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Camelina sativa, a climate proof crop, has high nutritive value and multiple-uses: a review

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Abstract

Camelina sativa is an oilseed crop that is currently being commercially produced in the USA as a feedstock for biodiesel. It is also known as gold of pleasure and false flax. Seeds and the fruit (siliculas) of *Camelina sativa* ssp. C. *linicola* (Schimp. and Spenn.), have been found in archaeological excavations from the Bronze Age in Scandinavia and Western Europe. In Russia and European countries Camelina was grown as an agricultural crop before the Second World War and up to the nineteen fifties. It holds promise as a source of human food and animal feed products. The renewed focus on this crop is mainly due to search for the new sources of essential fatty acids, particularly *n-3*(omega-3) fatty acids. The seed of Camelina can contain more than 40 % oil, 90 % of which is made up of unsaturated fatty acids, including a 30–40% fraction of alpha linolenic acid, another 15–25% fraction of linoleic acid, about a 15% fraction of oleic acid and around 15% eicosenoic acid. Tocopherol content is about 700 mg kg^{-1}. Camelina has potential as a source of lower cost vegetable oil for biodiesel. In this paper an overview of *Camelina sativa* as an alternative oilseed crop has been discussed in detail as how it can be potentially utilized for food, feed and industrial purposes.

Keywords: *Camelina sativa*, oil seed crop, human food, animal feed, multiple uses.
Abbreviations: GOP- government of Pakistan; n-3- omega-3- fatty acid; n-6- omega-6- fatty acid; μ g g^{-1}- microgram per gram; α-T- alpha tocopherol; γ –T- gama tocopherol; δ-T- delta –tocopherol; LDL- low density lipoprotein; ALA- alpha linoleic acid; EPA- eicosapentaenoic acid; DHA- docosahexaenoic acid; GHG- greenhouse gas.

Introduction

Conventional oil seed crops such as rapeseed (*Brassica napus*), mustard (*Brassica spp*.), groundnut (*Arachis hypogaea*), sesame (*Sesamum indicum*), soybean (*Glycine max*), linseed (*Linum usitatissimum*), and cotton (*Gossypium spp.*) are the main sources of edible oil (GOP, 2007). Rapeseed and mustards are the major winter oilseed crops and contribute about 10-13% to domestic edible oil. Unfortunately, rapeseed and mustard oils are not regularly used as cooking oils due to the presence of high concentrations of erucic acid and glucosinolates and are not used at more than 5% in food oil blends (GOP, 2007). Cotton seed is another source of available edible oil but it is not often used as regular cooking oil due to the presence of cyclopropanile fatty acid and gossypol. Cotton is mainly grown for fiber purposes and increasing its oil content will deteriorate the fiber quality as oil content and fiber quality are negatively correlated with each other (GOP, 2007). Camelina is an oilseed crop belonging to family Brassicaceae with agronomic low-input features (Putnam et al., 1993) and has an unusual fatty acid profile, consisting of higher levels of alpha-linolenic acid and comparatively low concentrations of erucic acid (Zubr and Matthaus, 2002). Camelina oil can serve as an interesting source of *n-3* (omega-3) fatty acid due to its cholesterol-lowering properties for the human diet Karvonen et al. (2002). The possible industrial applications of Camelina include its use in environmentally safe paintings, coatings, cosmetics and low emission biodiesel fuels (Bonjean and Goffic, 1999; Bernardo et al., 2003). Although the presence of polyunsaturated fatty acids make Camelina oil susceptible to lipid oxidation but it remains sufficiently stable during storage due to the presence of antioxidants in the seed (Ni Eidhin et al., 2003b; Abramovic and Abram, 2005). Camelina has not had intensive breeding efforts in the past. As compared to other spring-sown oilseed crops the agronomic performance of Camelina has been considered as acceptable (Marquard and Kuhlmann, 1986; Seehuber, 1984; Vollmann et al., 1996; Zubr, 1997). Camelina seed contains oil contents between 320 and 460 g kg^{-1} (Vollmann et al., 2007) and concentration of alpha linolenic acid was in the broad range from 28 to 43% of total fatty acids (Seehuber, 1984; Budin et al, 1995; Zubr and Matthaus, 2002). Very rare practice has been observed regarding the selection of particular seed quality characteristics (Bu chsenschu tz-Nothdurft et al., 1998) and the wide range in seed quality parameters reported previously is not only due to genetic differences among the Camelina genotypes alone, but environmental conditions may also be responsible for this to a large extent. This makes it difficult to compare particular results. Seed quality characteristics of Camelina are important features for processing and marketing of the crop in competition with other oilseeds. There are several reports that suggest Camelina is one of the most cost-effective oilseed crops to produce due to search for the new sources of essential fatty acids, particularly *n-3*(omega-3) fatty acids and multiple use values (Zubr, 1997). Some of the relevant work available on Camelina, its productivity and multiple uses as food, feed, medicinal values and industrial uses are reviewed in this paper.

Morphological characters

Camelina is a short, very fast growing annual or winter annual plant (Putnum et al., 1993).The taxonomic literature (Grubert, 1980; Schultze-Motel, 1986; Frankton and Mulligan, 1987; Blamey and Grey-Wilson, 1989; Rich, 1991; Alex, 1992; Akeroyd, 1993; Davis, 1993; Rollins, 1993; Zubr,1997; Douglas and Meidinger, 1998; Callihan et al., 2000; Cheo et al., 2001 and Vollmann, 2007) provides excellent characterization of the stem, leaf, flower, silique, fruit and seed characteristics of Camelina. Camelina is a self- pollinating and an auto-gamous plant (Mulligan, 2002b). Only about 3% of the 10,000 plants of Camelina were pollinated by bees or butterflies (Tedin, 1922; Schultze-Motel, 1986). However, Camelina is considered among the insect pollinated crops that gains benefit from high populations of bees and other insect pollinators (Goulson, 2003). Different scientists have reported different chromosome numbers for Camelina from different parts of the world: $2n = 40$ from Alberta and British Columbia (Mulligan, 1957; Mulligan, 1984; Mulligan, 2002a; Mulligan, 2002b) $2n = 12$, $2n = 26$, $n = 14$ and $n = 20$ from France, Bulgaria, Spain and China respectively (Warwick and Al-Shehbaz, 2006). However, the most common chromosome number for *Camelina sativa* is $2n = 40$ and the above variations in chromosome number could be due to natural variation among populations (Jalas et al., 1996).

Cultivation preferences

Crop cultivation

Generally, Camelina species are best adapted to cool temperate semi-arid climates (Mulligan, 2002b). Camelina can survive conditions of dry soil, low rainfall and frost due to a short growing season; for example, Camelina matures 21 days earlier than flaxseed (Shukla, 2002).

Various research studies have indicated the effects of differences in growing conditions on the agronomic performance of different crops. Sometimes the results of the research studies are complementary and sometimes contradictory, as documented in the Camelina literature. In the Maritime Province in Canada, the sowing time had no effect on emergence, plant height, seed yield or oil content in Camelina; however, the concentration of stearic acid in the oil was increased by early sowing as compared to late sowing (Urbaniak et al., 2008b). In other studies, plant stand and plant density were significantly affected by different seeding rates (Agegnehu and Honermeier, 1997; Hamid et al., 2002). A seeding rate in the range of 400-600 seeds m^{-2} (equates to 3 kg to 8 kg per hectare) was found to be optimum for Camelina in Canada (Urbaniak et al., 2008b). Seeding rate in this range not only helped to achieve maximum yield but also helped to withstand possible weed pressure through a competitive plant stand. Sowing of Camelina with a forage-type seeder produced a better crop stand than a seed drill, although crop establishment was satisfactory with both seeder types (Urbaniak et al., 2008b). According to McVay and Lamb, (2008) the recommended seeding rate in Montana is 5.55 kg ha^{-1} for a uniform, dense crop stand. Broadcast trials were not successful for Camelina and resulted in poor and uneven crop establishment, which ultimately provided uneven stands and crop maturity at harvest. Seed depth should not exceed ¼ inch with few seeds apparent on the soil surface (Zubr and Matthaus, 2002). The soil needs to be prepared carefully for sowing. Harrowing is an effective measure to eliminate germinating weeds; it improves the crop competition with weeds (McVay and Lamb, 2008). In the case of heavy weed infestation, a pre-emergent herbicide such as Trifluralin 1.5 kg ha^{-1} is recommended (Zubr, 1997).

Camelina being a low input crop does not require great amounts of fertilizers. It has low response to Nitrogen (N), Phosphorus (P) and Potassium (K) McVay and Lamb, (2008).Grant, (2008) reported that to achieve maximum yield in a study in Montana, Camelina required 78.5 to 100.9 kg N ha^{-1}. According to Zubr , (1997) 100 kg N ha^{-1}, 30 kg P ha^{-1} and 50 kg K ha^{-1} was sufficient for optimal seed production. However, nitrogen application rates affect yield components (Agegnehu and Honermeier, 1997) seed yield, protein and oil contents (Szczebiot, 2002; Zheljazkov et al., 2008). In Romania, seed yield of Camelina was increased by 14% and 27% with applications of 40 kg P ha^{-1} and 60 kg P ha^{-1}, respectively, while applications of 50 and 100 kg N ha^{-1}caused an increase of 37% and 58% in seed yield (Bugnarug and Borcean, 2000). Further, phosphorus increased the oil content from 39.2 to 41.9% and nitrogen decreased oil content from 40.9 to 40.1% respectively. The highest dose of N significantly reduced oil content (Sipalova et al., 2011; Losak et al., 2011; Losak et al., 2010). Different agronomic and quality parameters such as plant height, seed yield, oil content, total plant nitrogen and seed protein all responded to nitrogen application. Plant height, total nitrogen content in plant tissue and seed yield increased with increased nitrogen application, but oil content decreased (Urbaniak et al., 2008a).

Seed yield

Early trials of Camelina conducted in Canada showed seed yields of 1200 to 1500 kg ha^{-1} (Plessers et al., 1962). Recent trials in Canada indicated that seed production may not be affected by seeding date but can be affected by seeding rate producing 1338 kg ha^{-1} at a seed density of 200 seeds m^{-2}, 1496 kg ha^{-1} at 400 seeds m^{-2} and 1599 kg ha^{-1}at 600 seeds m^{-2} (Urbaniak et al., 2008a). Different seeding rates did not affect seed size significantly (Urbaniak et al., 2008b) Field trials in Germany indicated that seed production of Camelina is affected by seeding date and soil enrichment. Early seeded plants produced an average seed yield of 1600 kg ha^{-1} as compared to 1150 kg ha^{-1} with late sowing. Variation in thousand-seed weight ranged between 0.8 and 1.3 g. Marquard and Kuhlmann, 1986). In France, *Camelina sativa* cultivars produced a maximum yield of 2.3 t ha^{-1} with late sowing and nitrogen applied at 100 kg ha^{-1} (Merrien et al., 1996). Gehringer et al. (2006) achieved a maximum seed yield of 3 t ha^{-1} through breeding for marginal, poor soil with nitrogen application rate of 80 kg ha^{-1}.

Table 1. Average seed yield of *Camelina sativa* at different locations (t ha.$^{-1}$).

Country	Average seed yield	References
Canada	1.5	Plessers et al. (1962)
Canada	1.3 (200 seeds m^{-2}) 1.4 (400 seeds m^{-2}) 1.5 (600 seeds m^{-2})	Urbaniak et al. (2008 a)
Germany	1.6 (Early seeded) 1.1 (Late seeded)	Marquard and Kuhlmann, (1986)
France	2.3 2.8	Merrien et al. (1996)
Austria	2.2 (400 seeds m^{-2})	Vollmann et al. (2007)
Germany	1.3 1.9	Agegnehu and Honermeier, (1997)
Chile	2.3	Berti et al (2011)

(Seed yield increased with nitrogen application but when nitrogen doses were over 60 kg ha^{-1}or 80 kg ha^{-1} this increase was not significant (Urbaniak et al., 2008a). In a three years trial conducted in Italy on new oil seed crops, *Calendula officinalis*, *Lepidium sativum* and *Camelina sativa*, seed yield per plant of 1.9 to 4.3g was obtained with 1000-seed weight ranging between 1.6 to 2.2 g (Angelini et al., 1997). In Austria, some advanced breeding lines of Camelina having large 1000-seed weight, increased oil content or particular fatty acid concentration were evaluated for agronomic performance in different regions of east Austria. These selected cultivars produced yields of up to 2800 kg ha^{-1} but large seeded cultivars with 1000-seed weight of up to 1.81g gave less yield and oil content (Vollmann et al., 2007). Schuster and Friedt, (1995) noted that spring-sown cultivars could produce an average seed yield between 2.3 to 3 t ha^{-1}and an average 1000-seed weight of 1g. In a 3 year field trial in Germany, average yields of 1340, 1160 and 1800 kg ha^{-1} were reported and a seeding rate of 400 seeds m^{-2} with nitrogen applied at 120 kg ha^{-1} produced a maximum yield of 2280 kg ha^{-1}. Increased seed rate of 800 seeds m^{-2} decreased the number of branches, number of fruit, seeds per fruit and seed weight per plant. Increasing the rate of nitrogen application increased the yield and yield components (Honermeier and Agegnehu, 1996). A field trial in Chile showed that the sowing date did not affect seed yield and oil contents significantly at different locations. Average seed yields were 1310, 1995 and 2310 kg ha^{-1}at different locations with different sowing dates. Seed oil contents ranged from 420 to 457 g kg^{-1} (Berti, et al., 2011). Seed yield comparison at different locations is given in Table 1.

Potential economic values and applications

Human Food

The current research in human nutrition and health has determined the relationship between the diet and the occurrence of various diseases among the population in the industrialized countries. The nutritional deficiency due to the disproportion of poly-unsaturated fatty acids can be alleviated by the addition of *n-3* fatty acid rich oils in the diet. In such a situation Camelina oil can be an excellent source of poly-unsaturated fatty acids and *n-3* fatty acid in particular. Camelina oil can enhance the biological value of diet by changing the proportion of *n-6/n-3* fatty acids (Skjervold, 1993). Camelina seed oil is exceptionally rich in essential fatty acids (Table 2) and contains qualitatively high poly-unsaturated fatty acids as compared to common vegetable oils like soya oil, sunflower oil, rape oil, olive oil, etc. (Abramovic and Abram, 2005; Angelini, 1997; Goffman et al.,1999). Camelina seed contains up to 43% oil. The oil profile shows that unsaturated fatty acids make up about 90% of the fat with 50% of the total fatty acids being poly unsaturated –linoleic acid (18:2, *n-6*) and α- linoleic acid (18:3, *n-3*). Erucic acid (22:3, *n-9*) content in Camelina oil is about 3% (Zubr , 1997; Zubr and Matthaus, 2002). Camelina vegetable oil is an important source of omega -3 fatty acid due to its high concentration of α-linolenic acid (Ruxton, 2007). Zubr, (2009) verified the applicability of Camelina seed and press cake as ingredients in bread for human consumption. These ingredients can enrich the bread with *n-3*(omega-3) fatty acids. Zubr, (2010) investigated the carbohydrates, minerals and vitamins profile in Camelina seed and Camelina press cake. Monosccharides, disaccharides and oligosaccharides were present in low amount but sucrose had significant amount (5.5%). Vitamin content was high in Camelina seed containing 18.8 µ g g^{-1} thiamin (B_1), 194 µ g g^{-1} niacin (B_3) and 11.3 µ g g^{-1} pantothenic acid (B_5). Camelina seed contained macro minerals in small amounts. Among micro minerals of Camelina, Fe content (329 µ g g^{-1}) was remarkably high with substantial content of Mn (40 µ g g^{-1}) and Zn (40 µ g g^{-1}). Zubr, (2003a) in another study reported that the average content of seed crude protein ranged between 39.2-47.4% of dry matter and the average content of crude fiber was 12.5 to 16.8% of dry matter of Camelina grown and harvested simultaneously at different locations in Germany, Denmark, Ireland, Finland and Sweden. Camelina oil containing high amount of α-linolenic acid (*n-3*) has the potential to be used as a food additive (Pilgeram et al., 2007). Camelina also possesses high levels of tocopherols and phenolic compounds, which makes it oxidatively more stable than other highly unsaturated oils such as flax (Zubr, 1997; Hrastar et al.,2009; Abramovic et al., 2007. Zubr and Matthaus, (2002) reported that Camelina oil on an average contains 28.07 ppm of alpha tocopherol (α-T), 742 ppm of

Table.2. Oil content and fatty acid composition (%) of seeds of *Camelina sativa*. Fatty acid carbon chain and number of double bonds in the chain are: palmitic (16:00), stearic (18:00), oleic (18:01), linoleic (18:02), linolenic (18:03), eicosenoic (20:01), behenic (22:00) and erucic (22:01) acid.

Location	Oil%	Palmitic acid	Stearic acid	Oleic acid	Linoleic acid	linolenic acid	Eicosenoic acid	Erucic acid	Other	References
Canada	38-43	5.3-8	-	13-17	15-19.2	34-40	13-16	2.4- 4	13-15	Gugal and Falk,(2006)
Canada	35-40	-	1.4-3	13-16	15.4-21	31-37.2	14-16	3- 4.4	11-17	Urbaniak et al. (2008a; b)
USA	30-38	-	-	14-20	19-24	27-35	12-15	0-4	-	Budin et al. (1995)
Germany	37-41	6.5	2.3	16.2	18.1	39	13.2	2.6	-	Zubr and Matthaus, (2002)
Europe	-	-	-	15	15.2	37	16	03	-	Marquard, (1986)
Salovania	33	6	03	16.27	18.7	33	16	03	0.5	Rode, (2002)
Romania	-	6.51	2.5	-	21	35.58	-	-	-	Imbrea, (2011)

Table 3. Tocopherol content of different vegetable oils (mg/kg).

Oil	α-Tocopherol	β-Tocopherol	ϒ-Tocopherol	δ-Tocopherol	Plastocharomanonol	References
Camelina	28	-	742	20.47	14.94	Zubr and Matthaus (2002)
Canola	268	-	426	-	75	Zambiazi (1997) Normand (2001)
Soyabean	116	34	737	275	-	Zambiazi (1997) Normand (2001)
Sunflower	613	17	19	-	-	Zambiazi (1997) Normand (2001)
Corn	134	18	412	39	-	Zambiazi (1997) Normand (2001)

gamma tocopherol (γ-T), 20.47 ppm of delta tocopherol (δ-T), and 14.94 ppm of plastochromanol (Table 3). The average content of total tocopherols was 806 ppm. As resistance to oxidation and the storage stability of Camelina oil is low at high temperatures, it is best suited for use in cold dishes. The oil has unusually high cholesterol content (45 mg per100 g), as compared to other edible oils containing 10 mg per100 g (Matthaus, 2004). Camelina oil based salad dressings have the same oxidative stability as those prepared with sunflower oil. This was suggested by insignificant differences in peroxide values, ρ-anisinidine values, total oxidation values, conjugated diene levels and conjugated trine levels (Ni Eidhin and O' Beirne, 2010). Camelina oil appears to be more stable than tuna oil, fish oil and salmon oil as denoted by lower values of ρ-anisinidine values, thiobarbituric acid reactive substances and conjugated triene levels during storage at 60 ^{0}C for 20 days (Ni Eidhin and O' Beirne, 2011). Camelina also contains anti-nutritive compounds such as tannins (2.2 mg g^{-1}), phytic acid (19 mg g^{-1}), glucosinolates (24 µ mol g^{-1}) and sinapine (2 mg g^{-1}). Phytic acid causes poor bioavailability of minerals and proteins (Matthaus, 1997).

Animal feed

Camelina oil cake or meal can be used as a protein rich source in poultry diets (Zubr, 1997). Camelina oil mixed with chicken (*Gallus gallus domesticus)* feed increased the *n-3* (omega-3) content in the eggs without any unpleasant flavor, which often comes when flax oil is used (Rokka et al., 2002). A feeding trial in layer birds revealed that the meal can be mixed into poultry rations for energy, protein, essential *n-3* and *n-6* fatty acids but mixing of Camelina meal more than 10% can affect the quality of egg lipids, fatty acid and lipid oxidation products (Cherin, et al., 2009). In Finland, the meal was used in the feed of broiler chickens and it was concluded that the high glucosinolate content of Camelina meal was not suitable for broiler feeding. It depressed their feed intake, feed conversion ratio and growth. However, feeding Camelina meal to broiler chickens improved the *n-3* fatty acid content which is beneficial for human nutrition and no deleterious effect on the sensory quality of the meat was observed (Ryhanen et al., 2007). Camelina meal contains high amounts of protein and energy suitable for feeding pigs (*Sus domesticus)* and ruminants (Matthaus and Zubr, 2000). In Ireland, Camelina oil has increased plasma *n-3* fatty acid content and reduced plasma *n-6* fatty acid content and serum triglyceride levels in a controlled pig feeding trial (Ni Eidhin et al., 2003b). In other pig feeding trials, when the amount of Camelina meal exceeded 5% of rations, it caused a reduction in growth rate, carcass fat consistency and meat palatability (Bohme et al., 1997). Flachowsky et al. (1997) observed that when Camelina meal was fed to pigs, it substantially decreased the induction time of fat development and destroyed antioxidant vitamin E. When Camelina seed and meal were used in the diets of dairy cows (*Bos primigenius*), it reduced milk fat with softer, more spreadable butter mainly due to unsaturated fatty acids in the feed (Hurtaud and Peyraud, 2007). Sokolinska et al. (2011) found that feeding of ewes (*Ovis aries*) with Camelina cake at an amount of 10 and 20% as feed additive resulted in significant changes in aroma and content of volatile compounds in collected milk. Milk of ewes (*Ovis aries*) fed with Camelina cake had a distinct animal, grainy and processed aroma. After pasteurization, the cooked and dairy fat aroma intensified. However, the overall dairy aroma of unpasteurized milk was reduced. An addition of Camelina cake to the diet of ewes resulted in an increase in the volatile contents, primarily fatty acids. Peiretty et al. (2007) studied the effects of various levels of Camelina seed in the diet on growth performance, some carcass characteristics and fatty acid profile of rabbits (*Oryctolagus cuniculus*) meat and fat. It was found that rabbits can be fed with Camelina seed at levels up to 15% of the diet which does not affect the growth performance and carcass characteristics. This dietary treatment did not affect the chemical composition of the meat significantly, but the concentration of polyunsaturated fatty acid in the *Longissimus dorsi* muscle and perirenal fat increased significantly while saturated fatty acid concentration decreased. Use of Camelina seed at this percentage (15%) resulted in a more favorable fatty acid composition which is beneficial for human nutrition, because its importace in reducing the saturation, atherogenic and thrombogenic indexes of rabbit meat. In another experiment it was confirmed that Camelina seed included in rabbit's diet at 15% did not increase oxidation neither in meat nor in animals. Thus, by exploiting seeds rich in poly unsaturated fatty acids and in antioxidant substances it is possible to produce meat with improved fatty acid composition (Prola et al., 2011). Frame et al. (2007) evaluated the use of Camelina meal as a potential feed ingredient in young turkey (*Meleagris gallopavo*) stater diet. They reported that Camelina meal should not be more than 5% of finished feed in a poultry starter diet, as increased percentage resulted in decreased weight and poor feed conversion. In a collective test, a diet containing Camelina oil as a replacement for vegetable oil compared with the control diet resulted in similar weight gain and feed conversion.

Medicinal value

Because of its beneficial health effects (Ni Eidhin et al., 2003b). Camelina oil possesses great potential if used in the production of health promoting supplements. Karvonen et al. (2002) determined cholesterol reducing effect of Camelina oil in a test with mildly and moderately hypercholesterolemic subjects. The volunteers consumed 33 mL Camelina oil per day during 6 weeks. Their total cholesterol in blood serum was reduced from 5.9 to 5.6 m mol L^{-1} and LDL (low density lipoprotein) decreased by 12.2 percent. The high contents of ALA, tocopherols and other antioxidants make Camelina oil nutritionally very attractive. Besides being a substrate in human metabolism, ALA is capable of improving the *n-6*/*n-3* fatty acid ratio in food (Simopoulos, 1999). According to the report of Institute of Medicine on Dietary Reference Intakes for macronutrients, the *n-3* fatty acids being structural membrane lipids can play an important role in nerve tissue and the retina. Human body cannot synthesize ALA and its deficiency may result in clinical symptoms including neurological abnormalities and poor growth. Therefore, ALA should be included in the diet. ALA can be elongated to EPA (Eicosapentaenoic acid) and DHA (Docosahexaenoic acid), because their metabolic products have beneficial effects which help in preventing coronary heart disease, arrhythmias and thrombosis (Institute of Medicine, 2002). The consumption of Camelina oil can help to improve the general health of the population to the desired level (Zubr, 1997; Rokka et al., 2002; Lu and Kang, 2008). Camelina oil is helpful in the regeneration of cells, skin elasticity and slenderness recovery (Vollmann et al., 1996).

Biodiesel/fuel production.

Biodiesel, a low cost renewable fuel made from vegetable oils or animal fat, has recently attracted great attention as one of the more important alternatives for petro-diesel fuel. Biodegradability, lower sulfur and aromatic content, derivation from renewable and waste feedstock, higher cetane number and less emission of carbon monoxide are the main advantages of biodiesel (Demirbas, 1998; Harrington, 1986; Knothe et al.,2006; Yan and Lin, 2009). However, complete substitution of petroleum based diesel fuel is not possible at present due to some disadvantages that include lower oxidative stability, storage stability, cost of production, and high NO_x emissions (Lin et al., 2009; Moser, 2008; Zang, 2003). Currently, feedstock for biodiesel production comes from vegetable oils because they are renewable and can be produced on large scale (Patil et al., 2009). Recently, Camelina has been suggested as a low cost feed stock for biodiesel production (Aurore et al., 2003). In North America, Western Canada, Montana, Northern Great plains and in Colorado, primary interest is in its potential as biofuel additive or for biodiesel production (Reaney et al., 2007; Johnson, 2007; Bonjean and Le Goffic,1999). Frohlich and Rice, (2005) investigated the possibility of Camelina oil as feed stock for biodiesel production and revealed that methyl ester (biodiesel) generated from Camelina oil contained the same properties as that made from rapeseed with one exception, it had high iodine content, which protects against more rapid deterioration of the lubricating oil. Wu and Leung, (2011) attempted to optimize biodiesel production from Camelina oil through alkaline transesterification. Different properties such as density, kinematic viscosity and acid value of optimized biodiesel obtained from Camelina feed stock were examined and compared with those produced from other feed stocks. The optimized biodiesel from Camelina met the related ASTM D6571 and EN 14214 biodiesel standards and can be used for diesel engines as qualified fuel. In European fuel tests, cold-pressed and filtered Camelina oil increased power output and produced less smoke in diesel engines compared to petroleum fuel. However, Camelina oil resulted in higher fuel consumption and high O_2 and NO emissions (Bernardo et al., 2003). Recently, a jet fuel from Camelina oil has been developed and a 151 m^3 per year contract has been signed with a private company for the production of fuel. According to a life cycle analysis study, carbon emissions were reduced to 84% by Camelina based jet fuel when compared with petroleum based jet fuel (Biofuels Digest, 2009). Krohn and Fripp, (2012) studied the environmental feasibility of Camelina biodiesel and found that greenhouse gas (GHG) emissions and fossil fuel use have been reduced up to 40–60% by Camelina biodiesel as compared to petroleum diesel. According to their findings Camelina is an environmentally safe option as a biodiesel crop. They concluded that biodiesel from Camelina had lower life cycle and emissions than diesel fuel and when land use change emissions were compared, Camelina proved better due to its lower life cycle energy than traditional biodiesel crops like soybean and canola (Krohn and Fripp, 2012).

Future line of work

The following future line of work is suggested.

- There is a need to conduct more research on growing conditions of Camelina because flexibility of the crop offers a wide spectrum of naturally different qualities of oil.
- The fatty acid profile of Camelina should be manipulated to produce an oil best suited for industrial applications, so that it could be easily available and can be used in paints and coatings. Owing to specific dermatological effects of polyunsaturated fatty acids, the oil is suitable for cosmetic applications. The Camelina oil can be used as a bio fuel in mixture with diesel oil.
- There is a need to blend the Camelina oil with canola oil to increase *n-3*(omega-3) fatty acid content of the canola oil, a plus point for selling of Camelina.
- Specific feeding mixtures of Camelina must be developed for different types of animals.
- Research work should be conducted in future on the use of Camelina oil and meal in fish feed. These could provide a rich source of *n-3* fatty acids which has many health promoting effects especially against cardiovascular diseases.

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