The bio-based economy can serve as the springboard for camelina and crambe to quit the limbo

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Abstract – Social, economic and environmental importance of bio-based economy is rapidly growing and vegetable oils play an important role. About 75% of global production of vegetable oils derives from commodity oilseeds (i.e., soybean, oil palm, rapeseed), while the remaining 25% is produced from minor oilseeds characterized by unusual fatty acid composition. The present review aims at analyzing the potentialities of two alternative oilseed crops for Europe, camelina (Camelina sativa) and crambe (Crambe abyssinica), identified as major candidates for the future European bio-based economy as testified by the recently funded EU Project (Horizon 2020) COSMOS (Camelina and crambe Oil crops as Sources of Medium-chain Oils for Specialty oleochemicals). The interest on camelina and crambe is mainly due to their unique fatty acid profile, low input management and wide environmental adaptability. We attempted to analyze pros and cons of development of camelina and crambe in Europe in the light of biorefinery concept (i.e., using oil and whole produced biomass) as undertaken by COSMOS project.

Keywords: Bioeconomy / oil crops / Brassicaceae / PUFA / eicosenoic acid / erucic acid

1 Introduction

The European policy has set the course for a resource-efficient and low-emissions bioeconomy, including bio-based economy, reconciling agriculture, biodiversity, environmental safety, while promoting the displacement of fossil-based products with bio-based surrogates. The bio-based economy is expected to grow rapidly creating new markets and jobs. The traditional petrol-based chemical industry is the one suffering more from its dependence on depleting resources thus pushing the search for innovative applicable renewable alternatives (Monteiro de Espinosa and Meier, 2011). Apart from their renewability, vegetable oils offer many advantages such
as: world-wide availability, similarity to petrol derivates and prices that, even if much higher than petrol counterparts, are considered adequate (Monteiro de Espinosa and Meier, 2011).

Diverse chemistry could be easily applied on vegetable oils, leading to a large variety of monomers and polymers, highly requested by diverse bio-based industries, such those producing: surfactants, cosmetic products, lubricants, polymers, etc. For long it has been considered that oil and fat consumption was shared among food, feed, and industrial use in the ratio 80:6:14, but with the increasing production of biofuels (i.e., biodiesel) this is probably now close to 74:6:20 (Metzger, 2009). The current global production of vegetable fats is covered for 75% by commodity oilseeds (Tab. 1), such as soybean, oil palm, cottonseed, rapeseed and sunflower, while the remaining 25% is derived from minor oilseeds generally characterized by infrequent fatty acids (FA) in terms of carbon chain length, double bond position, and functional groups.

Although the demand by industry for unusual FAs has been always high and variegated, widely grown oilseeds (Tab. 1) mainly contain only five major FAs in their oil: palmitic (C16:0), stearic (C18:0), oleic (C18:1), linoleic (C18:2) and α-linolenic acids (C18:3) (Carlsson et al., 2011). Looking at the EU situation (Tab. 1), only mono and poly unsaturated FAs (MUFA and PUFA) are obtained by domestic grown oilseeds in spite of a considerable number of potential oilcrops, with variegate FA profiles, suitable to European environments, some of which (e.g. Brassica carinata, B. juncea, Crambe abyssinica and Camelina sativa) being also at a mature stage technically speaking (Zanetti et al., 2013) (Tab. 1).

Camelina (Camelina sativa (L.) Crantz) and crambe (Crambe abyssinica Hochst. ex R.E. Fries) have a unique FA profile, good agronomic performances and wide environmental adaptability, and they are also native to Mediterranean basin (Leppik and White, 1975). The unusual composition of crambe oil, containing up to 65% of erucic acid (C22:1), makes it particularly suitable to several bio-based productions such as lubricants and plasticizers. The potentiality of crambe as a source for bio-based applications has been extensively studied in Europe, USA and more recently also in Brazil, but the commercial viability has never been reached mostly due to its low productivity (Lessman, 1990; Meijer et al., 1999), high investment and energy costs for oil transformation (Bondioli et al., 1998).

Camelina was a fundamental part of human diet since the Iron Age (Zubr, 1997), thereafter it progressively declined its importance as food crop (Knorzer, 1978) with only sporadic cultivations in eastern Europe. Recently, the industrial interest on camellina has rapidly grown (Putnam et al., 1993) due to its unique FA composition and sound attractive applications such as drying oil with environmentally safe painting and coating applications similarly to linseed oil (Luehs and Friedt, 1993; Russo and Reggiani, 2012). Moreover, unlike the majority of wild-type Brassicaceae, camelina shows a rather low glucosinolate content (Lange et al., 1995), which makes the possible utilization of meal much easier.

An overview of the potentialities of camellina and crambe as new oilseed crops for European environments is presented in the next sections.

2 Description of crambe and camelina

Crambe and camelina are erect broadleaf oilseed species native to Mediterranean area and belonging to Brassicaceae family. They are characterized by high tolerance to drought and a shorter cycle compared to rapeseed. Crambe plants reach a maximum height of 1.20 m with a cycle length of 90–110 days (1300–1500 GDD, with a base temperature of 5 °C, Meijer and Mathijssen, 1996). Crambe shows the typical Brassicaceae morphological structure (Figs. 1a and 1b) with large, oval-shaped and smooth leaves, high number of very small white flowers clustered in racemes (Fig. 1c). The fruits are little, spherical, light brown seeds borne singly at or near the terminus of the branches. Each seed is enclosed in a pod or hull (Fig. 1d) that sticks on it at harvest as part of the yield (Lessman, 1990). The presence of this persistent and firm hull (11–40% of seed weight), that prevents the rapid seed emergence and worsens the establishment (Merrien et al., 2012), represents an agronomic constraint for this species. Crambe hulled seed weight is 5–7.5 mg per seed (Earle et al., 1966).

Alike crambe, camellina is a fast growing annual crop able to complete the cycle in only 90 days or less if seeded in springtime (1200–1300 GDD, with a base temperature of 4 °C, Gesch and Cermak, 2011). At full maturity, plants attain height of 0.90 m, and present a main stem with numerous lateral branches (Figs. 2b and 2c), which usually reach the same height. On the main stem, leaves are alternate on subsequent nodes; basal ones are usually oblanceolate and short-stalked (Figs. 2a and 2b), while upper ones are normally lanceolate and unstalked (Martinelli and Galasso, 2011).
Fig. 1. Crambe plant at different development stages. (a) rosette stage; (b) stem elongation and flowering induction; (c) flowers at full flowering stage; (d) pods during seed filling stage.

Fig. 2. Camelina plant at different development stages. (a) rosette stage; (b) stem elongation; (c) full flowering; (d) pod and seeds during seed filling stage; (e) plant at full maturity.

The number of lateral branches is extremely variable and highly dependent on both plant density and environmental conditions (Martinelli and Galasso, 2011). Camelina owns pale yellow flowers (Fig. 2c); about fifteen seeds are enclosed into each pear-shaped pods (Figs. 2d and 2e). The seed weight ranges from 0.8 to 1.8 mg (Zubr, 1997).

2.1 Adaptation and establishment

Crambe and camelina can be grown in a wide range of climatic and soil conditions. Crambe is adaptable to a broad range of soils including saline and contaminated (heavy metals) ones (Artus, 2006; Paulose et al., 2010). It is also a drought tolerant crop able to grow successfully in marginal or semiarid land (Francois and Kleiman, 1990; Fowler, 1991; Lonov et al., 2013). Camelina is also characterized by high resilience and can be planted on marginal soils under semiarid conditions (Rodríguez-Rodríguez et al., 2013).

Ideally, both crambe and camelina could be grown as summer crops or winter ones; however, crambe is less tolerant than camelina to cold stress. Interestingly real winter camelina varieties (Berti et al., 2014) are now available in the market broadening the possible cultivation environment for this species. It is worth noting that optimal planting dates for both crambe and camelina are critical management issues significantly affecting the final yield and oil composition. In particular, as reported by Adamsen and Coffelt (2005) for crambe an anticipation of sowing in autumn could negatively impact seed yield, in case of frost occurrence, conversely also a delay of sowing in spring could lead to lower yield performances. For camelina, Berti et al. (2011) and Gesch and Cermak (2011) demonstrated in different environments (i.e., Chile and USA) that an anticipation of sowing in autumn is able to significantly increase seed yield, since the positive effect of milder temperatures during flowering period.

2.2 Rotation

Crop diversification is a major objective of the new CAP (Common Agricultural Policy). It has been widely documented that optimized crop rotations generally lead to a reduction of fertilizers, weeds, pests and diseases, resulting in an overall increase of cropping system sustainability (Kirkegaard et al., 2008) and a significant reduction of management costs. Intercropping, double and relay cropping show detectable environmental benefits (Gaba et al., 2015; Lithourgidis et al., 2011), and increase land equivalent ratio. In view of their short cycle, crambe and camelina are good candidates to be included in new rotational schemes, as highlighted by recent studies (Gesch and Archer, 2013; Krupinsky et al., 2006); however, information on rotational effects of these crops is very scarce and almost all related to Northern American environments. According to Gesch and Archer (2013), the yields of double-cropped soybean and sunflower with winter camelina are respectively 82% and 72% of their equivalent monocrops, but the revenues derived from the sale of camelina seeds provided net return when double cropping system was adopted. Gesch et al. (2014) confirmed also the agronomic viability of relay-cropping of soybean with winter camelina compared with respective mono-crops full-season soybean. Furthermore, in a water limited environment for dual cropping systems, the low water use (WU) of camelina would benefit the subsequent crop (Gesch and Johnson, 2015; Hunsaker et al., 2011).

To the best of our knowledge, in literature there is very limited study on the rotational effects of crambe (Allen et al., 2014; Krupinsky et al., 2006); nonetheless, in view of its short cycle, crambe would fit as a perfect preceding crop for winter cereals, freeing early the soil thus allowing tillage operations to be done on time.
Table 2. Seed yield (Mg ha\(^{-1}\)) and oil content (%) of camelina and crambe grown in different localities of northern, central and southern Europe.

| Geographical Zone | Location                      | Seed yield (Mg ha\(^{-1}\)) | Oil content (%) | Ref. | Location     | Seed yield (Mg ha\(^{-1}\)) | Oil content (%) | Ref. |
|-------------------|-------------------------------|-----------------------------|-----------------|------|--------------|-----------------------------|-----------------|------|
| Northern Europe   | Germany, UK, Sweden, Denmark, | 1.27–2.36                   | 42              | 1    | Netherlands  | 2.49–2.97                   | 35.2–36.1        | 5    |
|                   | Finland, Ireland              |                             |                 |      |              |                             |                 |      |
| Central Europe    | Austria                       | 1.85                        | 43.7            | 2    | Austria      | 0.97–3.33                   | 22.6–38.4        | 6    |
|                   | Romania                       | 1.99–2.24                   | 32.7–35.9       | 3    |              |                             |                 |      |
| Southern Europe   | Central Italy                 | /                           | 23.6–27.5       | 4    | Northern Italy | 2.34–3.25                   | 33.9–36.8        | 7    |
|                   | Southern Italy                |                             |                 | 5    | Southern Italy | 0.44                        | 34.8            | 8    |

\(^{1}\) Zubr, 1997, 2003, \(^{2}\) Vollmann et al., 2007, \(^{3}\) Toncea et al., 2013, \(^{4}\) Angelini et al., 1997; \(^{5}\) Meijer et al., 1999; \(^{6}\) Vollmann and Rackenbauer, 1993; \(^{7}\) Fontana et al., 1998; \(^{8}\) Laghetti et al., 1995. * Considering encapsulated seed.

3 Productive performances

3.1 Seed yield

High seed yields are expected to make new oilseeds competitive with the established crops (Meijer et al., 1999). Literature refers to camelina seed yield can be up to 2.5–3.2 Mg ha\(^{-1}\) when grown in not-limiting conditions (Gugel and Folk, 2006; Pavlista et al., 2016); crambe was shown to exceed 3 Mg ha\(^{-1}\) of seed yield (Adamsen and Cofelt, 2005), but values include the hull weight (Tab. 2). Fontana et al. (1998) tested crambe in the Mediterranean basin, demonstrating that adverse environmental conditions (i.e., crust formation, temperatures below 10 °C at rosette stage, and very high temperatures during seed filling) are negatively affecting yields. The major constraint to reach high seed yields in crambe seems the low heritability in the progenies and the influence of adverse environmental conditions (e.g., temperature, uneven rainfall distribution). Furthermore, the inefficient radiation use of the crambe pods during seed formation, caused by their small surface, differently from rapeseed, seems negatively impacting on final seed yields (Meijer et al., 1999).

Also camelina productive performance appears dependent on environmental conditions during the main growing phases (i.e., emergence, flowering and seed ripening). Waterlogging during reproductive phases, or persistent drought conditions decreased seed yield by 25–30% (Gugel and Folk, 2006; Gesch and Cermak, 2011). Moreover, because of the small seed size (Fig. 3) a modified harvesting equipment should be adopted for camelina while for crambe the machineries for rapeseed could be easily adapted.

3.2 Oil production and quality

Seed quality is particularly affected by environmental factors such as temperature, precipitation, solar radiation, evapotranspiration and air circulation (Zubr, 2003). For this reason, a significant variation in seed quality can be expected across different locations and/or planting dates. Table 2 shows that oil content of camelina can vary from 26% to 43% moving from south to north Europe, respectively. Gesch and Cermak (2011) refer that the oil content of winter type camelina increased...
when delaying the planting date. Pecchia et al. (2014) studied winter vs. spring sown of camelina and they concluded that oil content seldom increased by anticipating the sowing point. Camelina oil (Tab.3) is characterized by a very high double bound position (melt-erucic acid content (<5%), and high eicosenoic acid content (C20:1) (~15%), the latter being very uncommon in plants, while it is normally contained in fish oils. Eicosenoic acid could be used as a source of MCFAs (Medium Chain Fatty Acid), which nowadays are not produced in Europe being totally derived from palm and coconut oils. Camelina has an exceptional high content in tocopherols (Budin et al., 1995), the latter conferring a reasonable oxidative stability despite the high desaturation level, differently from linseed oil.

The main characteristic of crambe oil is the outstanding content of erucic acid, up to 65% of the total FAs, that is significantly higher than those accumulate in high erucic acid rape-seed (HEAR) varieties, with a maximum of 50–55% (Meijer et al., 1999). Erucic acid is a very long chain MUFA with technical characteristics (oxidative stability) similar to oleic but allowing diverse chemical transformations.

As for other oil crops, environmental conditions and genotypes are considered the main factors influencing camelina and crambe FA profile (Vollmann and Ruckenbawer, 1993; Vollmann et al., 2007; Zubr, 2003). High temperatures during seed filling period interfere with the activity of enzymes responsible for PUFA metabolism (Cheesbrough, 1989), thus explaining why the temperature effect on FA composition (Schulte et al., 2013) is considerable in camelina and negligible in crambe, as the latter mainly contain MUFAs (i.e., erucic acid). Laghetto et al. (1995) confirmed that erucic acid is only lightly affected by environmental conditions.

3.3 Seed meal

Defatted camelina seed is composed of residual fats (5–10%), significant levels of high quality proteins (45%), soluble carbohydrates (10%) and different phytochemicals, such as glucosinolates (Zubr, 2010; Das et al., 2014). It is worth noting that compared to other Brassicaceae, not improved for this trait (e.g., “00” rapeseed), the glucosinolate content in camelina is rather low (10–40 μmol g⁻¹), Gugel and Falk, 2006), but it is anyway exceeding the legal limit (<30 μmol g⁻¹), thus not allowing the full use as livestock feed (Russo et al., 2014). Sinapine is an alkaloidal amine found in numerous Brassicaceae, it is responsible for the bitter taste of Brassica meal thus reducing its palatability, and causing disagreeable taste of milk and meat from cows and calves fed on it. Unfortunately camelina meal contains also significant amount of sinapine, but the content is normally lower than that of conventional rapeseed meal (Colombini et al., 2014).

Crambe seed meal is also characterized by good quality proteins, but the huge amounts of glucosinolates (70–150 μmol g⁻¹) and tannins dramatically limit its use as feed (Wang et al., 2000).

4 Uses

The growing interest for camelina and crambe is related to the wide range of products and by-products that can be obtained from their oil and crop residues. For example, high-erucic oils are fundamental raw materials for both oleochemical transformations (i.e., production of behenic, brassilic and

Table 3. Oil composition of camelina and crambe in comparison with high erucic acid rapeseed (*Brassica napus* L. HEAR) and linseed (*Linum usitatissimum*).

| Species | C16:0 | C18:0 | C18:1 | C18:2 | C18:3 | C20:1 | C22:1 | Ref. |
|---------|-------|-------|-------|-------|-------|-------|-------|------|
| Camelina | 5.2–7.0 | 2.3–3.2 | 14.5–18.5 | 14.7–20.4 | 29.9–35.1 | 14.4–17.6 | 2.4–4.0 | 1 |
| Linseed | 5.4–5.7 | 4.0–4.7 | 18.1–23.8 | 13.6–14.6 | 52.2–57.9 | Tr | Tr | 2 |
| Crambe | 1.8–2.2 | 0.7 | 16.5–17.2 | 8.7–9.3 | 4.8–5.2 | 3.4–4.7 | 56.2–62.5 | 3,4 |
| HEAR | 3.1–3.5 | 0.8–0.9 | 10.7–14.5 | 12.5–14.0 | 7.4–10.5 | 7.5–8.0 | 48.1–50.3 | 5 |

1 Vollmann et al., 2007; 2 Soto-Cerda et al., 2014; 3 Wang et al., 2000; 4 Boldioli et al., 1998; 5 Zanetti et al., 2009. Tr = Traces.
pelargonic acids) and direct use in producing erucamide—a slip agent enabling manufacture of extreme-temperature resistant plastic films (Walker, 2004; Zanetti et al., 2006).

Several studies tested camelina and crambe as potential biodiesel crops (Fröhlich and Rice 2005; Wazilewski et al., 2013), but due to their peculiar oil composition they would likely deserve higher consideration as a source for bio-based industry. Recently camelina oil has been identified as a potential feedstock for the production of aviation fuel at both European and international level (Li and Mupondwa, 2014; Natelson et al., 2013). In particular, the European project ITAKA (www.itaka-project.eu) addressed the potentiality of camelina as a crop emerging with promising results (Burke, 2015; Ye et al., 2016).

From the economical point of view, the valorization of by-products of camelina and crambe as source of feed protein would considerably increase the economic sustainability (Matthaus and Zubr, 2000); nonetheless, the use of crambe and camelina press cake as animal feed is thwarted by the high glucosinolate and tannin contents. Gonçalves et al. (2013) showed an interesting use of by-products from oil extraction of crambe seeds in the treatment of wastewater with high toxic metals content (e.g., Cd, Pb, Cr). Franca et al. (2014) identified crambe press cake as a suitable candidate for the productions of adsorbents to remove cationic dyes from wastewaters without previous treatment.

### Table 4. Pros and cons of crambe in Europe.

| **Agronomy** | **Positive traits** | **Implications** | **Ref.** | **Negative traits** | **Implications** | **Ref.** |
|--------------|---------------------|-----------------|---------|---------------------|-----------------|---------|
| Short cycle  | Several combinations of crop rotation | 1 | High frost sensitivity | Chilling stress risks in winter sown | 7 |
| Low input management | Environmental benefits, low management costs | 2, 3 | Low radiation use efficiency by pods | Low seed yield | 8 |
| Adaptability to marginal lands | Use of abandoned land (avoid food/non-food debates, nature conservation programmes) | 4, 5, 6 |

| **Seed and by-product quality** | **Positive traits** | **Implications** | **Ref.** | **Negative traits** | **Implications** | **Ref.** |
|--------------------------------|---------------------|-----------------|---------|---------------------|-----------------|---------|
| **High content of erucic acid (up to 60%)** | Erucamide production, several oleochemical streams | 9 |
| **High content of glucosinolates** | Bio-based compounds for plant protection and human health | 10, 11, 12 | High content of glucosinolates | Limitation as livestock feed | 14 |
| Encapsulated seeds | Prevention against abrasion and shocks, no seed shattering | 13 | Encapsulated seeds | High managing costs, difficult emergence | 15 |

1. Lenssen et al., 2012; 2. Rogério et al., 2013; 3. Dos Santos et al., 2013; 4. Francois and Kleiman, 1990; 5. Fowler, 1991; 6. Lonov et al., 2013; 7. Adamsen and Coffelt, 2005; 8. Mejier et al., 1999; 9. Bondioli et al., 1998; 10. Avato et al., 2013; 11. Bohinc et al., 2013; 12. Sapone et al., 2007; 13. Costa et al., 2013; 14. Wang et al., 2000; 15. Merrien et al., 2012.

### 5 The European Project COSMOS and the perspectives of crambe and camelina in the European bio-based economy

The EU project COSMOS (Camelina and crambe Oil crops as Sources of Medium-chain Oils for Specialty oleochemicals) started on March 2015 and will end on September 2019 (http://cosmos-h2020.eu/). The general scope of the project is to limit the European dependence on imported oils (i.e., coconut and palm kernel oils) as sources of MCFAs (C10–C14) as the cost of these oils is extremely volatile. Camelina and crambe have been selected as promising candidates for substituting coconut and palm kernel oils. Considering that European customers show very low acceptance for products derived from GMOs, the project aims to develop value chains based on non-GMO oils.

According to the biorefinery concept, the whole biomass should be also valorised by converting vegetative tissues (pods, straw, leaves, etc.) to valuable fats and proteins through insect metabolism by innovative “insect biorefinery” approaches. Finally, oleochemical co-products would be also valorised as feedstocks for flavour and fragrance precursors, high value polyamides and high performance synthetic lubricant based oils.

The COSMOS project will boost the research to overcome existing limits to crambe and camelina cultivation (Tabs. 4 and 5) and demonstrate the feasible use of the whole produced biomass to obtain high added value products. In particular, for camelina the selection of improved varieties, with contemporaneous maturity and the set up of tailored harvesting machineries will drastically reduce seed losses in the short cut.
For crambe, the optimization of the extraction process of glucosinolates will turn a problem into an opportunity, since they own several applications in human health, as anticancer, and cosinolates will turn a problem into an opportunity, since they have high content of PUFAs, interesting oleochemical pathways, high value feed supplements, and possible use as poultry feed.

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References

Adamsen FJ, Coffelt TA. 2005. Planting date effects on flowering, seed yield, and oil content of rape and crambe cultivars. Ind. Crop. Prod. 21: 293–307.

Allen BL, Lensen AW, Sainju UM, Caesar-That T, Evans RG. 2014. Nitrogen Use in Durum and Selected Brassicaceae Oilsseeds in Two-Year Rotations. Agron. J. 106: 821–830.

Anderson MD, Peng C, Weiss MJ. 1992. 
Crambe abyssinica
Hochst., as a flea beetle resistant crop (Coleoptera: Chrysomelidae). J. Econ. Entomol. 85: 594–600.

Angelini LG, Moscheni E, Colonna G, Belloni P, Bonari E. 1997. Variation in agronomic characteristics and seed composition of new oilseed crops in central Italy. Ind. Crop. Prod. 6: 313–323.

Artus NN. 2006. Arsenic and cadmium phytoextraction potential of crambe compared with Indian mustard. J. Plant Nutr. 29: 667–679.

Avato P, D’Addabbo T, Leonetti P, Argentieri MP. 2013. Nematicidal potential of 
Brassicaceae.
Phytochem. Rev.: 12: 791–802

Bernardo A, Howard-Hildige R. 2003. Camelina oil as a fuel for diesel transport engine. Ind. Crop. Prod. 17: 191–197.

Berti MT, Wückens R, Fischer S, Solis A, Johnson B. 2011. Seeding date influence on camelina seed yield, yield components, and oil content in Chile. Ind. Crop. Prod. 34: 1258–1365.

Berti MT, Johnson B, Gesch R et al. 2014. Energy balance of relay- and double-cropping systems for food, feed, and fuel in the north central region, USA. In proceedings of 22nd European Biomass Conference: setting the course for a biobased economy, Hamburg (Germany), 23–26/06/2014, pp. 102–107.

Bohinc T, Kosir IJ, Trdan S. 2013. Glucosinolates as arsenal for defending 
Brassicas against cabbage flea beetle (Phyllotreta spp.) attack. Zemdirbyste 100: 199–204

Bondioli P, Folegatti L, Lazzeri L, Palmieri S. 1998. Native 
Crambe abyssinica
oil and its derivates as renewable lubricants: an approach to improve its quality by chemical and biotechnological processes. Ind. Crop. Prod. 7: 231–238.

Brownie LM, Conn KL, Ayer WA, Tewari JP. 1991. The camalexins: New phytoalexins produced in the leaves of 
Camelina sativa
(Cruciferae). Tetrahedron 47: 3909–3914.

Budin JT, Breece WM, Putnam DH. 1995. Some compositional properties of camelina ( 
Camelina sativa
L. Crantz) seeds and oil. J. Am. Oil Chem. Soc. 72: 309–315.

Burke M. 2015. Fish oils from Camelina plants. Chem. Ind-London 79: 8.
