Camelina sativa: An Emerging Biofuel Crop

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Abstract

In current scenario, the petroleum products should be replaced by renewable plant originated products, but the food crops must be avoided for this. In these lines, *Camelina sativa* L. Crantz is very promising crop; it needs no special fertilizers, herbicides, or pesticides and produces decent amount of biofuel. *C. sativa* contains 30–48% oil and 33–47% protein and adequate micronutrients. With such wholesome composition, it displays varied applications, not only as feed but also for multiple industrial uses. It has compounds of bio-significance like glucosinolates, phenolic compounds, tocopherols, polyunsaturated fatty acids, polysaccharides, and lignans.

In biofuel industries it is utilized as biodiesel, jet fuel, glycerol, and biolubricants. In animal and human system, Camelina oil and seeds have applicability in treatment of burns, inflammations, heart disease, neurological abnormalities, cholesterol reduction, ulcers, and cancer. It is also used as health-promoting supplements. Its application as adhesive, alkyd resins, cosmetic products, soaps, lotions, gum, plastics, and wax manufacturing are many other alternatives to create new dimensions in the pathway of Camelina. In agronomical practices, the deoiled cake of Camelina can be useful as organic fertilizer, pesticide, insecticide, and antifungal agents.

Camelina has high ω-3 fatty acid, which has capacity to be used in therapeutic formulations. It is also rich in antioxidant like α-tocopherol that is responsible to enhance shelf life. With the development of some improved new varieties, Camelina may prove to be a potential crop for future renewable feedstock for biofuel industries.

Keywords

Camelina sativa · Biofuel crop · Antioxidant · Polyphenols · Omega-3-fatty acids

Introduction

Several seed bearing crops like soybean (*Glycine max*), groundnut (*Arachis hypogaea*), mustard *(Brassica spp.)*, Camelina (*Camelina sativa*), etc., are rich source of oil. Some of these varieties are commonly used for edible oil; Camelina is an exception. The “fuel versus food” debate has drawn attention toward the nonfood biodiesel crops which demand less nutrient, water, and land as compare to traditional oil seed crops. Oil from plant origin (generally nonedible type) is being used as an alternative to petroleum products as new renewable industrial products

(Carlsson 2009; Schneider 2006; Wittkop et al. 2009). *C. sativa* from *Brassicaceae* family or mustard family is an example of plant-based renewable oil which not only helps in different industries to produce useful products but is also an environmentally sustainable source of energy. It is known to be economically sustainable, less weather dependent, and requiring less tillage and weed control. It is a short duration biofuel crop having consistent yield (Urbaniak et al. 2008; Krohn and Fripp 2012; Razeq et al. 2014). Furthermore, it has an ability to grow in very poor quality soil, without any expense on herbicides and pesticides (Iskandarov et al. 2014).

Present review covers various aspects of Camelina research including its origin, morphology, cultivational practices, future potential areas, biologically significant compound, nutritional composition, and multiple applications for medicinal, industrial, and agricultural purposes.

Morphological Features, Cultivation, and Yield

Morphological Features of Camelina

Camelina is self-pollinated and autogamous plant (Mulligan 2002). It has shorter root system, a property that makes it suitable for dry land and marginal land cultivation (Putnam et al. 1993). Camelina plant turns woody on maturity and reaches height from 30 to 80 cm (Pavlista et al. 2011). It has arrow-shaped, pointed, smooth edges leaves, with 5–9 cm in length (Hulbert et al. 2005). Camelina has teardrop-shaped pods having small seeds. Generally, 350,000 seeds per pound are produced, but this depends upon growing conditions and the variety which is selected by the grower (Hulbert et al. 2005).

Camelina Plant and Cultivational Practices

Since Camelina has very recently become a crop of significant commercial interest, its agricultural management is still to be developed (Vollmann et al. 2007). In normal conditions, the oil content in Camelina is 30–48% on dry weight basis (Pavlista et al. 2011; Vollmann et al. 2007), which is twice as that of soybean seed oil (18–22%) (Moser 2012).

It can be grown in spring as well as winter climate (Gesch and Cermak 2011). The seeds of Camelina can emerge at 0 °C in controlled environmental conditions (Allen et al. 2014). In comparison to other oil seed crops (flax, rapeseed, and mustard) their seedlings can sustain even lower temperatures like −2 °C (Robinson 1987). This quality makes it suitable to be grown in colder climatic conditions. The germination of Camelina seeds is inhibited or delayed of the early growth development because of high temperature (Zanetti et al. 2013). Camelina also has frost tolerance and winter hardiness as spatial and temporal crop (Russo and Reggiani 2012). During seed development the temperature increase of more than 25 °C may lead to a significant reduction of unsaturated fatty acid content (Zubr and Matthäus 2002;

Gilbertson et al. 2007). If seed bed is prepared with standard agricultural specification, then it displays high germination rate (Schillinger et al. 2012). Adapted to different environmental conditions and with improved traits, lot of varieties of seeds are now available in the market (Berti et al. 2011).

The seed yield and plant establishment depends upon soil preparation, seeding rate, method of planting, and seeding depth (Berti et al. 2011). Camelina crop needs less fertilization to give good yield and can be grown on marginal land (Putnam et al. 1993). In general, 5–7 kg seeds ha^{-1} is enough for good dense stand. However, use of excessive crop residue without appropriate tilling practices can reduce seedling emergence (Enjalbert and Johnson 2011).

For Camelina production (growth, yield, and quality of seed) soil nutrient management is necessary. The key factors that affect cultivation are the type of soil, pre-plant soil fertility, and soil moisture. By prior researches it has been demonstrated that with the increase in input of nitrogen fertilizer, the yield of seed is increased but oil content in the seeds is reduced (Jiang et al. 2014). For this, nitrogen 50–120 kg ha^{-1}, phosphorous 15–30 kg ha^{-1}, and 10–25 kg ha^{-1} sulfur is considered to be adequate (Jiang et al. 2014; Obour et al. 2015). Varying quantities of nitrogen give sufficient yield such as 45–50 kg ha^{-1} (Obour et al. 2015), 120 kg N ha^{-1} (Wysocki et al. 2013), and 185 kg N ha^{-1} (Solis et al. 2013). It has been reported earlier that if nitrogen application increased beyond an optimal dose, it may lead to increased lodging (Berti et al. 2011; Rathke et al. 2006).

Proper crop spacing is an important factor for high yield and better oil content in seed crops. Row spacing should be maintained for better vegetative and productive phases. Prior researchers have standardized row spacing under central western Himalayas of India (Kumari et al. 2012). The harvesting should not be delayed since it can result in pod shattering and can lead to loss of yield (Obour et al. 2015). It is recommended that harvesting be done early as soon as plants achieve physiological maturity or when 50–75% silicles are turned brown in color (Berti et al. 2011).

According to field experiments, the fallow period between two wheat crops in the field may be utilized for Camelina cultivation in semiarid region (Obour et al. 2015). This will help in increasing nutrient cycling with decomposition of soil organic matter (Chen et al. 2015). Being short duration crop of 85–100 days, suitability of Camelina as potential alternative crop to fill abovementioned fallow period is further strengthened (McVay and Lamb 2008).

Crop Pest, Insect, Disease, and Weed Management

Unlike Canola, Camelina is unaffected by flea beetle and bird damage (Pavlista et al. 2011). It demonstrated tolerance against spring freezing and drought conditions in comparison to Canola crop (McVay and Lamb 2008). It was also resistant to insect pests (Iskandarov et al. 2014; Kirkhus et al. 2013). For Camelina crop, quizalofop herbicide is used for weed control (Assure II, Yuma GL) and glyphosate is useful for the preharvest weeds control (Jha and Stougaard 2013). Prior researchers had used treflan and bonanza as pre-plant herbicides to control broad leaf and grassy weed

(Yang et al. 2016). Sethoxydim is the only labeled herbicide available for weed control for this crop and even get control on grass weeds but ineffective on broad leaves (Obour et al. 2015).

A disease Downy Mildew (*Peronospora parasitica*) was detected in Camelina (Séguin-Swartz et al. 2009). Sclerotinia (*Sclerotinia sclerotiorum*) is also found in fields of Camelina, which may reduce yield (Yang et al. 2016).

There is limited information available on application of pre-emergence herbicides (PRE) on weed management of Camelina (Schillinger et al. 2012; Steiner et al. 2006). Therefore, available alternatives of weed management have to apply a labeled broad-spectrum herbicide before sowing or remove the weeds done mechanically in field which is very time-consuming practice (Froment et al. 2006).

Crop Yield

According to United States Department of Agriculture (USDA) and Department of Energy oil seeds are included in the bioenergy crops (USDA). Oil seed accounts for 36 billion gallons biofuel production of which around 0.5 billion gallons is expected to come from these oil seed crops.

Camelina seed yield is around 106–907 L ha^{-1}, which is significantly higher than sunflower (500–750 L ha^{-1}) and soybean (247–562 L ha^{-1}) with similar kind of conditions (Moser and Vaughn 2010).

Cultivation Aspects in Indian Context

In Indian conditions, Camelina seeds produce around 320–480 g kg^{-1} and yield is up to 600–1700 kg ha^{-1} (Kumari et al. 2012). The spacing between the rows significantly impact the yield and oil content of *Camelina sativa* cv. Calena (Kumari et al. 2012). Wider row spacing results in higher flowering (Kumari et al. 2012). It was found that early flowering, pod formation, taller plants, and early physiological maturity were found in wider (35 cm) spacing (Kumari et al. 2012). This may be due to sufficient availability of light (Rana and Pachauri 2001) and soil nutrition (Kumari et al. 2012). Proper row spacing results in efficient translocation, utilization of photosynthetic products, and better availability of nutrients, moisture, light, and space (Kumari et al. 2012).

In Indian tropical climate, period between August to February was suitable for sowing Camelina, while month of October was found the best for optimum seed production. Seed sown in October yields highest 217–218 g m^{-2}, that is, 2171–2180 kg ha^{-1}.

Camelina was grown in field with standardized agronomic factors at Defence Institute of Bio-Energy Research project site biofuel Park at Harsola, Defence Research and Development Organisation (DRDO) India. They intercropped the Camelina with Jatropha plantation. The sowing was carried both in rows and broadcast; on an average 120 plant per m^2 of plot were sown. It took 5–9 days for germination, 35–45 days for flowering, and 55–60 days for fruiting (Parker 2014).

DRDO-DIBER project site Secunderabad, Andhra Pradesh, and Pithoragarh (India) also under took field trials for its agricultural standardization and intercropping with Jatropha crop (Parker 2014). The crop rotations of Camelina with leguminous fodder crops were done. Berseem and Lucerne were rotated with main crop of Camelina. The yield of Camelina seed was recorded improved upto 2000–2200 kg ha^{-1}. The possible reason could be presence of "*Sinorhizobium meliloti*" in root nodules of Lucern, which has ability to fix nitrogen in the soil. In the same way, Berseem if ploughed into the soil will act as green manure to the soil and improve the nitrogen content in the soil part (Parker 2014). With above experimental demonstration of different topographic cultivational practices, Camelina exhibits favorable agronomic and environmental conditions of three different zones of Indian subcontinent as an alternative biofuel crop.

Bioactive Constituents in Camelina

According to earlier researchers, the variation in place and environment not only affects the yield but also made a difference in composition.

Camelina has vast number of neutraceutically important bioactive compounds. Bioactive components like different classes of phenolics, glucosinolates, tocopherols, poly unsaturated fatty acids (PUFA), mono unsaturated fatty acids (MUFA), polysaccharides, and lignans are reported by researchers in Camelina. They display their significance in defense mechanism, reducing risk of cancer, and other vital activity of organisms. In prior researches using soybean crop, the saponin, isoflavone, phenol, and flaonoid content antioxidant activity were explored for health benefits (Chaturvedi et al. 2012, 2014). It was concluded that by utilization of other bioactive compounds present in oil seeds can be helpful in lowering overall bio-fuel cost. The list of some of these bioactive compounds present in Camelina is mentioned below; it can be helpful in lowering overall biofuel cost. These compounds not only improve the health of the consumers but also affect the cost effectiveness of fuel crops. The list of some of these bioactive compounds present in Camelina is mentioned below.

Glucosinolates

Glucosinolates (GSL) are natural pesticides (Fahey et al. 2003; Halkier and Gershenzon 2006). In defatted Camelina seed meal, the glucosinolate content vary in the range of 10–25 μmol/g due to varying growing conditions, genotype, and losses during processing (Berhow et al. 2013). It has both aliphatic and aromatic forms of glucosinolate, and their biological activity is also different.

Camelina seed contains two aliphatic glucosinolates in a significant level; these are glucoarabin (9-(methylsulfinyl)nonylglucosinolate); GSL9 and glucocamelinin (10-(methylsulfinyl) Decylglucosinolate); GSL10 while the third glucosinolate

11-(ethylsulfinyl) undecylglucosynolate); GSL11 is in very small amount (Vaughn and Berhow 2005).

Plants having GSL have myrosinase (this is a group of thiohydrolase enzyme) that can cleave glucose from GSL in the presence of water. After forming an unstable intermediate it converts into thiocynate, isothiocyanate, or nitrile, which helps in plant defense (Spencer and Daxenbichler 1980).

The indolylglucosinolates (in aromatic form) have been reported to promote some cancers, even though they protect against others (Androutsopoulos et al. 2009).

The glucosinolate (in aliphatic form) hydrolysis products are inhibitors of cytochrome P450 which could be cancerous (Skupinska et al. 2009). It has methyl sulfinyl aliphatic which are similar to glucoraphanin the parent glucosinolates to sulforaphane. The methyl sulfinyl aliphatic provides similar health benefits as sulforaphane (it is an anticancerous compound).

Phenolic Compounds

Flavonoids, tannins, chalcones along with coumarins, and phenolic acids are the main class of phenolics and all of these display antioxidant properties. Flavonoids are the important constituent of food and most potent antioxidant derived from plant (Hertog et al. 1992; Jovanovic et al. 1994). Majority of flavonoids are present in Camelina like flavonols, flavanols, flavones, isoflavones, anthrocinins or anthrocynadins, and flavonones.

In the Camelina plants, the presence of phenolics is not uniform at tissue, cellular, and subcellular levels. The phenolic compounds remain attached to cell walls but some of them are in the cytoplasmic vacuoles along with various carbohydrates and organic acids. This makes choosing the extraction method difficult. Methanol mix with water is a good solvent for most of the phenolics. Methanol not only disrupts cell wall but also inhibits the action of enzymes (Obied et al. 2005).

The quantification of phenolics is dependent on its chemical nature, assay method, selection of standards, and the interfering substance present (Naczk and Shahidi 2006). To remove nonphenolic compounds few additional steps are required (Oomah et al. 1995). After solvent extraction, solid phase extraction, and purification process, it was found that the residue or cake has most of the phenolic content (Koski et al. 2003; Terpinc et al. 2012).

Fresh Camelina oil has 123 mg kg^{-1} (expressed as chlorogenic acid) of polar phenolic compounds (Abramovič et al. 2007). The total phenolic contents were highest in Camelina cake extract (1666 ± 40)mg CA 100 g^{-1} (here CA is chlorogenic acid) followed by Camelina seed extract (1536 ± 91)mg CA 100 g^{-1} and very low amount is in crude Camelina oil extract (9.1 ± 0.6)mg CA 100 g^{-1}. This high value of total phenolic was possibly due to high temperature and pressure of water during steaming of seeds which resulted in phenolic acids getting released from its conjugated esters (insoluble forms) attached to cell wall of seeds.

Camelina leaf has quercetin in it (Onyilagha et al. 2003). Camelina cake consists of high quercetin glycosides, which display antioxidant activity (Salminen et al. 2006).

Camelina cake has good amount of catechin, quercetin, quercetin-3-0-glucoside, and rutin. However, they were at low levels in oil part.

Among the phenolic acids, only sinapic acid was transferred to oil in high amount. Salcyclic acid and hydroxyl benzoic acid were in low amount in oil. Protocatechuic acid content was higher in cake as compared to seed probably due to steaming and pressing of seed. Þ-hydroxibenzoic acid and salicylic acid were also very high in cake as compared to seed due to heat treatment (Terpinc et al. 2012).

The ellagic acid content in oil is similar to catechin and salicyclic acid. Moreover, it is higher than in cake because of roasting and processing of the seeds (Peričin et al. 2009; Terpinc et al. 2012).

Most of the antioxidant properties to the scavenging effectiveness of Camelina extract against DPPH radicals are due to phenolic acids, 4-vinyl derivatives, sinapine, ellagic acid, and flavonoids (Hayes et al. 2009; Lue et al. 2010; Terpinc and Abramovič 2010; Terpinc et al. 2011). Camelina cake is found to be the best source of total phenolics and shows highest reducing power and also most effective against DPPH radicals. While Camelina oil has low presence of phenolic compounds, it shows high iron-chelating ability and displays protective action against oxidation of emulsion as demonstrated through β-carotene bleaching test. Camelina cake is not only cheap source for natural polyphenol but also easy and reasonable raw material for food or plasma industries (Terpinc et al. 2012).

Camelina seed has different flavonoids out of which flavonol quercetin is in high amount (Onyilagha et al. 2003). As compared to other vegetables of cruciferous family, the size of bioactive molecules were found to be much larger in Camelina ranging between C_9–C_{11}.

Tocopherols

Camelina shows high tocopherols and phenolic compounds responsible for oxidative stability than other highly unsaturated oils like flax (Hrastar et al. 2009; Peschel et al. 2007). Since Camelina oil is unstable in high temperature, it is advisable to use in cold dishes. Camelina oil-based salad dressing has similar kind of oxidative stability as sunflower oil. This suggestion was on the basis of value of peroxide, þ-anicinidine, total oxidation, conjugated diene levels, and conjugated triene levels (Eidhin and O'Beirne 2010).

The comparative oil stability test conducted among Camelina tuna fish and salmon oil showed that oil from Camelina was more stable at 60 °C for 20 days (Eidhin and O'Beirne 2010). Few researchers observed the improved quality of meat in those birds that used Camelina as food. They found 1.7-fold increases in γ-tocopherols and antioxidant activity in thigh meat, which may be due to tocopherols and other flavonoids supply to the birds through Camelina feed (Aziza et al. 2010b).

The tocopherol content in Camelina seed is 700 mg kg^{-1} (Waraich et al. 2013), in meal it is 200 μg g^{-1} (Aziza et al. 2010a, b; Cherian et al. 2009), and in oil part it is reported 806 ppm–800 mg kg^{-1} (Zubr and Matthäus 2002).

The amount of α-tocopherol in seed oil is 28 mg kg^{-1} (Zubr and Matthäus 2002), in meal 5.2 mg kg^{-1} (Aziza et al. 2010a, b; Cherian et al. 2009), γ-tocopherol in oil 742 mg kg^{-1} (Zubr and Matthäus 2002), in meal 201.7 mg kg^{-1} (Aziza et al. 2010a, b; Cherian et al. 2009), δ-tocopherol 20.47 mg kg^{-1} (Zubr and Matthäus 2002), plastocharomanonol 14.94 mg kg^{-1} (Zubr and Matthäus 2002).

World's majority of population depends on the eggs and meat to fulfill their omega-3 FA and tocopherols level. If Camelina will be used as fodder for poultry, then this will definitely enhance the quality and quantity of these essential FA and ultimately humans will be benefited by this (Cherian 2012).

Poly Unsaturated Fatty Acids (PUFA), Mono Unsaturated Fatty Acids (MUFA), and Saturated Fatty Acids

Camelina oil contains fatty acids, which are poly unsaturated fatty acid (PUFA), mono unsaturated fatty acid (MUFA), and saturated fatty acid. The Camelina oil has almost 90% of unsaturated fatty acids, with 5.8 double bonds per triglycerides (Kim et al. 2015), higher amount of unsaturated fatty acid and degree of unsaturation in comparison to soybean oil. This quality as Camelina oil makes it useful for industrial applications (derivatives of higher functionality for higher performance biopolymers).

Being the structural component of mammalian cell membranes, n-3 and n-6 polyunsaturated fatty acids (PUFA) are essential component of human diet (Vella et al. 2013; Ganesan et al. 2014). Three important n-3 PUFA are eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA), and α-linolenic acid (ALA). Out of these, eicosapentaeoic acid (EPA) and docosahexaenoic acid (DHA) are found in marine sources (fish and algae) (Bermúdez-Aguirre and Barbosa-Cánovas 2011). While third α-linolenic acid (ALA) can be obtained from Camelina. In general, n-3 PUFA is called "good fats" (Table 3). The ratio is 0.90 to 0.70 between ω-6 FA: ω-3 essential FA. ω-3 FAs major portion 29% is of α-linolenic acid (18:3 n-3), while 23% constitute by linoleic acid (18:2 n-6) (Aziza et al. 2010b).

Major MUFA is oleic acid, which is followed by eicosenoic acid (20:1). Palmitoleic (16:1) and erucic acid (22:1, >2%) are also present as MUFAs. The eicosenoic acid is used in making polyamide bioplastic (polyamide-11). Research has revealed that eicosenoic acid (C20:1) is present in Camelina in good amount and has demonstrated unique industrial applications (Zubr and Matthäus 2002). In saturated fatty acids, Camelina meal has palmitic acid (16:0, 9%) and stearic acid (18:0, 2.5%) (Aziza et al. 2010b), which are also very useful compounds.

If 10% Camelina meal is included in chicken feed, there is threefold increase in ω-3 FAs in meat of chicken and eightfold increase in egg of chicken, which will enhance the nutritional value of meat (Aziza et al. 2010b). It is concluded by earlier research that Camelina meal is rich in bioactive compounds, as it is providing ω-3 FAs and simultaneously reducing the oxidative stress (Aziza et al. 2010b).

Polysaccharides (Hydrocolloids)

Like other members of *Brassica* family, Camelina is rich in nonstarch polysaccharides (Budin et al. 1995). Mucilage or hydrocolloids are gums derived from natural resources. It can develop high viscosity in low concentrations. It is used both in food or nonfood industries as thickening agent. In agriculture crops, yellow mustard or flaxseeds also produce gums from coat layers of their seeds (Cui 2000). Being a member of the mustard family, Camelina can also be used as gum.

Camelina gum (CG) contains polysaccharides (75.1%) and protein (12.3%). The polysaccharide part is formed by four monosugars, glactose (58.1%), glucose (25.0%), rhamnose (11.6%), and xylose (5.2%) (Li et al. 2016).

With experiments it was found that at 1% concentration, the viscosity of Camelina gum was more than two times and four times higher than that of commercially available gums such as k-carrageenan and hydroxyethyl cellulose (HEC) (Li et al. 2016). These properties made Camelina as excellent food and industrial thickening agent or stabilizing agent (Li et al. 2016).

Lignans

Cinnamic acid residues or their biogenetic equivalent unite to form lignan and are found in plants. Lignans have their important enantiomers which are same compounds displaying different biological effects. Usually one of the enantiomeric compound is present in certain species (Ayres and Loike 1990). A particular type of enantiomer displays peculiar biological effects, thus it is also important to know enantiomeric composition of lignans in specific food (Smeds et al. 2012).

In earlier studies, the lignans are found in berry and oilseed species (Smeds et al. 2012). In prior researches, it has been proved that lignans are concentrated in hull part of cereal grains, so they investigated the hull portion in oil seeds. The lignin is mainly dependent on genetic and environmental variations. They emphasis the hull part of seeds to be used in diet so that the loss of lignans can be recovered, since oil seed crops are generally used after dehulling practices (Smeds et al. 2007). Therefore, it is recommended to use seed intact along with its hull portion.

In another studies lignin was found to be high in Camelina seeds dominated by (−) lariciresinol (LAR) and (+) Secoisolariciresinol (SECO). In addition, hydroxymatairesinol (HMR) 38 μg 100 g^{-1} and (7S,8R,8’R)-(−)-7-hydroxymatairesinol (major isomer, called HMR2) were also detected (Willför et al. 2003; Smeds et al. 2012). Enantiomeric compositions as analyzed by Smeds et al. (2012) are (−) SYR, (−) MED, (+) PIN, (−) LAR, and (−) SECO (slightly high).

Lignans have wide range of health promoting qualities like anti-tumorigenic, antioxidant, antiviral (Saarinen et al. 2007), anti-obesity, anti-diabetic (Bhathena and Velasquez 2002) effects, and protective in cardiovascular diseases (Vanharanta et al. 1999), and so by utilizing intact seed (without hulling) of Camelina we can enjoy the health benefits of lignans present in seed.

Major Applications of Camelina

In total, 80% of Camelina oil is utilized in health-food products. Approximately, 14% of oil is used in industrial raw materials like cosmetics, detergents, surfactants, emulsifiers, lubricants, fuel, oleo chemicals, plasticizers, and adhesives (Carlsson 2009). Use of Camelina as edible oil is very limited, so it can contribute in fulfilling the oil demand of biofuel (Davis et al. 2011). This crop has unique fatty acid profile; therefore, it has multiple applications in medicinal, agricultural, nutritional, and biofuel industries as demonstrated in (Hulbert et al. 2012) Fig. 1.

As Feed Stock for Biofuels

In Egyptian times, plant originated castor oil was used for cosmetics and illuminations. The unprocessed pure raw seed oil is commonly used in lubricating chainsaws, concrete mould release oils, and lamp illuminations (Zanetti et al. 2013). At present, it has a variety of applications in different industries such as biodiesel, jet fuel, glycerol, and as biolubricants.

Biodiesel

The benefits of using Camelina as biofuel have been explored time to time by many researchers. Camelina proved as a better low cost biodiesel feed stock (Bernardo et al. 2003) due to its lower energy life cycle as compared to canola and soyabean. Camelina can be used as biodiesel additive for improving its characteristics (Reaney et al. 2006; Johnson 2007). After cold pressing and filtration, the oil has improved power output and causes less smoke as compared to petroleum fuel (Wu and Leung 2011). The oil of Camelina generates methyl ester similar to rapeseed that can be used in industries; it also has high iodine content and protects against rapid deterioration of the lubricating oil (Fröhlich and Rice 2005).

The fatty acid profile of a transestrified biodiesel is similar to the fatty acid of parent oil. The physical properties and chemical composition of transestrified biodiesel has to be up to the customer's satisfaction. The pure form of biodiesel (B100) should meet the American society for testing and material standards or ASTM D6751 in North America and EN14214 in European Union specified parameters, then only it can be applied for use in diesel engines (Table 1). The fatty acid composition of parent oil affects the standards of cetane number, kinematic viscosity, distillation temperature, oxidative stability, and cold flow properties (Ciubota-Rosie et al. 2013). The chain length of parent oil fatty acid esters and its degree of unsaturation affects the properties of biodiesel (Knothe 2005). So, it becomes imperative to check the profile of fatty acid.

The low value (from both the standards) of sulfur (S), phosphorus (P), sodium (Na), potassium (K), calcium (Ca), and magnesium (Mg) is good for the fuel quality of biodiesel. Camelina biodiesel's cetane number is 49.7, whichis almost near to both US and European standards but still not up to the mark. Thus, its use as a fuel

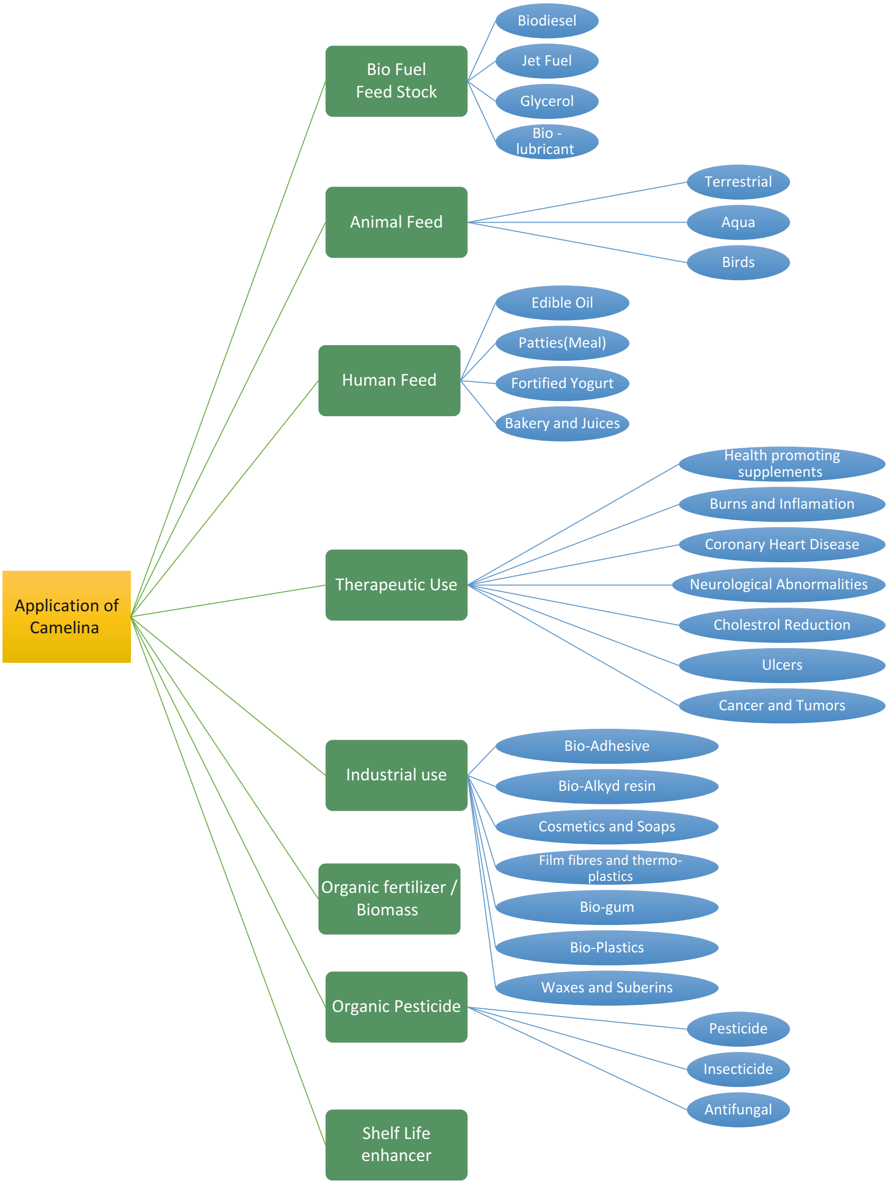

Fig. 1 Various applications of *C. Sativa* (Source: compiled by authors)

during combustion of engine may cause knocking of engine due to incomplete combustion and will produce higher NOx (Yang et al. 2016).

The higher unsaturation degree and its cold soak filtration time is not up to the standards of ASTM D6751 and EN 14214, which could be due to the presence of free steryl glycosides and this may result in cold soak filtration failure. Cost effective

Table 1 Physio-chemical properties and composition of Camelina seed oil suitable for biofuel

References		ASTM D6751-15a	EN14214:2012 + A1						
Physical properties	Units	American standards	European standards	Yang et al. 2016	Nosal et al. 2015	Ciubota-Rosie 2014	Soriano Jr and Narani 2012	Moser 2010	Fröhlich and Rice 2005
Density at 15 °C	Kg/m^3	–	860–900	887.6		888	–	–	882
Kinematic viscosity at 40 °C	Mm^2/s	1.9–6	3.5–5	3.9		4.3	4.32	4.15	6.43
Cetane number	–	≥47	≥51	49.7		42.76	–	52.8	–
Acid number	mgKOH/g	≤0.5	≤0.5	0.25	0.2	0.15	–	0.31	0.33
Iodine value	g12/g	–	≤120	166.2	150	152	–	151	153
Water content	mg/g	–	≤500	427	0.02 wt%	120	–	–	–
Methanol content	Volume%	≤0.2	≤0.2	<0.01		0.01	–	–	≤0.1
Flash point	°C	≥93	≥101	152		152	172	–	–
Cloud point	°C	According to climate zone	–	−1.6		0	2.7	3	3
Oxidative stability, 110 °C	Hour	≥3	≥8	1.9		1.3	0.6	2.5	–
Sulfur content	mg/kg	≤15	≤10	3.6		0.57	5.46	–	–
Phosphorus content	mg/kg	≤10	≤4	<2.0	5.8 ppm	<0.1	–	3	–

Source: Compiled by authors

and convenient method should be developed for the transesterification (alkali-catalysed) of parent oil at farm level. The high level of polyunsaturated fatty acids (lenoleic acid 19.1 wt % and lenolenic acid 33.5 wt (%) will cause poor oxidative stability and lower induction time. For Camelina the induction time is 1.9 h in comparison to 3 h limit by ASTM D6571 standard. Earlier researchers concluded that addition of antioxidants or blend petro-diesel in specific ratio and standardized amount may improve its oxidative stability and induction time (Yang et al. 2016; Liang et al. 2006). Similarly, the other group of researchers suggested that genetic engineering or plant breeding can solve this problem by developing a genetically engineered Camelina crop having less unsaturated fatty acids (Kang et al. 2011).

Jet Fuel

The use of Camelina as jet fuel can reduce the carbon emission up to 84% as compared to petroleum-based jet fuel (Lane 2008). Camelina possesses good biofuel properties, and fuel produced by Camelina has been used in military and commercial aircraft (Winchester et al. 2013; Soriano Jr and Narani 2012; Wu and Leung 2011; Moser and Vaughn 2010).

Hydrogenated renewable jet fuel derived from crop oil is approved by American society for testing and materials standards (ASTM) for use in commercial aviation. Commercial aviation industry of USA sets a target of carbon neutral growth by 2020 and reduction of petroleum generated jet fuel consumption 50% by year 2050 (IATA A 2009). Industrial oil seed crops can be helpful in achieving this goal (Fishel et al. 2011). The cost of feedstock for biofuel can be reduced by using food oil crops and developing low cost for hydrogenated renewable jet fuel production (Johnson 2007).

To develop the cost effective and reliable feedstock for hydrogenated renewable jet fuel (HRJ), proper cropping system along with its suitability with ecoregion, crop yield balance, agricultural input costs, choice of cultivar, and optimum species needs to be considered (Gesch et al. 2015).

In USA the Camelina-based jet fuel is produced by many companies like “Accelergy corp. Attair, Inc.,” “Biojet corp., and sustainable oils, LLC” (Moser and Vaughn 2010). In commercial, military and private aviation flights of USA, Camelina-based jet oil with blending are being tested (http://www.susoils.com/flights.php). This testing not only met all aviation fuel specifications but was successful in both categories of flights. Its application also reduced 75–80% of the carbon emission comparison to petroleum products (Shonnard et al. 2010). This not only provides cleaner environment but also reduces pressure on fossil fuel resources.

Glycerol

The glycerol generated from Camelina can be helpful in many ways due to its nontoxicity and biodegradability as compared to other petroleum sources. In polymer industries, it can be added as stabilizer, plasticizer, and cosolvent in emulsion polymerization. It can also be used as alkyd resins (Güner et al. 2006). Its palmitic and stearic fatty acid esters (mono and di) have been used as emulsifiers in processed foods (Soares et al. 2011).

Glycerol is used in medicinal drugs as nitroglycerin form. Glycerol can form glycerol carbonate, which is an intermediate compound in the chemical synthesis process and useful as gelation agent in polyglycerols formation. Polyglycerols are useful in cosmetics, medicinal applications, and controlled drug release (Behr et al. 2008). In biodiesel production, transesterification of triglycerides with methanol was done to get fatty acid methyl esters (biofuel) and glycerol. In an experimental estimation, 100 kg of biodiesel along with 10 kg of crude glycerol was produced through this process (Soares et al. 2011).

As per another report, the properties of fatty acid methyl ester content in Camelina was compared with the EN 14214 and ASTM D6751 standards (Yang et al. 2016). The methanol content is in accordance with both the standards. The standard value of flash point from both the standards is in the range of 93–101 °C; however, the value of Camelina oil is 152 °C which makes it much safer for transportation and storage point of view. Other important values like density, kinematic viscosity, acid number, water content free glycerol, total glycerol, mono-, di-, and triglyceride content were in compliance with both the standards (ASTM D6751 and EN 14214).

Biolubricants

Mineral oil based lubricants are being replaced by vegetable oil based lubricants. As far as degradability is concerned, petroleum based lubricant leads to carcinogenic toxicity (Dalbey and Biles 2003), while biolubricants are nontoxic and safe for environment (Luna et al. 2011). It also displays the performance benefits like higher flash point, higher detergency, better lubricity, lower volatility, higher viscosity indices, lower compressibility, higher resistance to humidity, higher shear stability, and higher dispersancy (Rani et al. 2015; Cermak et al. 2013). However, they have certain limitations such as feed stock reliability, poor low temperature performance, and low thermal oxidative stability (Soni and Agarwal 2014).

A lot of research has been undertaken to improve these physical properties. The feed stock for developing biolubricants is vegetable oil and mainly triglycerides, esters of glycerol, and three straight chained fatty acids (C12–C24 range fatty acid) (McNutt 2016). Monounsaturated fatty acid like oleic and palmitoleic acid found to have good balance of low melting point with good thermo-oxidative stability and viscosity (Nagendramma and Kaul 2012). Genetically modified varieties of Camelina were used which can alter its seed oil composition (Liu et al. 2015; Gryglewicz et al. 2013). In current researches vegetable oil generated biolubricants were formed by chemical modification with the help of esterification/trans-esterification, estolide formation, and epoxidation methods (McNutt 2016). The Camelina generated biolubricants are good in quality and safe for the environment.

Animal Feed

The Camelina base feed is given to different terrestrial animals, aquatic animals, and birds to improve their general health. It is also helpful in introducing some peculiar health enhancer (like ω-3 fatty acids, antioxidants) to human as they consumed their meat. Previous researchers used Camelina seeds and cakes as feed in terrestrial animals, aquatic animals, and birds.

Terrestrial Animals

Camelina meal is full of mineral content that makes it suitable for animal feed. It has 10,214–12,231 ppm phosphorus, 13,204–14,879 ppm potassium, 2,597–2,703 ppm calcium, 4,696 ppm magnesium, 18.7 ppm chloride, 9,122 ppm sulfur, 15.4–17.6 ppm sodium, 151 ppm iron, 25.1 ppm manganese, 61.1 ppm zinc, 9.18 ppm copper, and 5.37 ppm aluminum (Frame et al. 2007; Cherian et al. 2009). Even Camelina meal can be used as additive for animal feed because it has good amount of protein and omega-3-FA (Ryhänen et al. 2007; Rokka et al. 2002) (Table 2). It is also rich in protein and poly unsaturated fatty acids (PUFAs) (Hurtaud and Peyraud 2007) and can be used in cattle or pig feed (Cappellozza et al. 2012; Ciuca 2013). Camelina meal has high amount of protein and energy, which can be a good source for ruminant feeds (Matthäus and Zubr 2000).

Being a good source of polyphenolic compounds, Camelina meal could be given in the ratio of 1:23 in the diet of dairy cows (275.67 ± 15.19 mg GAE l VS^{-1} 189.37 ± 8.67 mg GAE l VS^{-1}). It was found that polyphenols in plasma of cow fed with Camelina meal was around 12.31 ± 7.17 mg GAE l^{-1} (Chedea et al. 2014).

In dairy cows, this meal can reduce milk fat, resulting in more spreadable butter (Hurtaud and Peyraud 2007). Addition of 10–20% cake of Camelina in the feed of ewes could change the aroma and the content of volatile compounds in milk (Cais-Sokolińska et al. 2013; Szumacher-Strabel et al. 2011).

Few researchers found that Camelina seed is helpful in reducing atherogenic and thrombogenic indexes of rabbit meat (Peiretti et al. 2007). If it is added to rabbit feed (upto 15% addition), it will increase concentration of poly unsaturated fatty acids

Table 2 Proximate composition of Camelina seed cake and defatted cake

References	Bullerwell et al. 2016			Zubr 2010	Cherian et al. 2009	Aziza et al. 2010a, b	Sampath 2009
Composition	Seed	HORM	SECM	Cake	Meal	Meal	Cake
Dry matter %	91.9	89.5	90.8	–	–	–	–
Gross energy kcal/kg	6123	4653	4270	–	4600	4755	–
Ash	3.78	5.89	6.29	–	6.5	6.5	–
Crude Protein%	25.2	35.7	39.0	45	36.2	–	40
Residual oils%	34.6	9.9	2.8	10	–	–	15
Acid detergent fiber %	23.6	18.3	18.0	15	41.8	8.4	12
Glucosinolates (GSLS) and flavonoids%	–	–	–	14	21.2	21.2	–

Source: Compiled by authors
– Not available

and decrease the concentration of saturated FA in the body of rabbits. It was also found that addition of more than 5% of Camelina meal in pig feed can cause reduction in growth and meat palatability (Flachowsky et al. 1997).

Aquatic Animals

Prior researchers included Camelina not only in the form of meal but also used oil and other forms in aquatic animals and ended up with encouraging results. Camelina seeds can produce oil, pressed meal, and solvent extracted Camelina meal (SECM). Camelina seed has 35% α-linolenic acid and 15% linoleic acid as essential FA. To get meal from seed, cold pressing technique is used, which produces press cake. The meal has still some residual oil (approximately 10%), 45% crude protein, and 12.8% of crude fiber. This kind of meal is called "high oil residue meal" (HORM). If this meal is again processed to remove oil by solvent extraction technique, it is called "solvent extracted Camelina meal" (SECM), which has high protein content than HORM (Korsrud et al. 1978).

In earlier research, the effect of Camelina meal and oil as feed for rainbow trout, Atlantic cod has been tested (Betancor et al. 2015; Ye et al. 2016; Hixson et al. 2014a, b; Morais et al. 2012). According to experimental data, the use of fish oil can be replaced with Camelina oil in Atlantic salmon diet, without any impact on weight gain (Hixson et al. 2014a). In prior research, it was found that in rainbow trout if HORM is given up to 160 g/kg, it has no adverse effect on growth performance (Pan et al. 2011). The other group experimented on Atlantic salmon, and they have given SECM at the rate of 50 g kg^{-1} rate. Lower level (50 g kg^{-1} SECM) did not affect fish performance while higher doses (100 g kg^{-1}) did affect the fish health (Ye et al. 2016). Some scientists performed 112 days trial on rainbow trout and found that 100 g kg^{-1} Camelina seed, HORM, or SECM in the diet does not affect negatively on the performance of fish, while the obtained fish meat is having better nutrition as compared to fish feed with conventional feed (Bullerwell et al. 2016). Hence, it is clear that Camelina products as diet are suitable. HORM, SECM, and seed has good amount of micronutrient (Bullerwell et al. 2016).

The metabolic or protective function in plant may be due to presence of anti-nutritive factors (ANF) but may impair the nutritive value (Blades and Zubr 2010; Matthäus and Zubr 2000).

Birds

Camelina meal is rich source of both protein and ω-3 FA, so it is a very good food supplement for birds. Cake or meal is utilized in poultry (Rokka et al. 2002). It is also being given to young turkey (Frame et al. 2007) and layer birds (Cherian et al. 2009).

Camelina oil mixed with chicken feed increases n-3 (omega-3) content in the egg without any unpleasant flavor (Rokka et al. 2002). If meal is added to broiler chicken feed, it may reduce feed intake and growth of chickens, but it improves ω-3-fatty acids which is indirectly beneficial for human nutrition when they consume them (Ryhänen et al. 2007). Few researchers found that if more than 5% meal of Camelina is used as feed, then the weight of young turkey will decrease (Frame et al. 2007). In another research, the layer birds feeding higher level of energy, protein, essential ω-3

Table 3 Camelina seed oil fatty acid composition reported in different countries

Fatty acids composition (%)	Myristic C14:0	Palmitic C16:0	Palmitoleic C16:1	Stearic C18:0	Oleic C18:1	Linoleic C18:2	Linolenic C18:3	Arachidic C20:0	Gandoleic C20:1	Eicosadienoic C20:2	Eicosatrienoic C20:3 acid	Arachidonic C20:4	Behanic C22:0	Erucic C22:1	Clupanodinic C22:2	Docosatrienoic C22:3	Docosahexaenoic C22:6	LignocericC24:0	Nervonic C24:1	Location
References																				
Marquard and Kuhlmann 1986		–		–	15	15.2	37		–	16				3						Europe
Budin et al. 1995		–		–	14–20	19–24	27–35		–	12–15				0–4						USA
Rode 2002		6		3	16.27	18.7	33		–	16				3						Slovenia
Zubr and Matthäus 2002		6.5		2.3	16.2	18.1	39		–	13.2				2.6						Germany
Fröhlich and Rice 2005	–	5.4	–	2.6	14.3	14.3	38.4	0.25	16.8	–	–	–	1.4	2.9	–	–	–	–	–	Ireland
Gugel and Falk 2006		5.3–8		–	13–17	15–19.2	34–40		–	13–16				2.4–4						Canada
Vollmann et al. 2007		–		–	14.5–19.7	16.9–19.6	32.6–38.2		12.4–16.2	–				–						Austria
Urbaniak et al. 2008a, b		–		1.4–3	13–16	15.4–21	31–37.2		–	14–16				3–4.4						Canada
Hrastar et al. 2011	–	5.7	–	3.37	15.01	18.48	34.72	1.83	12.71	1.48	1.05	–	0.37	3.24	–	–	–	–	0.64	Slovenia
Moser 2010	0.1	6.8	–	2.7	18.6	19.6	32.6	1.2	12.4	1.3	0.8	–	–	2.3	–	–	–	–	–	USA
Imbrea et al. 2011		6.51		2.5	–	21	35.58		–	–				–						Romania
Wu and Leung 2011	0.2	5.1	0.3	2.4	17.6	18.7	28.6	1.8	11.9	1.9	–	–	0.8	4.2	0.4	–	–	–	–	China
Waraich et al. 2013					15.0	15.0–25.0	30.0–40.0			15.0										Italy
Ciubota-Rosie 2014	0.05	5.16	0.04	2.68	15.21	17.9	34.64	1.44	15.14	2.17	–	1.47	0.3	2.57	–	–	0.62	0.14	–	Spain
Nosal et al. 2015				2.31	14.44	16.52	35.22	1.50	18.76											Poland
Yang et al. 2016	0.1	5.5	0.1	2.4	14.4	19.1	33.5	1.5	15	2.2	–	1.4	0.3	3.1	0.2	0.4	–	0.2	0.6	Canada

Source: Compiled by authors

FA, and n-6 FA was found in the meal of Camelina. But more than 10% can adversely affect the health of birds (Cherian et al. 2009).

Human Feed

Using Camelina as animal feed encouraged researchers to use them as human feed. As already proved that Camelina oil is a rich source of essential FA (linoleic and α-linolenic acids) as well as ω-3 FA (α-linolenic) (Hrastar et al. 2009; Zubr and Matthäus 2002) (Table 3). There are many varied ways to consume this nutrient rich meal and from last few decades, research is going well on this aspect. They utilized it in direct or indirect form of diet.

In Form of Edible Oil

Camelina oil can be promoted in the form of dietary supplement in human and animal nutrition (Obour et al. 2015). The crushed form of Camelina seeds was used as one of the ingredients in forming bread (Zubr and Matthäus 2002). The cultivation conditions (genotype, location, fertilizer, and environmental conditions) affect the profile of Camelina fatty acids (Jiang et al. 2014). This Camelina oil after purification can be used in different cooking process as cooking medium or as additives, while high erucic acid limits its use (Zubr 1997).

Camelina Meal as Patties

Camelina meal is nutritionally very good as it has high ω-3-fatty acid (>35%), vitamin E content, crude protein (>45%), and fiber content (10–11) (Meadus et al. 2014). Some researchers used the protein, lipid, and antioxidant high meal to prepare pork meat patties (Salminen et al. 2006). This form of preparation can be easily accepted by consumers, and they are benefited with its high nutritional qualities.

Camelina Oil in Fortified Yogurt Form

Our daily diet contains naturally bioactive compounds but fortified food is also available in market. In human diet, n-3 and n-6 polyunsaturated fatty acids are very important component. These "healthful fats" are helpful in maintaining normal health of humans.

The recommended basic requirement of PUFA (ALA, EPA, and DHA) in human body is 250 mg by European council, 2006, while 2 g dose was recommended by European Union 2012 (European council regulation no. 432/2012). Globally, present intake of ω-3 PUFA is not sufficient (Sioen et al. 2009).

Marine sources for n-3 PUFA have fishy flavor which limits its use in food, so the vegetable sources were accepted for food fortification (Dal Bello et al. 2015). Vegetable sources as explored by many researchers are flaxseed, soybean, kiwi, rapeseed, echium, raspberry, and Camelina (Botelho et al. 2013; Waraich et al. 2013; Ganesan et al. 2014).

Bello et al. (2015) used five different vegetable oils and fortified with skim milk before lactic acid fermentation at 10% of daily recommendation 2 g day^{-1} of α-lenolenic acid according to European council regulations that is around 200 mg of 125 g per serving size (Dal Bello et al. 2015). To prevent oil from rising to the surface, the modified vegetable originated starch Novation indulge 1720 (Prodotti Gianni S.p.A, Milan, Italy) was mixed with oil before adding it to milk. The milk was slightly heated (5 min at 60 °C and cooled to 42 °C) and starter is added to it. The starter is cultures of *Lactobacillus delbruccki* ssp. *Bulgaricus* and *Streptococcus thermophilus* (LYOFAST Y450B, Clerici-Sacco, Milan, Italy). The microbiological, chemical, and sensory evaluation was done of fortified yogurt after 0, 7, 14, and 21 days of storage at 4 °C.

The oil content addition does not affect the growth of lactic acid bacteria, and all yogurts were accepted by consumers except raspberry and E-plantagineum oil. Many of the yogurts were sensorially appreciated specially when fortification was done with the oil of flaxseeds and Camelina seeds. So by this α-linolenic acid with significantly higher amount is provided with natural fortification in a yogurt form (Dal Bello et al. 2015).

Bakery Products and Juices

The ω-3 PUFA benefits (Welch et al. 2010) can be used in infant formula, some dairy meat (Özer and Kirmaci 2010; Escobar et al. 2011), and bakery products, and juices (Ganesan et al. 2014) have been used as vehicles for EPA and DHA fortification. These fortified backery items and dairy meat products are easily accepted by consumers and simultaneously enjoy the benefits of nutrients.

Medicinal Therapeutic Applications

Health Promoting Supplements

As earlier mentioned, Camelina cake contains a good amount of bioactive compounds such as glucosinolates, vitamins, and antioxidants (Matthäus 2002; Eidhin et al. 2003). α-linoleic acid substrate is helpful in human metabolism. By including Camelina oil in diet, the n-6/n-3 fatty acid proportion improves in food. It has high α-linoleic acid, tocopherols, and antioxidants contents (Simopoulos 1999). It helps to improve general health (Rokka et al. 2002; Lu and Kang 2008). Lignans present in Camelina has antioxidant and antiviral properties (Saarinen et al. 2007). It also displays antidiabeteic and antiobesity qualities (Bhathena and Velasquez 2002).

Camelina extract has natural phenolic compounds and have antioxidant activity (Matthäus 2002; Zubr and Matthäus 2002). Camelina oil contains 760 mg tocopherols kg^{-1} of oil (Abramovič et al. 2007). Tocopherols not only act as natural antioxidants but also provide oxidative stability to the oil.

Cake of Camelina seed contains many phenolic compounds, which showed antioxidant activity like tocopherols, sinapine, and sinapic acid (Salminen et al. 2006). Flavanols and flavonols both are also responsible for antioxidant activity (Salminen and Heinonen 2008).

Ellagic acid (a polyphenol with four OH groups) is also an important antioxidant showing high radical scavenging activity (Hayes et al. 2009; Terpinc et al. 2012).

A major phenolic ester sinapine (sinapoylcholine) can be derived from sinapic acid (Matthäs 1997; Thiyam et al. 2004). Sinapine found in Camelina cake is one of the effective antioxidant (Matthäus and Zubr 2000; Salminen et al. 2006). Camelina has another kind of phenolic compound 4-vinyl derivatives of hydroxycinnamicacid; it is formed by enzymatic or thermal decarboxylation (Vanbeneden et al. 2008). 4-vinyl derivatives contain antioxidant properties; it reduces 2, 2-diphenyl-1-picrylhydrazyl (DPPH) radicals and the superoxide anion radicals (Terpinc et al. 2011). These four vinyl derivatives were lowest in oil, lesser in cake than its defatted seeds. This may be due to the steaming and crushing of seeds where highly volatile nature of these compounds gets lost (Terpinc et al. 2011).

Burns and Inflammations

Camelina oil is also helpful in treatment of burns, wounds, and eye inflammations, and it is applied topically (Rode 2002). It has anti-inflammatory properties (Sampath 2009). It can be used as remedy for the treatment of burns, wounds, and eye inflammations. Camelina oil also helps in regeneration of cells, recovery of skin elasticity, and slenderness, and so improves skin condition (Vollmann et al. 1996). In Slovenia, Camelina oil is used as traditional home remedy (Rode 2002). In USA, this oil is used in cosmetics and in biofuel industries. Camelina oil has not yet GRAS status, but in France and UK and Denmark it has legal food status (Sampath 2009).

Coronary Heart Diseases

Camelina oil is also very helpful in preventing coronary heart disease, arrhythmias, and thrombosis (Trumbo et al. 2002). In general, n-3 PUFA are called "healthful fats." They are helpful in maintaining normal blood pressure, levels of triglycerides in blood, reduces the risk of cardiovascular diseases, protects in some cancers and tumors, also good for brain, nervous system, and retina of eye (Harris et al. 2008; Gogus and Smith 2010). Some lignans may also have protective ability for cardiovascular diseases (Willför et al. 2003).

Neurological Abnormalities

Deficiency of α linoleic acid results in neurological abnormalities and poor growth. To cure this deficiency Camelina oil can be added to the diet that will make available α linoleic acid (ALA), eicosapentaenoic acid (EPA), and docosahexanoic acid (DHA) components (Trumbo et al. 2002). By adding Camelina in diet, one can reduce the risk of poor growth and abnormalities.

Cholesterol Reduction

Camelina has cholesterol reducing effect on mildly and moderately hyper-cholesteromic subjects (Karvonen et al. 2002). It is therefore advisable to add Camelina in any acceptable form to the daily diet of hypercholestromic patients.

Ulcers

In traditional home treatments, Camelina oil is useful in the treatment of stomach and duodenal ulcers (Rode 2002). Following previous work it was found that sulforaphane and other hydrolysis products may have multiple sites of action, upregulation of the phase II detoxification enzyme NAD(P)-H: quinoneoxidoreductase 1 (NQ01) is often used as a biomarker of beneficial bioactivity (Cuendet et al. 2006). Oil of Camelina gives soothing effect to the ulcer patients.

Cancers and Tumors

Lignans are antitumorigenic (Willför et al. 2003). Some researchers concluded that the consumption of isothiocyanaes showed chemoprotective activity if consumed by mammals (Jeffery and Araya 2009). It not only acts against tumor initiation but also helps in steroid hormone metabolism modification. Isothiocyanate ingestion induces detoxification enzymes, inhibits enzyme activation, and by these overall helps in improvement of consumers defense system.

The aliphatic glucosinolates hydrolysis products behave as inhibitors of cytochrome P450 activation of carcinogens (Skupinska et al. 2009). The form of glucosinolates in Camelina is methyl sulfinyl aliphatic which are similar to glucoraphanin the parent glucosinolates to sulforaphane. This methyl sulfinyl aliphatic provides similar health benefits as sulforaphane (anticarcinogenic).

In same lines, other researchers added aliphatic glucosinolate hydrolysis products along with NQ01 were associated with upregulation of anti-inflammatory, antioxidant, and anticarcinogenic effects (Androutsopoulos et al. 2009). Following research evaluated induction of phase I and phase II detoxification enzymes, cytochrome P450 1A1 (CYP 1A1) and NAD(P)-H:quinine oxidoreductase1 (NQ01) as biomarkers of potential bioactivity (Das et al. 2014). They also found the impact of glucosinolate 9 and 10, quercetin, and rutin in Camelina seed and defatted meal extract (Das et al. 2014). The role of various bioactive components like rutin, catechin, quercetin, and flavonoids are natural powerful antimicrobial, antimutagenic, anticarcinogenic, and antioxidant (Rice-Evans et al. 1997); since Camelina is rich in these bioactive compounds it may help in reducing the number of cancer sufferers.

Industrial Use

There is huge possibility to use Camelina oil in manufacturing of many bio-based products. Since the oil has about 90% of unsaturated FA, it contributes in quick drying, thus useful in making polymers, paints, varnishes, cosmetics, and dermatological products (Kasetaite et al. 2014; Hixson et al. 2013; Merrien et al. 2012; Zaleckas et al. 2012). It can also be used in many other industries like lubricants, resins, coatings, and adhesives (Obour et al. 2015). Researchers optimized the method of epoxidation by formic acid and hydrogen peroxide for Camelina oil, which have the potential to be used in biopolymer industry to produce pressure sensitive adhesives, resins, and coatings (Obour et al. 2015; Kim and Netravali 2012; Kim et al. 2015).

Bioadhesive

It is reported that the amino acid profile of Camelina protein is similar with canola protein. This was already reported that canola protein has a potential to be replace the conventional petroleum based adhesives (Li et al. 2011, 2014). Likewise soybean also shows promising bio-based adhesive source (Qi et al. 2012; Qi and Sun 2011), but since soybean has been used for human food consumption. Alternatives like Camelina should be explored as bioadhesives (Li et al. 2015). It was reported that albumin, globulin, and gluteline are three fractions of protein from meal of Camelina (Li et al. 2014). To test the adhesive quality water solubility, protein electrophoresis profile, crystallization, thermal, morphological and rhenological properties were examined. Since, albumin has strong water swallowing properties it has poor ability as adhesive (Li et al. 2015). The adhesive strength of Camelina protein fractions were isolated from defatted Camelina meal were studied and they are globulin and glutelins. The results showed that overall adhesive strength of globulin is better than glutelin fraction. He also found that glutelin had higher protein aggregation than globulin. Due to glutelins compact structure the properties of adhesion is lower than globulin (Li et al. 2015). Pressure sensitive adhesives could be useful in many applications like graphics, medical supplies, tapes, and labels (Tse and Jacob 1996; Satas 1989).

The majority of pressure sensitive adhesives, which are useful in forming adhesion joints, are being manufactured by petroleum based acrylated monomers (Li et al. 2014, 2015; Czech 2007). The oleo chemicals and biopolymers are also used for adhesion which was derived from oil of Camelina (Kim et al. 2015).

Acryicpolyol has both vinyl group and multihydroxyl functionalities; Camelina oil can synthesize acrylic polyol with some reaction steps like epoxidation, partial acrylation, and dihydroxyletion of remaining epoxy group (Kim et al. 2015). In these steps, various intermediates were formed like epoxidized Camelina oil (ECO), acrylated epoxidized Camelina oil (AECO), and dihydroxyl acrylated epoxidized Camelina oil (DAEO), which is an acrylic polyol. Acryl polyol offers good polar attraction to substrate when used as pressure sensitive adhesives. Addition of a moderate amount of rosin ester reduces adhesive plateau modulus and energy dissipation while maintaining high cohesive strength. This will convert PSAs with good peel, tack, and shear performance (Kim et al. 2015).

Bio Alkyd Resin

In paint industries, a commercial polymer alkyd resins is used and it is useful in metal, wood or wood based materials, cement, and gypsum plasters. The soybean oil and linseed oils and synthetic pentaerythriol and pthalic anhydride were used as raw material in the preparation of alkyd resins. These synthetic compounds (pentaerythriol and pthalic acids) were toxic for the environment (Gandini 2011). For future production of alkyd resins, the fatty acid raw material should be in large amount and it should not be in direct competition with our food crops. Camelina is appropriate for such type of selection (Nosal et al. 2015). The number and distribution of hydroxyl groups in polyols are important for its drying properties. Therefore, resins produced from pentaerythriol showed better coating than glycerol. Pentaerythritol dry out faster, turnout harder, and more resistant toward moisture (Erhan 2005). The glycerol is not only easily renewable raw material but also economical cheap so more commonly used for coating raw matter (Tuck 2000).

In some researches, they have developed one pot synthesis of alkyd resin by Camelina oil (Nosal et al. 2015). In the presence of LiOH (0.1 wt%) at 245 °C temperature, the oligomerization of glycerol was done. This oligomerized product was alcoholized with purified Camelina oil. This alcoholysis product was again gone through polycondensation with pthalic and malic anhydrides at 230–250 °C temperature and form alkyd resin (Nosal et al. 2015).

Nowadays, we try to reduce the edible oil which is generally consumed in industrial purposes and they have lower unsaturated fatty acid than in normal oils. As comparison to other oil seed crops, Camelina oil has high iodine number and is suitable for drying oils for producing paints.

The key parameters of prepared resins indicate that Camelina oil proves to be very promising raw material. Alkyd resin can be produced from diglycerol and polyglycerols with some properties like flexibility and drying time similar to the product from pentaerythriol. The varnish films formulated from alkyd resin based on penetration by scratching than those based on diglycerol and far better than poly glycerols. The resin formed with pentaerythritol also has better hardness than glycerol and poly glycerols (Nosal et al. 2015).

Cosmetics and Soaps

Oil of Camelina is very useful in the small scale industries like soaps and cosmatics. In USA, small businesses like Manor hall soap company springfield; Siberian Tiger Naturals Inc. Seattle, etc., make soaps for smaller markets. Some cosmetics like lotions and creams are also manufactured with Camelina oil (Obour et al. 2015; Bernardo et al. 2003). There is a group of people who prefer vegetable oil in their cosmetics (herbal cosmatics), so for them these Camelina based products is preferable.

Film, Fibers, and Thermoplastics

Camelina oil seed could be used for films, fibers, and thermoplastics when grafted with various acrylates. For this application, optimization to increase its tensile properties should be done (Reddy et al. 2012). Researchers have been done to improve its tensile qualities and applications in manufacturing of fibers, films, and other useful products.

Bio-Gum

Hydrocolloids (polysaccharides) are used in industries as thickening agents, swelling agents, emulsify agent, crystal inhibitors, foam stabilizers, gelling agents, and water bonding agents (Walter 1997). These are also known as natural gums. Camelina seed is also one of the natural resource for making these gums. Camelina meal showed distinct quality of binding in water (Taasevigen 2010). Soil exposure and erosion can be amended with the Camelina gum during construction works (Grady and Nleya 2010).

During their extensive research on Camelina gum, it was found that the physiochemical and rheological properties are mostly similar to hydrocolloids (Li et al. 2016). Camelina gum has thinning behavior which may be due to six mono sugars, high viscosity, storage modulus, pH, and temperature tolerance.

This could be due to linear molecular structure. Camelina displayed superior rheological behavior when compared with commercial gums such as hydroxyethylcellulose (HEC) and k-carrageenan. These properties are useful in thickening agent, suspending agent, and emulsification agent in food and nonfood industries (Li et al. 2016).

Bioplastic

Camelina is rich source of uncommon fatty acid eicosenoic acid used in making poly amide-11 a form of bioplastic (Zubr and Matthäus 2002; Zanetti et al. 2013). Researchers have isolated protein fractions from Camelina meal (Li and Sun 2014). They tried to develop biodegradable plastics and composites from meal of Camelina (Kim and Netravali 2012; Reddy et al. 2012). Still there is a dearth of techniques to produce high-value chemicals and polymers from oil of Camelina (Balanuca et al. 2014; Kasetaite et al. 2014; Kim et al. 2015).

Cuticular Waxes and Suberins

Plant waxes have aliphatic and phenolic based barriers which protect them against environmental interfaces like water loss and various stresses. The aerial surfaces of plant are coated with cuticle which is made from cutin and waxes (Samuels et al. 2008). The cutin polymer forms structural backbone of cuticle. Cutin is formed of glycerol and long-chained (C16–C18) fatty acid derivatives and covers the cell wall of plant. The cuticular waxes are mixtures of low polarity compounds, including very long chain ($\geq$C20) straight chain aliphatics, triterpinoids, and phenolic lipids (von Wettstein-Knowles 2012). Cuticular waxes limit nonstomatal water loss (Vogg et al. 2004). Epicuticular waxes are in direct contact with the environment; they work on insect, pathogen interaction, and also help on dust water and spores shedding (Kerstiens 1996). The composition of cuticular waxes varies between species, organs of the same plant, development stages, and environmental condition (Jetter et al. 2008).

Suberin is also a hydrophobic surface barrier; it is polyester of glycerol, phenolic, and fatty acid derivatives (Franke and Schreiber 2007). It is found in cell walls inner surface (endodermis and peridermis) called root waxes (Kosma et al. 2012; Li et al. 2007).

In Camelina, these surface waxes make tolerance to abiotic and biotic stresses (Razeq et al. 2014). The wax mixture obtained from stem, leaves, flowers, seeds, and root part gives qualitative and quantitative information of Camelina boundary tissues wax. This work also made the understanding about wax biosynthetic pathways in every organ of plant. The knowledge of Camelina wax protective surface, drought tolerance, and pathogen-resistant properties will help to make renewable high value natural products of industrial utility (Razeq et al. 2014).

Organic Fertilizer

Oil cakes of different plants have been utilized as compost for years and increased yield is reported for crops like pongamia for tomato crop (Chaturvedi et al. 2013) and jatropha compost for tomato crop (Chaturvedi et al. 2009, 2010, 2013; Chaturvedi 2011; Chaturvedi and Kumar 2012). Camelina cake having high protein content may be used in animal feed and as fertilizer. With new researches this cake is also utilized in the production of industrial enzymes, antibiotics, biopesticides, vitamins, and other biochemicals (Ramachandran et al. 2007).

Pesticide or Insecticide and Antifungal Activities

Camelina can be used as potent antifungal, pesticidal, or insecticide in the field crops. When Camelina meal is applied at 5% and 1% to soil, it suppresses the *Phymatotrichopsis omnivore* (Duggar) sclerotial germination and hyphal growth of fungi (Hu et al. 2011). This fungus causes cotton root rot to the cotton and Alfalfa production; by using Camelina meal one can protect fungal attack (Hu et al. 2011).

GSLs are secondary metabolites and act as natural pesticides and prevent herbivory (Fahey et al. 2003; Halkier and Gershenzon 2006). GSL in the presence of water after an unstable intermediate formation converts into thiocynate, isothiocyanate, or nitrile. These compounds help in defense of plant (Spencer and Daxenbichler 1980).

Shelf Life Enhancer

The oil extracted by mechanically pressed Camelina seed called virgin, crude, or unrefined oil. It has mustard like odor with mild nutty notes and golden yellow in color. This crude oil showed 12–24 months shelf life without change in flavor and aroma under normal environmental conditions of storage (Crowley and Fröhlich 1998). The oil can get degraded by light rather than temperature (Abramovic and Abram 2005).

This unrefined Camelina oil has a natural antioxidant (Tocopherols) in it which makes it stable in ambient storage conditions (Sampath 2009). Among tocopherol, the γ-tocopherol (vitamin E) is responsible for good shelf life and it does not need special storage conditions (Zubr and Matthäus 2002).

Oil having high omega-3-FA shows low shelf life (Eidhin et al. 2003). Camelina has very high omega-3-fatty acid so its oxidative stability could be also low. But it was observed that Camelina displayed longer shelf life than similar oils. In conditions of room temperature, it has higher stability than fish oil (Eidhin et al. 2003). This quality will be used both for meal and oil during storage transportation (Brandess 2007).

Phytoremediation

Bioenergy crops can be used for phytoremediation activity for polluted lands. Apart from application in cleaning-up process, several end products can be obtained like charcoal, biodiesel, bioethanol, wood, alkaloids, fiber, bioplastics, etc. (Tripathi et al. 2016). Utilizing polluted and abandoned land for the production of bioenergy with phytoremediation is getting attention globally (Abhilash et al. 2013). The growth of the crop or production will be hampered due to several pollutants toxicity (like metal, metalloids, persistent organic pollutants, petroleum hydrocarbons, organo phosphorus pesticides, carbamate insecticides, herbicides, radio nuclides, nano-particles, and other new and emerging pollutants).

To overcome this problem, appropriate crop species and agronomical practices must be optimized (Tripathi et al. 2016). The photoproducts generated at the end may have pollutants, so it is a kind of challenge to research on these aspects (Abhilash et al. 2013). Camelina can phytoremediate cadmium (Cd) and atrazine along with biofuel production (Fairley 2011; Graham-Rowe 2011).

Reasons for Low Acceptability by the Growers

Despite its several applications, Camelina has some constraints which affect its production and economic viability. The initial problem is with its cultivation. Farmers' faces lack of information regarding specification of genotype recommendations in particular type of climate (winter or spring). There is less awareness about best agronomic practices in cultivation (Obour et al. 2015). At existing production cost and lack of markets, Camelina is a less profitable crop. Harvesting and post-harvesting losses also makes it less beneficial as oil seed crop (Obour et al. 2015). Shattering and uneven maturation causes loss in yield (McVay and Lamb 2008; Lenssen et al. 2012). Downy mildew infestation causes lesser outcome of seeds (Obour et al. 2015). Consequently, farmers face loss by cultivating Camelina in fields leading to less preferable crop.

Another problem arises with its compositional aspect that is antinutrient. Camelina meal contains erucic acid, sinapine, and glucosinolates as antinutrient which may be harmful for human health. In Camelina, the amount of tannins are 2.2 mg g^{-1} and 2–4 mg kg^{-1} sinapine (Meadus et al. 2014; Matthäs 1997). The presence of phytic acid in Camelina causes poor bioavailability of minerals and proteins (19 mg g^{-1}) (Matthäs 1997). The effect of glucosinolates (19–25 mmol kg^{-1}) causes impairment of growth and fertility, irritation of gastro-intestinal mucosa, followed by necrosis in livestock (Meadus et al. 2014; Russo and Reggiani 2012; Matthäs 1997). The erucic acid 2.4–5% can cause fat deposits in heart muscle and myocardial lesions in experimental animals (Pavlista et al. 2011; Zubr and Matthäus 2002). According to some research, Camelina has some properties like unusual fatty acid profile, high α-linoleic acid, low erucic acid, unusually high cholesterol content (45 mg 100 g^{-1} of oil) which makes it unpopular as oil (Matthaus 2004).

Camelina based bioindustries face major challenge as its processing is relatively high cost and also due to lack of known effective techniques for the meal and oil conversion into high value biobased products (Kim et al. 2015).

Potential for Future

There are many reasons for this crop to be grown in future as it is exceptionally rich in essential fatty acid, qualitatively high polyunsaturated FA as compared to other vegetable oil (Abramovic and Abram 2005; Angelini et al. 1997; Goffman et al. 1999), and high α-linolenic acid (n-3) that can be used as food additive.

Future research prospects for Camelina are several. There is need to develop production recommendations for Camelina as fallow replacement crop in non-irrigated cropping systems. Its nitrogen and sulfur fertility requirements are to be standardized (Obour et al. 2015). The difficulty of postharvest management, seed shattering, and harvesting should be more explored. Postemergence broadleaf weeds control and downy mildew control should be researched (Obour et al. 2015). High yielding Camelina cultivars, high oil content desired fatty acid composition, improved cetane value and quality with regional environmental adaptation (like less sensitive toward heat stress) will be developed through plant breeding researches (Obour et al. 2015). Recommendations for alternative uses of meal and oil to develop bio-based useful products will create ready markets for growers of Camelina (Obour et al. 2015).

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