crops such as maize, sorghum, soybean, etc. The biggest advantage of biofuel crops especially camelina is that they greatly suck CO_2 from the air as they grow and thus might be declared as zero net emitter. But considering camelina like biofuel crops as zero emitter crop is not too simplistic as its cultivation requires application of fertilizers, use of fossil fuel-run tractors for performing different operations, transportation of farm inputs to field, and energy for converting the plant material into liquid fuels. Under changing climate, cultivation of camelina can also increase carbon storage in the soil. However, a careful and precise life cycle analysis of camelina encompasses fossil fuel consumption for crop cultivation, harvest, plant material conversion into fuel, transportation of biofuel to distribution facilities, and their combustion effect on environment.

Climate change tends to trigger most of oilseed crop growth and development on the cost of shortening the crop growth duration (Farooq et al. 2022). It has been reported that increased air saturation and vapor pressure owing to higher temperature in the longer run restrict moisture exchange among crop leaves and atmosphere (Faisal et al. 2020). Additionally, high temperature as a result of climate change gives rise to heat stress that is detrimental to crop plants especially at reproductive crop stage which leads to notable reduction in crop yield (Sabagh et al. 2020; Raza et al. 2022). Moreover, warmer climate coupled with CO_2-enriched environment invites significantly higher pests and diseases (both indigenous and exogenous). Oilseed crops have witnessed a sharp decline in their productivity owing to the adverse effects of climate change during the last decade. In particular, heat stress and erratic precipitation have served as the most vital climatic factors determining the seed yield as well as oil concentration of seeds (Ahmad et al. 2021). Therefore, there is a dire need to investigate alternative oilseed crops such as camelina that are either preadapted or hold potential to thrive well under rising temperature and erratic precipitation levels as predicted by numerous climate change models. Despite due recognization of the need to produce biodiesel and cooking oil from alternative crops including camelina, the agroecological requirements of alternative crops and degree of adaptive variation in their seeds and ecophysiological characteristics have remained unclear. Thorough investigations pertaining to determining the ecological requirements for biofuel-cum-oilseed crops like camelina might be used for identification of suitable present as well as future cultivation areas. Moreover, there is need to develop viable analytical tools for appropriate modeling of camelina like crops niches and their potential distributions enabling the projection of changes for their cultivation in climatically suitable areas.

7.3 History

Camelina (*Camelina sativa* L.) originated from Finland to Romania and east to Ural Mountains. The very first cultivation of *C. sativa* was done after the bronze ages (between the stone ages and the iron ages) in Northern Europe (Francis and Warwick 2009; Toncea 2014). It is native to Northern Europe. According to Francis and Warwick (2009), the *Camelina* spp. in the cards originated in southwestern Asia and southeastern Europe, while the exact origin of *C. sativa* is still undefined (Larsson 2013). A number of its species got under the molecular analysis that suggested the center of its origin is Russia and Ukraine (Ghamkhar et al. 2010). According to archaeologists, the origin of *C. sativa* is southern Europe, and its cultivation is started in Neolithic times. Till the iron ages, it was a famous cultivated crop all over Europe (Knörzer 1978). Its introduction to North America is a contaminant in the seed lots of different crops (Francis and Warwick 2009). It was deliberately introduced in Canada in 1863 in Manitoba and then cultivated in the Peace River district during the mid-1990s (Francis and Warwick 2009). In North America, its proper cultivation was started in the late 1990s (Robinson 1987). It belongs to the family Brassicaceae and is famous as “false flax” and “gold of pleasure.” It was a well-known oilseed crop before World War II, but after the explosions, the cultivation of *C. sativa* declined and was replaced by other oilseed crops (Ehrensing and Guy 2008; Séguin-Swartz et al. 2013). The very initial trial that was carried out in North America renowned that *C. sativa* bearing a high level of oil content, economic yield, and short duration lifecycle which assets grave consideration as a potential crop (Plessers et al. 1962) and three trials were carried out in Ottawa and Ontario. The second trial was performed at Fort Vermillion, Alberta (Plessers et al. 1962), and found that camellia is performing better than other oilseed crops of the area like rapeseed and flaxseed. These trials were followed, and additional trials were conducted in Denmark, England, and Finland, showing that *C. sativa* has an oil content of 40–44% (Zubr 2003a, b).

7.3.1 Native Range

The native region of *C. sativa* in Asia includes Pakistan, Armenia, Georgia, Azerbaijan, India, Mongolia, Russian Federations, Turkey, Tajikistan, Kazakhstan, and Turkmenistan (USDA 2011), and in Europe, Albania, Macedonia, Austria, Slovakia, Belgium, France (including Corsica), Bosnia and Herzegovina, Montenegro, Bulgaria, Czech Republic, Croatia, Ukraine (Crimea), Denmark, Greece (Crete), Germany, Hungary, Italy, Spain (Sardinia, Sicily), Russian Federation, Moldova, Slovenia, the Netherlands, Switzerland, Sweden, and the UK (USDA 2011).

7.3.2 Range

In Asia, the *C. sativa* was first introduced in China and Japan (USDA 2011), while in Africa, it was introduced in Tunisia (USDA 2011). In Australasia, *C. sativa* was first introduced in Australia (Southern regions of the country, Tasmania, Victoria, and Western regions) and New Zealand (Western Australian Herbarium, 2010, USDA-ARS 2011). In the USA, it was introduced in almost 38 states, including California, Indiana, Arkansas, Florida, Mississippi, Tennessee, Nevada, Colorado, etc. (USDA 2011). The introduction of *C. sativa* is reported in South America in Uruguay, Chile, Mexico, and Argentina (Francis and Warwick 2009; USDA 2011). In Canada, it was introduced throughout the whole country except Newfoundland province (Govt. of Canada 2011; Francis and Warwick 2009), and in Europe, it was reported as a naturalized crop in Belarus, Ireland, Finland, Estonia, Lithuania, Latvia, Poland, Norway, Romania, and Ukraine (Milbau and Stout 2008; USDA-ARS 2011)

7.4 Classification

7.4.1 Taxonomy and Genetics

The genera Camelina belongs to the tribe Camelineae and family Brassicaceae (mustard family) (Al-Shehbaz et al. 2006). Camelineae tribe also includes the model plant known as *Capsella bursa-pastoris* and *Arabidopsis thaliana*. It is polyploidy in nature, evidenced by the genetic mapping of its genome (Galasso et al. 2011), and the hexaploid genome is also reported (Hutcheon et al. 2010). Chromosome numbers for *C. sativa* are 14 or $n = 6$ or 26 or $2n = 12$, or 40, with $2n = 40$, a common count (Gehringer et al. 2006). USDA-NRCS (2010) stated the taxonomic position of *C. sativa* as it belongs to the kingdom Plantae, subkingdom Tracheobionta, superdivision Spermatophyta, division Magnoliophyta, class Magnoliopsida, subclass Dilleniidae, order Capparales, family Brassicaceae, tribe Camelineae, genus *Camelina* Crantz, and species *Camelina sativa* (L.) Crantz (gold-of-pleasure) (Al-Shehbaz et al. 2006).

7.5 Plant Growth

7.5.1 Morphology

It is assumed that *C. sativa* was originally cultured as a winter oilseed crop (Waraich et al. 2017) that can attain height up to 30–90 cm (Putnam et al. 1993). After germination, the initial growth is conceded on the conical room having axial branches. In the initial growth phase, the plant part above the ground consists of rosettes of leaves. These rosettes then will be turned into an erect stalk having several leaves. Its stem becomes woody when the plant reaches maturity with glabrous or sparse hairs (Klinkenberg 2008). The stem is non-branched most of the time, but sometimes it has branches (Klinkenberg 2008). In the case of hairy stems, the starlike hairs are more in numbers than normal hairs. Leaves are narrow in shape with pointed edges and are 2–8 cm long (Putnam et al. 1993). During the consequent stage of growth, flowering and axial branches having flowers develop from the apex. Its flowers are small and prolific, known as racemes, which are greenish-yellow (Putnam et al. 1993), pale yellow, or white (Klinkenberg 2008) in color. Camelina flowers consist of four petals with 4–5 mm length and sepals with 2–3 mm, style length is 2–2.5 mm, and length of flower stalk is 10–25 mm. Its fruit is known as silique, which is shaped like a pear pod or teardrop-shaped having 5–6 mm width and 7–9 mm in length with a squared-off tip, 0.7–2.5 mm in diameter, brown to orange in color, and results from self-pollination, though they can be cross-pollinated by different pollinator insects. Seed pods resembled the bolls of flax and range 6–14 mm in length, containing 10–25 seeds. The seeds are pale yellow, tiny in size (0.7 mm × 1.5 mm) (Klinkenberg 2008), and oblong with a tough surface (Putnam et al. 1993). Seedling emergence takes around 6 days after sowing, while fluorescence appeared and seed formation initiates 37 and 57 days after sowing and plant takes ~80 days after emergence to reach maturity (Alina and Roman 2009). At harvesting time, the plant reached a height of 51.4 cm, with an average of 87–121 siliques per plant having ~739 seeds/plant and ~6.55 seeds per silique (Alina and Roman 2009; Waraich et al. 2017).

7.5.2 Phenology

C. sativa has got much attention due to its salient features, but the exact depiction of its phenological growth stages is not understood yet. Martinelli and Galasso (2011) planned an experiment to elaborate the phenological growth stages based on the extended BBCH scale (Hack et al. 1992). The knowledge of growth stages is essential and supposed to be fundamental for studying the ability of crops to adopt different environmental conditions, for development of highly suitable and appropriate agronomic techniques, for different breeding programs, and for the setup of application protocols of different fertilizer and herbicide.

7.5.3 Growth of Camelina: Overall Depiction

It can be subdivided into three subspecies on taxonomic bases (*pilosa*, *foetida*, and *sativa*) (Angelini and Moscheni 1998). So, its cultivation extended from overwintering to spring period. *C. sativa* ssp. *pilosa and sativa* were supposed to be good in an agronomic context. *Pilosa* is known for its character of verbalization requiring the maximum growth of stem and consequent flowering. One of the main characteristics of camelina is its morphological plasticity. This species is characterized as a short-growing seasonal crop that completes its life cycle with 110 days in spring, and it might be shortened under adverse conditions.

7.5.4 BBCH Scale for C. sativa

Table 7.1 shows the ten different growth stages of *C. sativa* based on two- and three-digit BBCH scales. For the overall depiction of development, the two-digit code is

Table 7.1 Depiction of the *C. sativa* phenological growth stages in accordance with the extended BBCH scale (Used with permission of Martinelli and Galasso, 2011)

BBCH codes		
Two digits (00)	Three digits (000)	Explanation
Germination: the principal growth stage 0		
00	000	Dry seed
01	001	Imbibition of seed starts
03	003	Imbibition finished
05	005	Emergence of radicle from seed
07	007	Hypocotyl emergence from seed with cotyledons
08	008	Hypocotyl along with cotyledons mounting toward the soil
09	009	Cotyledons emergence through the soil surface
Leaf enlargement: principal growth stage 1		
10	100	Unfolded Cotyledons (node 0)
11	101	True leaf pair on first node
12	102	Single true leaf on second node
13	103	Single true leaf on third node
14	104	Single true leaf on fourth node
15	105	Single true leaf on fifth node
16	106	Single true leaf on sixth node
17	107	Single true leaf on seventh node
18	108	Single true leaf on eighth node
19	109	Single true leaf on ninth node
	110	Single true leaf on tenth node
	118	Till stage 199 the coding lasts with the same trend
	119	Single true leaf on 19th or succeeding node
Development of side shoots[a]: principal growth stage 2		
21	201	One-sided shoot developed
22	202	Two-sided shoots developed
2.	20.	Coding continues with the same scheme up until stage 29 (209)
29	209	Nine or more side shoots visible
	21.	Till 219 the coding lasts with the same trend
	219	19 or >19 side shoots developed
Elongation of main stem: principal growth stage 3		
31	301	Stem elongated 10% of final extension
32	302	Stem elongated 20% of final extension
3.	30.	Till 39 the coding lasts with the same trend
39	309	Maximum stem elongation
Harvestable vegetative parts development[b]: principal growth stage 4 (mislaid)		
Emergence of inflorescence: principal growth stage 5 (main shoot)		
50	500	Enclosed inflorescence in leaves
51	501	Visible inflorescence
55	505	Enclosed individual flower buds
59	509	First petals visible but still all flowers enclosed

(continued)

Table 7.1 (continued)

BBCH codes		
Two digits (00)	Three digits (000)	Explanation
Flowering: principal growth stage 6 (main shoot)		
60	600	First flower opened
61	601	10% flowers opened
62	602	20% flowers opened
63	603	30% of flowers opened, first petal dried or fallen
64	604	40% flowers opened
65	605	Complete flowering: 50% flowers opened
67	607	Flowering ending: most petals dried or fallen
69	609	Flowering ended: Visibility of fruit
Fruit development: principal growth stage 7 (main shoot)		
71	701	10% siliques touched maximum size
72	702	20% siliques touched maximum size
73	703	30% siliques completed maximum size
7.	70.	Till 79 the coding lasts with the same trend
79	709	All siliques touched maximum size
Ripening: principal growth stage 8		
81	801	Ripened silique 10% (seeds are deep yellow/orange and hard)
82	802	Ripened silique 20%
83	803	Ripened silique 30%
8.	80.	Till 89 the coding lasts with the same trend
89	809	Almost every silique is ripe; the crop is prepared to be reaped
Senescence: principal growth stage 9		
97	907	Plant death and dryness
99	909	Harvested produce[c]

[a]In *C. sativa*, the side shoot development generally happens either concurrently or after inflorescence emergence. Consequently, the second principal growth stage ordinarily mislaid. If formation of side shoot is taken a feature of specific attention, then principal growth stage 2 can be counted in along with principal growth stage 5 by using diagonal stroke
[b]As vegetative part was not harvested, so principal growth stage 4 has been omitted
[c]Storage treatments were applied at this stage

used, but the three-digit code is used in case of more accuracy. The application of three-digit code permits for selecting 19 leaves (Hack et al. 1992), thus allowing the precise depiction of plant growth before the emergence of an inflorescence. This is predominantly essential as in camelina, the scoring of stem enlargement, a phase that generally happens concurrently with the development of leaf, doesn't allow the instant valuation of the existing growth stage stated as a percentage of the final plant height. The accurate knowledge of the growth stage developed before the emergence of fluorescence then goes for the three-digit growth stage. The main-stem elongation can be directly assessed by the scoring of clearly protracted internodes on the main stem, but this is very difficult in the case of *Camelina sativa* as the identification of enlarged internodes is habitually equivocal and mainly operative dependent. To address this problem, main-stem elongation capacity as a percentage of the final stem length was taken as a highly suitable means to measure stem elongation in camelina. As different growth stages in *Camelina sativa* overlapped, like fluorescence emergence and formation of side shoot that take place simultaneously, the operator might skip the advanced stage or consider both the BBCH codes alienated by a diagonal stroke.

7.6 Reproduction

7.6.1 Floral Biology

C. sativa is considered an autogamous, self-compatible species (Mulligan 2002). The selfing process in camelina starts at dusk; stamen turned toward the stigma in the evening and deposited its pollen that lasts for the whole night that results from withering the flower that falls in 2–3 days. The same thing happens next to the stem, which grows longer as a new flower blooms (Schultze-Motel 1986). Out of 10,000 plants, the cross-pollinated were less than 3% (Tedin 1922). Contrastingly results were published by those who erroneously stated that camelina benefited from different pollinators (Goulson 2003).

7.7 Seed Production and Dispersal

7.7.1 Planting Time

Planting date is a key aspect in the satisfactory production of camelina due to favorable and unfavorable environmental conditions, i.e., temperature and soil moisture, which affects seed yield and seed quality. Generally, high-temperature stress might result in plant sterility, seed abortion, reduced number of seeds, and grain filling duration (Hatfield and Prueger 2015). Studies showed that camelina oil content is greater under cool environmental conditions (Obour et al. 2017; Zanetti et al. 2017), as grain weight is affected by seeding date and lower thousand seed weight has been reported in late seeded crop (Liu et al. 2021). Contrastingly, Urbaniak et al. (2008) stated that the seeding date has no effect on the 1000-grain weight and yield in field trials of Canada. Due to climatic variations among different regions globally, it defines the optimum planting time of camelina (Table 7.2).

Table 7.2 Optimum planting times of camelina around the world

Country	Planting time	References
USA/Montana	Late February or early March	McVay and Lamb (2008)
USA/Minnesota	Mid-April to mid-May	Gesch (2014)
USA/Minnesota	Mid-April to mid-May	Sintim et al. (2016a)
USA/Western Nebraska	Late March to end of April	Pavlista et al. (2011)
USA/Kansas State	April	Obeng et al. (2019)
USA/Nevada	Mid-March	Neupane et al. (2019)
Chile	April 30	Berti et al. (2011)
Europe	Mid-March and mid-April	Zanetti et al. (2017)
Canada	Mid-April to mid-May	Gesch (2014)
Pakistan	Mid-November	Waraich et al. (2017)
Poland	September 1	Czarnik et al. (2018)

7.7.2 Seed Rate

Optimization of the seed rate of a crop is a critical aspect for balancing seed cost with proper crop stand establishment to improve yield and, particularly for camelina, to contend with weeds because there are only a few herbicides used for its better performance (Sobiech et al. 2020; Gesch et al. 2018). Urbaniak et al. (2008) demonstrated that 1000-grain weight and yield are significantly affected by seed rate in field trials in Canada. They reported seed yield of 1.34, 1.50, and 1.60 ton ha^{-1}at seed rate of 200, 400, and 600 seed m^{-2}, respectively. They also observed more silique and branches per plant at lower seed rate. In another 3-year trial in Germany, 1.34, 1.16, and 1.80 ton ha^{-1}average yield was recorded each year, respectively, while seed rate of 400 m^{-2} and 120 kg N ha^{-1} application produced the highest yield (2.28 ton ha^{-1}). However, a higher seed rate (800 seed m^{-2}) reduced the total branches plant^{-1}, number of silique plant^{-1}, seeds silique^{-1}, and seed weight plant^{-1}. The positive effect of N application on yield and yield contributing traits was also affirmed by other field studies (Gao et al. 2018).

7.7.3 Seed Banks, Viability, and Germination

C. sativa is not a novel crop in the field, but unfortunately it was being ignored by the researchers despite its unique characters. The literature on seed dormancy and crop volunteers in camelina is very rare. Zhang and Auer (2019) have little information about seed dormancy in camelina as the seeds have shown little dormancy period, and seed emergence was recorded after 2 weeks of harvesting in a 3-year experiment in Ireland by Crowley (1999). Ellis et al. (1989) found that the germination of camelina was related to the dose of white light photon and was subdued by high radiation, which generally hinders emergence, and was significantly stimulated by gibberellic acid (GA_3). In Maritime Canada, the rate of germination of camelina was

>95%, although the seedling emergence rate was dependent on the environment (Urbaniak et al. 2008).

7.8 Camelina: Agronomy, Prospects, and Challenges

C. sativa is a short-day plant and completes its life cycle within 100 days (McVay and Lamb 2008). It can't reach the lower soil surfaces in search of water because of the shallow root system (Putnam et al. 1993). It can either be grown as an annual spring or biannual winter crop. It can be successfully grown under various soil and climatic conditions due to its high adaptability.

7.8.1 Sowing Date

The production of *C. sativa* can be optimized by following the basic principle of crop production, starting from the optimum sowing date. Sowing of camelina at an optimum time prevents pod abortion by preventing its exposure to severe heat and drought in early summer. Soil moisture and environmental conditions are the main driving forces behind the optimization of sowing date. Pavlista et al. (2011) did not find any effect of sowing date on the crop yield in western Nebraska. In the summer crop, the sowing after mid-April despite late March or mid-April negatively impacts the yield. The winter sowing in September and October (Gesch and Cermak 2011) bears the chilling conditions of winter and resumes its growth with favorable conditions. Winter-sown camelina has distinctive benefits like proper stand establishment of crop leads to better plant growth which lowers the weed pressure (Gesch and Cermak 2011) and it permits the crop to mature before the start of severe summer leading to early harvesting which helps in soil moisture conservation for the succeeding crop (Gesch and Archer 2009; Gesch and Cermak 2011).

7.8.2 Tillage

This would be best suited in winter-based nonirrigated traditional cropping systems where crop failure could be prevented by moisture availability. Soil preparation must be done carefully. Before the sowing of the crop, multiple harrowing must be done to eliminate the weed infestation. Camelina has the potential to perform under no-till and traditional tillage (Enjalbert and Johnson 2011). However, under no-till/ excessive crop residue, the seed rate needs to be increased as emergence rate can be negatively effected (Enjalbert and Johnson 2011).

7.8.3 Seed Rate

Optimal seed rate is very crucial for proper stand establishment, active plant growth, and high economic yield. There must be 210 plants m^{-2} (20 plants ft^{-2}), which can be achieved with optimal seed rate (6 kg ha^{-1}); seed must be incorporated into the soil. Its seeds must be planted at shallow depths (6–8 mm) due to small seeds for a better crop stand. Primary and secondary tillage, seed rate, sowing method, and sowing depth are the key dynamics that affect the plant population and consequent yield (McVay and Khan 2011). It is known as a drought- and chilling-tolerant crop as compared to canola and can thrive and give satisfactory yield under these conditions (Putnam et al. 1993; McVay and Lamb 2008; Berti et al. 2016). The seedling of camelina can tolerate the freezing temperature up to −2 °C, whereas the seedlings of rapeseed, mustard, and flax cannot survive (Robinson 1987). Schulte et al. (2013) published that the temperature fluctuations do not influence the lipid profile of camelina. However, there is a possibility that the sowing date might affect the lipid profile as late sowing exposes the crop to high summer temperatures.

7.8.4 Herbicide Control

There is no proper post-emergence herbicide of camelina, so pendimethalin and glyphosate could be the better option for pre-emergence control. Camelina is a short-duration biofuel crop having consistent yield without using many weedicides and pesticides (Razeq et al. 2014; Iskandarov et al. 2014). Unlike *Brassica*, camelina is not affected by birds and flea beetle damage (Pavlista et al. 2011). It is also resistant to insect pests (Iskandarov et al. 2014; Kirkhus et al. 2013). Quizalofop is used for post-emergence chemical weed control, while glyphosate is useful for pre-emergence weed control (Jha and Stougaard 2013). Prior researchers had used bonanza and treflan as pre-plant herbicides to restrict weed invasion (Yang et al. 2016). The only labeled herbicide for camelina is sethoxydim, which is ineffective on broad leaves (Obour et al. 2015). *Sclerotinia sclerotiorum* is also documented in *Camelina* fields, reducing its production (Yang et al. 2016). The literature on pre-emergence herbicide (PRE) usage is very limited for weed control in camelina (Schillinger et al. 2012). Consequently, existing substitutes of weed control have to use a labeled pre-emergence broad-spectrum herbicide, while mechanical removal of weeds is a very time-consuming practice (Froment et al. 2006). Sethoxydim is the only registered herbicide for camelina, but it controls narrow-leaf herbs, and quinclorac is suitable for broadleaf herbs (Jha and Stougaard 2013). The lower rates of S-metolachlor, dimethenamid-P, and pendimethalin, keeping in view the toxic level for use, could be approved for camelina (Jha and Stougaard 2013). However, certain residual herbicides from sulfonylurea are reported to affect the crop stand of camelina (Enjalbert and Johnson 2011).

7.8.5 Fertilizer Applications

Optimum nutrient application is a driving force behind better growth and development, yield quantity, and quality. Depending upon soil type, fertility, and soil moisture, 20–50:10–25:0 kg ha^{-1}of nitrogen (N) and sulfur (S) are required for camelina, respectively (Jiang et al. 2013). Soil organic matter and moisture are the main factors behind the response of *C. sativa* toward N and S (Jankowski et al. 2019). As camelina has shown maximum yield at 45–56 kg N ha^{-1}. *C. sativa* does not need any intercultural practice from the seedling stage till harvesting. The response of camelina toward phosphorus (P) application was not good even in P-deficient soil (Obour et al. 2012), and P at 15–30 kg ha^{-1}might be suitable for the *C. sativa* production.

7.8.6 Harvesting

The plant reached its harvesting maturity when 50–75% of silique got brown, which is the best time to harvest the crop (Sintim et al. 2016b). Harvesting at a proper time decreases the chances of yield loss by shattering, so swathing of the crop must be considered for harvesting at uneven maturity. Regular grain combine harvester can be used to harvest camelina with certain adjustments like the height of header must be fixed at the highest spot to deny the plugging and airflow adjustments to minimize the chances of seed to blow away. However, the cleaning of seed might be needed due to this slow airflow as a seed might be mixed with plant material. The mixing of plant material with seeds could be fixed by installing a 0.35 cm screen before the lower sieves beneath the harvester (Enjalbert and Johnson 2011).

7.8.7 Seed Yield

The nonirrigated areas where the total precipitation recorded was 400–500 mm gave seed yield of 1.68–2.02 ton ha^{-1}and 0.50–1.34 ton ha^{-1} in low rainfall areas (McVay and Lamb 2008). Seed yield of 0.45–1.30 ton ha^{-1} has been recorded in trials in years 2013 and 2014. The trial conducted in Eastern Europe gave 2.88 ton ha^{-1} of seed yield (Vollmann et al. 2008). Camelina seed yield varies in different continents (Table 7.3).

7.9 Potential of *C. sativa* Over Nonirrigated Areas Compared to Other Oilseeds

C. sativa has greater potential in nonirrigated areas due to its lower requirements of water. The intercropping of camelina has been tested in wheat-based cropping systems in dryland regions. The trials under dryland regions resulted that camelina

Table 7.3 The difference in seed yield and oil content of *C. sativa* in experiments conducted in different parts of the world

Location	Oil content range	Yield range (kg ha^{-1})	Major source of variation	References
Iran	33–34.4%	1868–3209	Irrigation levels, sulfur	Amiri-Darban et al. (2020)
Nevada, USA		594–961	Sowing dates, years	Neupane et al. (2019)
Kansas, USA	290 g kg^{-1}	317–483	Sowing dates, years	Obeng et al. (2019)
Germany	32.0–49.0%	1100–2650	Breeding lines	Gehringer et al. (2006) and Berti et al. (2011)
Romania		1761–2892	Cultivars	
Austria	40.5–46.7%	1574–2248	Breeding lines, seed size	Vollmann et al. (2007)
Ireland	43.1–44.7%	1630–3200	Sowing date, N rates	Crowley and Fröhlich (1998) and Berti et al. (2011)
Chili		420–2390	Sowing dates, NPS, Fertilization	
Denmark	40.4–46.7%	1270–2360	Spring/fall sowing	Zubr (1997)
Pakistan		300–400	Drought, selenium	Ahmad et al. (2020)
Germany	34.3–42.4%	1290–3230	Breeding lines	Seehuber et al. (1987)
Germany	32.1–42.3%	500–2620	Genebank accessions	Seehuber (1984) and Katar et al. (2012)
Turkey		572–997	Accessions and breeding lines	
West Canada	37.0–46.3%	1000–3000	N fertilizer rates, environments	Malhi et al. (2014)
Minnesota, USA	37.7–41.0%	800–1900	Cultivars, sowing date	Gesch (2014)
Pacific Northwest USA	29.6–36.8%	127–3302	Cultivars, spring/fall planting	Guy et al. (2014)
East Canada	35.5–37.8%	1400–2050	N, S fertilization	Jiang et al. (2013)
Nebraska, USA	29.8–34.3%	556–1456	Sowing date	Pavlista et al. (2011)
East Canada	35.5–40.1%	426–2568	Cultivars, N rate	Urbaniak et al. (2008)
West Canada	35.8–43.2%	962–3320	Genebank accessions, environments	Gugel and Falk (2006)
Minnesota, USA	34.3–37.5%	1007–1218	Genebank accessions	Putnam et al. (1993) and Rode (2002)
Slovenia		400–800	Cultivars	

yielded more or somewhere the same as other oilseed crops, but the shattering, lodging, disease, and insect factors were minimal compared to others (Putnam et al. 2009; Gao et al. 2018). Likewise, Johnson et al. (2009) stated that the performance of camelina under nonirrigated conditions was way better than rapeseed as camelina produced more seed yield than rapeseed. *C. sativa* can be used as a potential fallow crop in cereal-based crop system, which results in crop diversification, minimizes pest population, and increases the profit of the farmer, log-term crop sustainability, and farm in the region. *C. sativa* proved a potential crop with minimum reduction in yield as it can replace fallow in the wheat-fallow system (McVay and Lamb 2008). Cultivation of *C. sativa* on underutilized fallow wheat-based production systems strips to evade uninterrupted competition for land use.

7.10 Constraints

Several restraints affect the outcome and economic feasibility of *C. sativa* regardless of its capability as a substitute potential bioenergy crop for dryland regions. Information regarding the agronomic practices, production systems, and adapted spring and winter genotype is scarce. *C. sativa* is facing problems regarding the benefit-cost ratio and lack of marketing system that could lose the productivity of the crop. Like other constraints, uneven maturation results in the harvesting problems that might cause shattering, and postharvest losses are another significant constraint in the profitability of camelina (McVay and Khan 2011; Lenssen et al. 2012). Certain fungal infections have been reported in camelina, like downy mildew infestation in Pacific Northwest in the USA (Putnam et al. 2009; Harveson et al. 2011), and the control of downy mildew has not been reported yet for camelina. All these challenges bring much-needed attention of researchers to conduct more research on camelina to optimize its production and profitability.

7.11 Camelina Agronomic Performance, Oil Quality, Properties, and Potential

C. sativa oil has many advantages over other oilseeds. One of them is the presence of unsaturated omega-fatty acid (80%) of total fatty acid and 35–40% of linolenic acid (18: 3n·3) (Belayneh et al. 2015). Camelina oil has many advantages over other oilseeds. Its oil is a rich source of omega-3 fatty acid (80%) of total fatty acid and 35–40% of linolenic acid (18: 3n·3) (Budin et al. 1995; Abramovič and Abram 2005; Abramovič et al. 2007; Schwartz et al. 2008), and it has more than 50% polyunsaturated fatty acids in cold-pressed camelina oil (Budin et al. 1995; Abramovič et al. 2007), and it has tenfold of more oil as compared to other oilseeds (Alice et al. 2007; Tabără et al. 2007). The fatty acids pattern in camelina is very particular with the characterization of 30–40% linolenic acid (C18:3), almost 4% of erucic acid, and 15% of eicosenic acid (C20:1) (Budin et al. 1995). Member of order Brassicales, especially the Brassicaceae family, has a secondary metabolite known as glucosinolates (Clarke 2010). There are almost 120 types of glucosinolates discovered yet which are naturally present in the plants. These secondary metabolites are responsible for the sharp and bitter taste in cruciferous vegetable oil and also release chemicals that act as defensive agents against herbivores and natural pests (Fahey et al. 2003). Glucosinolates can cause damage to plants, and plants compartmentalize this compound to avoid the damage. Camelina also does the same and accumulates the glucosinolates (glucoarabin (9-(methylsulfinyl)nonylglucosinolate – GS9), glucocamelinin (10-(methylsulfinyl)decylglucosinolate – GS10), and 11-(methylsulfinyl)undecylglucosinolate (GS11) in its seeds. Camelina oil is also known as golden liquid, which contains more than 50% of polyunsaturated essential fatty acids primarily linoleic acid and alpha-linoleic acid, and it also contains tenfold more fatty acids than other oilseed crops (Alice et al. 2007; Tabără et al. 2007). It has a significant shelf life due to the presence of Vit-E (tocopherol) that saves it from oxidation (www.simplunatura.ro), and it also plays a vital role in slenderness recovery, the elasticity of skin, and regeneration of cell (Vollmann et al. 1996). The basic properties of camelina make it specifically suitable, which are (1) exceptional aroma and taste, (2) color, (3) chemical and physical composition, and (4) extended conservation duration (up to 2 years). Table 7.4 has shown the fatty acid composition in the camelina oil.

The camelina oil yield and quality has shown variations on different location. Though the modern breeding history of *C. sativa* is relatively little, *C. sativa* trials have shown a satisfactory seed yield and other promising agronomic features than other novel crops that may be due to the long adaptation history of *C. sativa*. A

Table 7.4 Fatty acid profile of *C. sativa* oil (research conducted in the Constanta County, 2009) (Imbrea et al. 2011; El Sabagh et al. 2019; Borzoo et al. 2020; Yuan and Li 2020; Amiri-Darban et al. 2020)

Fatty acids	Bonds ratio	Oil content (%)
Myristic acid	C14:0	0.10
Palmitic acid	C16:0	6.51–8.1
Palmitoleic acid	C16:1	0.18
Stearic acid	C18:0	2.15
Oleic acid	C18:1n–9	16.27–16.38
Linoleic acid	C18:2n–6	20.99–21.52
Linolenic acid	C18:3n–6	32.20–35.58
Conjugated linoleic acid	C18:2	1.06
A-Linolenic acid	C18:3n–3	11.59
Arachidonic acid	C20:4n–6	1.11
Erucic acid	C22:1n–9	1.6
Docosadienoic acid	C22:2n–3	2.24
Gadeolic acid	C20:1	14.4
Eicosadienoic + eicosatrienoic	C20:2	2.64
PUFAs/MUFAs		1.83
Polyunsaturated fatty acid		90.0
Other fatty acids		0.61
Glucosinolate		15.7–28.2

detailed number of published research on the difference of camelina seed yield and oil content in European and North American locations are presented (Table 7.4). The use of camelina oil in the human diet has been established in many European countries like the UK, Germany, Finland, Denmark, and Ireland. Camelina is found to be used in the bread of human consumption. It has a specific composition that enriches the bread with essential amino acids (Zubr 2003b), omega-3 fatty acids (Amiri-Darban et al. 2020), fatty acids (Zubr 2003b), dietary fibers (Zubr 2003a), and other minor compounds. It is also rich in oil (Sehgal et al. 2018), fatty acids (Anderson et al. 2019), tocopherols (Zubr 2009; Fernández-Cuesta et al. 2014), bioactive compounds (Matthäus and Zubr 2000b), and amino acids (Zubr 2003b).

7.12 Camelina Response to Insects, Disease, Herbivory, and Higher Plant Parasites

7.12.1 Insects

The insect attack on *C. sativa* is not very extensive because the insect damage has never been enough to warrant control measures (Robinson 1987) for flea beetles (Soroka et al. 2015). It was found that the possible reasons behind the resistance against insects shown by camelina could be due to either the occurrence of repellents or the nonexistence of volatile stimulatory compounds, probably because of the low concentration of glucosinolates (Henderson et al. 2004). The European tainted plant bug is the possible insect species connected with camelina developed as a potential crop (Palagesiu 2000). Further studies have proved that camelina insects susceptibility depends upon the host specificity (Soroka et al. 2015).

7.13 Diseases

7.13.1 Fungal Diseases

Downy mildew, botanically known as *Peronospora parasitica* (Pers. ex Fr.) Fr., was found on camelina in Canada (Conners 1967). *C. sativa* was found resistant to various fungal diseases due to the production of camalexin, methoxycamalexin, and phytoalexins (Browne et al. 1991). The concentration of these compounds can be increased by the inoculation of *A. brassicae* inoculum (Jejelowo et al. 1991), which is the first reported antifungal compound. Pedras et al. (2003) suggested that the resistance in camelina against blackleg could be found by the mixture of phytoalexin production and the destruxin B detoxification pathway. Camelina has also shown massive variability toward different diseases as the variability toward leaf spot was 34% and 10% toward black rot (Westman and Dickson 1998; Westman et al. 1999). The resistance of *Camelina* against several diseases is stated in different regions as Camelina was found resistant to blackleg fungus from Australia (Salisbury 1987) and Poland (Karolewski 1999), and no virulence reported yet (Li et al. 2005). *C. sativa* was also found susceptible to *Botrytis* spp. and *Sclerotinia* in Poland (Crowley 1999) and downy mildew in Austria and the USA (Vollmann et al. 2001; Dimmock and Edwards-Jones 2006).

7.13.2 Viral Diseases

C. sativa has shown susceptibility to aster yellows phytoplasma (Zhao et al. 2010), turnip yellow mosaic tymovirus (TYMV) and *erysimum* latent tymovirus (ELV), beet western yellows virus (BWYV) in Germany, and radish mosaic virus (RaMV) in the Czech Republic. TYMV was also transmitted by *C. sativa* seed (Brunt et al. 1996; Špak and Kubelková 2000).

7.13.3 Bacterial Diseases

In Germany, Camelina was reported to be infested by bacterial blight caused by *Pseudomonas syringae* pv. *camelinae* (Mavridis et al. 2002).

7.13.4 Phytoplasmas

C. sativa was reported to be infected by the aster-yellows-phytoplasma disease (Khadhair et al. 2001) from Alberta, Canada.

7.13.5 Invertebrates

In mixed crop with wildflower, *Camelina* seeds have shown big damage by *Arion lusitanicus* Mabille and *Deroceras reticulatum* Muller by destroying more than 50% of seed, but this did not happen in the crop grown in harrowed plots (Kollmann and Bassin 2001).

7.14 Nutritional Values of Camelina Seed

The nutritional values of camelina seed have been shown in Table 7.5. The analysis of water-soluble B series vitamins has found the contents of thiamin (B1), riboflavin (B2), niacin (B3), pantothenic acid (B5), pyridoxine (B6), biotin (B7), and folate

Table 7.5 Amount of different compounds, amino acids, sugars, vitamins, and minerals in camelina seed oil (Rode 2002; Bătrîna et al. 2020)

Compounds	Amount (%)	Compounds	Amount	Minerals	Amount
Glucose	0.42	Flavonoid	143 mg/kg of seed	Ca	1%
Fructose	0.04	Polar phenolic	439 mg/kg	Mg	0.51%
Sucrose	5.5	Sitosterol	1884 μg/g of oil	Na	0.06%
Raffinose	0.64	Stigmasterol	103 μg/g of oil	K	1.6%
Stachyose	0.36	Brassicasterol	133 μg/g of oil	Cl	0.04%
Starch	1.21	Campesterol	893 μg/g of oil	P	1.4%
Pectin	0.96	Cholesterol	188 μg/g of oil	S	0.24%
Lignin	7.4	Thiamin	18.8 mg/g	Cu	9.9 mg/g
Crude fiber	12.8	Riboflavin	4.4 mg/g	Mn	40 mg/g
Mucilages	6.7	Niacin	194 mg/g	Ni	1.9 mg/g
		Pantothenic acid	11.3 mg/g	Zn	69 mg/g
		Pyridoxine	1.9 mg/g	Fe	329 mg/g
		Biotin	1.0 mg/g		
		Folate	3.2 mg/g		
Amino acids (%)					
Histidine	4.06	Lysine	4.46	Threonine	2.89
Isoleucine	4.38	Methionine	2.70	Tryptophan	1.21
Leucine	7.04	Phenylalanine	5.06	Valine	6.10
Alanine	6.14	Glutamate	16.03	Proline	5.88
Arginine	8.45	Glycine	5.44	Serine	5.84
Aspartate	8.96	Cysteine	1.84	Tyrosine	3.52

(B9). Camelina oil also possessed phenolics such as polar phenolic compounds (Abramovič et al. 2007; Chaturvedi et al. 2017) and flavonoid (Matthäus and Zubr 2000a). Its oil has a significant amount of sterols as sitosterol, cholesterol, campesterol (Shukla et al. 2002; Szterk et al. 2010), brassicasterol, and stigmasterol (Shukla et al. 2002). Topically applied, a healing effect on bruises, skin scratches, squeezing, and sprains, and skin diseases (e.g., acne) and inflammations, is described in the literature (Rode 2002).

7.15 Agro-industrial Uses

The huge oil content in camelina seeds makes it a special product for industrial use and nutritional application. The seed meal of defatted *C. sativa* has a substantial level of carbohydrates, proteins, and a number of phytochemicals, which can be used in the feed and agriculture sector (Gugel and Falk 2006; Zubr 2009). Its oil has great potential for industrial applications. It is reported that camelina has a unique fatty acid profile that makes it early drier, making it good in making polymers, paints, varnishes, dermatological products, and cosmetics (Kasetaite et al. 2014; Zaleckas et al. 2012). Its epoxidized oil has great industrial uses, like in the making of pressure-sensitive resins, adhesives, and coatings (Kim et al. 2015). Its oil content (106–907 L ha^{-1}) is far more as compared to sunflower (500–750 L ha^{-1}) and soybean (247–562 L ha^{-1}), which make it best fit agriculture industrial growth medium (Moser 2010). Due to the presence of omega-3 fatty acid in such a high percentage, camelina oil is being promoted as a dietary supplement in animals (Ponnampalam et al. 2019) and human diet (Rahman et al. 2018). The composition of hen egg can be changed through alteration in diet. If their feed is rich in long-chain fatty acids like omega-3 fatty acids, their concentration will be increased in the yolk, and flax is the best source of omega-3 fatty acid (Jiang et al. 1992; Pilgeram 2007).

7.16 Camelina and Animal Feed

Oilseed crops can also be used as a source of feed for humans and animals like *C. sativa* (Sawyer 2008), which is a source of protein-rich meal having a unique amino acid profile including cysteine, methionine, glycine, arginine, threonine, and lysine which are more in concentration than soymeal (Pekel et al. 2009). This unique profile of amino acids made the camelina meal a good feed source for poultry. Camelina meal consists of 5–10% lipid content that enhances its nutritive values and provides a high-value meal as compared to soymeal (Zubr 1997). This makes the camelina meal one of the best additions to feeding the livestock and poultry (Frame et al. 2007).The first publication on the use of camelina meal for livestock feed was published in 1962 reported that its meal has more proteins than rapeseed and flaxseed (Plessers et al. 1962). A study has been reported on camelina meal usage as a starter diet in turkey production at 5%, 15%, and 20%, a good source of protein, and 5% is recommended for starter diet (Frame et al. 2007). The replacement of soymeal with *C. sativa* in the ruminant (beef steer) diet resulted in a significant decrease in the stress-responsive hormones (Cappellozza et al. 2012). Its meal contains 23–40 glucosinolates μ moles g^{-1} (Singh et al. 2014), 1–6% phytate (Adhikari et al. 2016), and 100–150 g kg^{-1} crude fiber (Kakani et al. 2012). In addition to this, there was no change noticed in the function of the thyroid. However, camelina meal reduced the acute-phase reduction protein reactions, which are normally enhanced during transportation or when animals are subjected to a feed lot setting (Cappellozza et al. 2012). This research is evidence of the positive role of camelina meal in reducing the stress response in cattle. A fat reduction was observed in the cow milk by using camelina meal (2 kg of DM), but it did not reduce the milk yield (Hurtaud and Peyraud 2007). After oil extraction, the by-products of *C. sativa* seeds can be used as a nutritious feed meal with high levels of crude protein (>45%), omega-3 fatty acids (>35%), fiber (10^{-11}), and vitamin E (Meadus et al. 2014) for livestock.

7.17 Biofuel

Total global fossil reserves are 1707 billion barrels, which is an alarming number because it will only be able to fulfill of global supply for 50.6 years (BP 2017). Due to limited resources, conservation of fossil fuels, and climate change, renewable energy sources such as camelina are under the limelight (Sainger et al. 2017). Oilseed feedstocks counting camelina are estimated to contribute 0.5 billion gallons of the 36 billion gallons of conveyance fuel required by the US economy by 2022 (USDA 2010; Mohammed et al. 2017). The worldwide emphasis on energy security accompanied by the determinations to subordinate the greenhouse gas emissions (GHGs) has pushed many governments to begin with inflexible policies on cleaner-energy production, predominantly biofuels' production goals and utilization, joined with continuous efforts that focused on research and progress of bioenergy crops (e.g., Glithero et al. 2012; Radzi and Droege 2014). Past literature indicated that camelina is apt for aviation fuel and biodiesel production (Keshavarz-Afshar and Chen 2015; Yang et al. 2016). Biodiesel production from vegetable oils is an excellent alternative to conventional petroleum-biodiesel due to its remarkable environmentally safe qualities. It has a huge market as it can be used in agricultural machinery, automobiles, power generation, and stationary power sector (Xue et al. 2011; Tabatabaie and Murthy, 2017). Almost 95% of the world's biodiesel is produced from vegetable oils like canola, sunflower, and soybean (Gui et al. 2008). Besides other advantages and use of oilseed crops, they are projected to play a vital part in alleviating greenhouse gas emissions by their capacity to produce biofuel. USDA report has lightened up the potential of camelina to produce biofuel (USDA 2010). The properties (acid value, the lubricity of the oil, permeability at low temperature, kinematic velocity, and acid value) of biodiesel produced by camelina have the same properties of biodiesel produced by soybean (Moser and Vaughn 2010). This shows the potential of high-quality biodiesel production in camelina. Mineral diesel fuel can produce a power of 38.5 kW, which is less than that of camelina (43.5 kW), which is produced by coldly pressed neat oil of camelina seeds. However, mineral diesel fuel has less consumption efficiency as compared to camelina (Bernardo et al. 2003). In the recent few years, the demand for camelina is increasing due to its ability to grow in fewer input requirement, and its oil can be used for a nonfood purpose (Seehuber 1984; Putnam et al. 1993; Mohammad et al. 2018). The fatty acids pattern in camelina is very particular with the characterization of 30%–40% linolenic acid (C18:3), almost 4% of erucic acid, and 15% of eicosenic acid (C20:1) (Budin et al. 1995); this will make it best for the utilization of drying oil which is used to form environment-friendly paints and coatings same as of linseed oil (Zaleckas et al. 2012; Kasetaite et al. 2014). Camelina oil can be used as biodiesel and can also be an alternative to petroleum due to its huge production ability. Its oil can be utilized in different vehicles as biodiesel (Fröhlich and Rice 2005). As camelina is known for its diverse use in industrial products, that makes it a profitable enterprise (Table 7.6).

Table 7.6 Research has been done in different countries to evaluate the uses of camelina oil in different industries and products

Products	Country	References
Chemicals, paints and coatings, resins, adhesives	Poland, USA	Nosal et al. (2015), Kim et al. (2015) and Li et al. (2015)
Cosmetics and soaps	USA	Obour et al. (2015)
Film, fibers, and thermoplastics	China	Reddy et al. (2012)
Bio-Gum	USA	Li et al. (2016)
Bioplastic	USA	Kim et al. (2015)
Cuticular waxes and suberins	USA	Razeq et al. (2014)
Shelf life enhancer	Ireland	Eidhin et al. (2003)
Phytoremediation	India	Tripathi et al. (2016)
Bio-alkyd resin	Poland	Nosal et al. (2015)
Bioadhesive	USA	Kim et al. (2015) and Obour et al. (2015)
Animal feed	Romania, Turkey, Denmark, India	Ponnampalam et al. (2019), Ciurescu et al. (2016), Pekel et al. (2015) and Singh et al. (2014)
Fish	Canada	Bullerwell et al. (2016) and Booman et al. (2014)
Jet fuel	USA, Canada	Drenth et al. (2015), Li and Mupondwa (2014) and Vollmann and Eynck (2015)
Food and supplements	Egypt	Ibrahim and El Habbasha (2015)
Bio-oils	USA, Ireland, Spain	Mohammad et al. (2018), Drenth et al. (2015) and Gómez-Monedero et al. (2015)
Herbicide, fungicide	USA	Cao et al. (2015) and Ma et al. (2015)
Medical use		
Cancers and tumors	USA	Das et al. (2014)
Ulcers	USA	Cuendet et al. (2006)
Cholesterol reduction	Finland	Karvonen et al. (2002)
Neurological abnormalities	USA	Trumbo et al. (2002)
Coronary heart diseases	Turkey	Gogus and Smith (2010)
Burns and inflammations	USA	Sampath (2009)
Antioxidant	Germany	Terpinc et al. (2012)

7.18 Alternative Uses

The *C. sativa* meal is very nutritious and is used as feed for ewe's milk (Salminen et al. 2006), cattle's, hens, turkey's, rabbits, etc. If we want to expand this industry, we must find new alternative uses of camelina meal. There must be strong collaboration among universities, research wing, and stakeholders to find new ways of camelina meal uses as bio-based products like adhesive, coating, and packing materials (Li et al. 2015; Kalita et al. 2018; Liu et al. 2018). The dearth of a marketing system and less productivity when related to several other oilseeds are currently impeding its adoption. The government policy must be clear about the rates and marketing of *C. sativa* and its products. This will boost camelina production. An extended marketing system will be able to improve the cost-effective feasibility of camelina as a profitable oilseed.

7.19 Camelina in the Fallow Season

This crop can be used as a replacement for the fallow season before sowing wheat in the main winter fallow and can also be sown in the wheat summer fallow system (Obour et al. 2015; Berti et al. 2016; Obour et al. 2018). It will be a big success for agronomic assistance; the crop management is comparatively very easy because the insect pest infestation is very low and no extra mechanization is required which will result in high economic yield. Crops that could replace the wheat-summer crop-fallow phase system must have some unique features, including agronomic assistance, companionable with available technology, comparatively easy to handle, lowest disease and invasion, and increasing the final profitability. In the cereal-based cropping system of dryland area, the incorporation of camelina will diversify the cropping system and increase profitability (Johnston et al. 2002). A yield reduction has been reported in wheat yields following camelina in drier years might be due to sustained fallow period (Hess et al. 2011; Sintim et al. 2014).

7.20 Prospects for Future Research

Unfortunately, price and low seed yield contributed to the decline in camelina production acreage (NASS 2015). Camelina is being grown under contracts in Canada, with about half in the province of Saskatchewan (Li and Mupondwa 2014). Because there is no established market for camelina, many economic studies have used canola prices for economic feasibility evaluations (Gesch et al. 2018). Barriers to wide-scale adoption of this crop as feed or feedstock for biofuels include low seed yield, lack of an open market, low price for the seed, perception as a weed by farmers (Jewett 2015), and anti-nutritional aspects in both the meal and oil.

7.20.1 Agronomic Research

The main concern with camelina is that very little effort is being made in technology development and transformation regarding breeding efforts to updated genotypes, the latest and appropriate production systems, and best agronomic practices. In contrast, many trials have been conducted to produce elite germplasm via conventional breeding efforts to improve the potential of *C. sativa* in field conditions. Several efforts should be made to conduct multi-locational experiments to check its response in water shortage conditions, thermal stress, salinity, or heavy metal stress conditions as were being made for canola by Pavlista et al. (2011). Studies must be made on the optimum fertilizer requirements of *C. sativa* on different soils to enhance its productivity and must try to incorporate it into an existing cropping system. Trials must be conducted to investigate weed and disease control. *C. sativa* is reported to be highly susceptible against residual class two herbicide. Nonetheless, efforts were made to address this problem; they transformed it by *Arabidopsis acetolactate* synthase (ALS) engineered with a number of particular changes/mutations in various combinations in the active site of camelina (Ala122Thr, Pro197Ser, and Trp574Leu). The studies on the camelina issue like shattering, harvesting, and postharvest management must be done to improve its response. Most of the oilseed crops are raised in marginal and submarginal lands which are having poor fertility status. So, it's an agronomist's job to convince the farmers and increase the cultivation area on fertile and productive soils. Agronomic research to recognize the appropriate spring and winter genotypes, seeding dates, and soil fertility requirements are desired to optimize the site-specific production technologies for camelina.

7.20.2 Plant Breeding Efforts

Unlike other oilseed crops, there is a minimum number of breeding efforts being made in *C. sativa*. Most of the cultivars being used in the USA are from their native origin, with minimum improvements that were screened and adjusted to regional conditions. If we want to increase the camelina seed yield, oil content, and oil quality, we need to make plant breeding efforts to develop new high potential varieties. These cultivars must have the ability to cope with environmental stresses effectively. The ability to outcross in *C. sativa* is minimal so efforts must be needed to explore this wing (Julié-Galau et al. 2014). The genotypic research in camelina was very limited because of the self-pollinating nature of camelina that makes it a complex process, so biotechnological techniques could give a breakthrough. However, scientists have forged the utilization of an agrobacterium-mediated transformation by spending ex-plants of camelina and floral dip procedure to incorporate bacterial strains in camelina plant. So, we need to use plant breeding approaches to improve the performance of *C. sativa*.

7.21 Climate Change

A growing global population is driving up the demand for food. This challenge is intensified in agriculture by extreme vulnerability to climate change. Climate change noticeably affects crop productivity and global food security by increasing temperatures, atmospheric carbon dioxide and ground-level ozone concentrations, weather variability, shifting agroecosystem boundaries, invasive crops and pests, and more frequent extreme weather events. However, the changing climate is having far-reaching impacts on agricultural production, which are likely to challenge food security in the future. Therefore, extensive actions will be needed for increasing yield and quality food to meet the future demand.

Agriculture is a foremost part of the climate problem (climate change) and also a major source of greenhouse gases (GHGs) which contribute to the greenhouse effect. Agriculture contributes toward climate change through *anthropogenic* GHG emissions and by the conversion of nonagricultural land such as *forests* into agricultural land (Sarkodie et al. 2019). Blanco et al. (2014) estimated that agriculture, forestry, and land-use change contributes 20–25% of global annual emissions. The food system as a whole contributes 37% of total GHG emissions estimated by *European Union's Scientific Advice Mechanism*, and this figure will increase up to 40% by 2050 due to population growth and dietary change (SAPEA 2020). However, crop insecurity will increase over time and with rising GHG emissions. Therefore, climate change will affect in agriculture, and the potential agrobiodiversity can provide resilient solutions in future agriculture.

7.22 Role of Camelina to Mitigate Climate Change Issues

Camelina can endorse biodiversity, decrease soil erosion, improve water infiltration (Gaba et al. 2015; Meyer et al. 2019), and encourage the sustainable intensification of cropping systems (Sindelar et al. 2017; Struik and Kuyper 2017). Mixed or relay cropping with camelina is valuable and widespread organic farming to overcome weed pressure (Leclère et al. 2019).

The production of plant-based liquid fuels has major implications to improve the environment and to mitigate climate change. Camelina is well known as advanced biofuel producer crop. A biofuel qualifies as an "advanced biofuel" if the fuel reduces GHG emissions by at least 50% compared to baseline petroleum fuel (EISA 2007). In 2013, the US Environmental Protection Agency identified the fuel pathways for biofuels produced from camelina oil and stated that camelina biodiesel could qualify as an advanced biofuel (USEPA 2013). It was estimated that use of camelina biodiesel reduces GHG emissions by 69% compared to 2005 baseline diesel (Dangol et al. 2015). Biofuels have the potential to emit less pollution compared with fossil fuels and, if implemented correctly, could help alleviate the rise of CO_2 levels and climate change (Bernardo et al. 2003). It is often reported that oilseed crops are the most efficient and effective biofuel source (Hill et al. 2006). In another study using camelina in place of mineral-diesel to power trucks showed that emissions of carbon monoxide (CO), carbon dioxide (CO_2), and smoke were significantly less from trucks powered by camelina oil (Bernardo et al. 2003).

7.23 Conclusion and Suggestions

The worldwide alimentary-oil requirement is increasing; thus, despite the development of hybrids and cultivars, improvement in production machinery, and technologies of oil-bearing crops, we need to incorporate the novel species in the cropping system that have the unique fat profile as reserve substances. Camelina as an oilseed holds a promise with the ability as the commercial oilseed, animal feed, and other industrial uses. As camelina has important agronomic characters that must highlight its scope as a new addition in a cropping system. BBCH's two- or three-digit coding system that described the phenological growth stages of a crop provides the phenological information and is complemented by depictions of most descriptive stages. Existing approaches for adjusting endogenous lipid profile and oil yield in camelina have a huge success, and it can also offer industrial products derived from it. The abiotic stress tolerance and low-input requirements are novel characters of this crop that makes it best fit in semiarid and arid conditions like Pakistan. The one biggest harmer of camelina adoption is the lack of a proper marketing system and low productivity in competition with other oilseed crops. The economic yield of camelina needs to improve the challenges relating to seed yield and new lipids. Novel approaches are being instigated to understand the intricate metabolic fluctuations over time and space with synthetic biological apparatuses to fine-tune lipid metabolism for explicit requirements. So, there is a dire need to develop a proper marketing system and a government policy for its production. Research on *Camelina* is limited, and its production systems are not being fully optimized. Agronomic research to identify suitable winter and spring *C. sativa* genotypes, seeding dates, and soil fertility requirements are needed to develop site-specific production recommendations for camelina. A prolonged proper marketing system will improve the financial feasibility of camelina as a salable oilseed. The latter will guarantee the grower's adoption of camelina in the semiarid regions due to its desired agronomic features as a dryland crop.

To attain numerous high-valued lipid foodstuffs, it is vital to reform the enzyme with enhanced activities or precise characteristics. Numerous methods can be employed to alter or produce innovative enzymes essential for the specific lipid amalgamation and accretion, together with focused protein alteration and upright-translation amendments. Lastly, modified metabolic paths for elevating innovative and high-esteemed lipids would be shared with additional breeding plans in camelina, for instance, cumulative harvest and seed oil contents and enlightening resistance to numerous environmental stress circumstances.

Conflict of Interest Authors declare that they have no conflict of interest.

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