

## REVIEW

# Camelina Oil as Ethiopia's Next Edible Oil: Insights into Chemical Composition and Agro-Ecological Adaptability – A Review

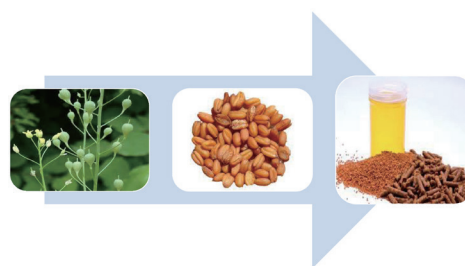
Banchiywsen Kidane<sup>1</sup>, Wesena Hunde<sup>1</sup>, Markos Makiso Urugo<sup>1\*</sup>, Fikadu Tessema<sup>2</sup>, and Tilahun A Teka<sup>3</sup>

<sup>1</sup> Food Science and Post-Harvest Technology, College of Agricultural Sciences, Wachemo University, Hosaena, ETHIOPIA P.O. Box 667

<sup>2</sup> International Livestock Research Institute (ILRI), Addis Ababa, ETHIOPIA

<sup>3</sup> Department of Postharvest Management, College of Agriculture and Veterinary Medicine, Jimma University, ETHIOPIA P.O. Box 307

**Abstract:** *Camelina sativa*, commonly known as Camelina, has emerged as a promising oilseed crop due to its remarkable adaptability to various environmental conditions and its rich nutritional profile. The high content of dietary polyunsaturated fatty acids (PUFAs), particularly omega-3 fatty acids, including alpha-linolenic acid (ALA), tocopherols, and phytosterols, distinguishes this oilseed and sets it apart from many traditional vegetable oils. Its advantageous agronomic characteristics, such as strong drought resistance, early maturation, low input requirements, and the ability to be cultivated twice in a single season, position Camelina as a viable cash crop capable of meeting diverse market demands ranging from dietary supplements to cosmetics and high-quality animal feed. In Ethiopia, where the vegetable oil market faces significant challenges, approximately 95% of domestic consumption is met through imports, resulting in substantial foreign exchange expenditures. This reliance highlights the urgent need for local oil sources to enhance nutritional diversity and food security. Camelina's adaptability to Ethiopia's diverse agro-ecological zones offers a unique opportunity to cultivate this crop under various climatic conditions, thereby increasing local production and reducing dependency on imports. Despite the growing interest in Camelina's commercialization, there remains a notable lack of awareness and research regarding its potential applications and benefits within the Ethiopian context. The successful integration of Camelina into Ethiopia's agricultural framework could significantly alleviate the current oil shortage while contributing to sustainable agricultural practices and rural development. Future research should prioritize the development of high-yielding varieties suited to Ethiopia's agro-ecologies and cost-effective, locally adapted post-harvest processing techniques to enhance value addition and market competitiveness. Increased investment in research and development, along with targeted policy support, will be essential to fully realizing the crop's potential in enhancing the country's oilseed production and ensuring a sustainable food supply.



**Key words:** Camelina oil, Camelina meal, fatty acids, polyunsaturated fatty acid, vegetable oil

## 1 Introduction

Camelina (*Camelina sativa* L.), commonly known as false flax or gold-of-pleasure, is likely native to the Mediterranean region of Europe and parts of Southwest and

Central Asia, where it has been cultivated for thousands of years for its oil-rich seeds and as a feed crop. Its use dates back to the Bronze Age, particularly in regions like Northern Europe, where it was widely grown for lamp oil, medic-

\*Correspondence to: Markos Makiso Urugo, Food Science and Post-Harvest Technology, College of Agricultural Sciences, Wachemo University, Hosaena, ETHIOPIA P.O. Box 667

E-mail: markosmakiso@gmail.com ORCID ID: <https://orcid.org/0000-0002-6241-1417>

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inal purposes, and as a food source<sup>1,2</sup>). However, with the rise of more commercially profitable crops like canola and sunflower, its cultivation declined in the 20<sup>th</sup> century. In recent decades, interest in *Camelina* has resurged due to its adaptability to harsh climates, low input requirements, and nutritional oil profile rich in omega-3 fatty acids. *Camelina* is now cultivated across temperate regions of Europe, North America, and parts of Asia, with growing attention in arid and semi-arid regions due to its drought tolerance and potential as a sustainable oilseed crop for marginal lands<sup>3-5</sup>).

Oil-bearing plant seeds are gaining increasing attention due to their versatile applications in food, feed, biofuel, and medicine<sup>6</sup>). One such crop is *Camelina*, an ancient oilseed known for its diverse uses and environmental adaptability. *Camelina* has become valued for its low input requirements, thriving in low-fertility soils with minimal fertilizers. Its short growing season (85–100 days) makes it a practical crop for regions with challenging climates<sup>7</sup>). The oil's color varies from golden to reddish-brown, depending on the variety. *Camelina* oil has been classified as Generally Recognized As Safe (GRAS) by the U.S. Food and Drug Administration<sup>8</sup>). Unlike flax oil, which spoils easily, *Camelina* oil is more stable at low to moderate cooking temperatures, although it may develop a distinct flavor when used for deep frying. It is suitable for use in specialty oils, omega-3-enriched products, salad dressings, and baked goods. Additionally, *Camelina* by-products show potential as a valuable component of animal feed, further expanding its agricultural utility<sup>7,9</sup>).

*Camelina* seeds are rich in essential micronutrients such as iron, manganese, and zinc, along with important vitamins like B1, B3, B5, and gamma-tocopherol (Vitamin E). Additionally, *Camelina* oil is well-regarded for its high concentration of polyunsaturated fatty acids, particularly omega-3 and omega-6, which enhance its value as a nutritious edible oil<sup>2,10</sup>). Originally native to Europe and parts of Southwest and Central Asia, the crop is increasingly being adopted to promote diversification within oilseed production systems. However, many emerging nations continue to rely heavily on a limited range of oil-bearing crops, making their economies vulnerable to external market fluctuations. Expanding oilseed options with crops like *Camelina* could help strengthen economic resilience and ensure greater stability. Despite the growing interest in *Camelina*'s commercialization, recent years have seen a steady increase in global patenting activity around *Camelina* oil, particularly in sectors such as biofuel, nutritional supplements, and bioplastics, reflecting the crop's emerging industrial and economic significance<sup>11</sup>).

In Ethiopia, the demand for edible oils is high, but local production falls significantly short of meeting domestic needs, with around 95% of the country's vegetable oil supply being imported and less than 5% produced locally<sup>12</sup>). This reliance on imports strains the economy, in-

creases prices, and limits access to quality oils, while locally produced oils often suffer from inconsistent quality due to an underdeveloped supply chain. The oilseed production sector is crucial for generating foreign exchange, but Ethiopia has yet to fully incorporate novel, nutritionally rich oilseed crops<sup>12,13</sup>). *Camelina sativa*, a drought-tolerant, low-input crop well-suited to Ethiopia's semi-arid and marginal lands, offers a promising solution. With its high content of omega-3 fatty acids, antioxidants, and other valuable nutrients, *Camelina* oil presents a healthier and potentially more affordable alternative to imported oils<sup>2,14,15</sup>). Cultivating *Camelina* could not only improve local oil production but also diversify the agricultural sector, enhance rural livelihoods, and reduce Ethiopia's dependence on foreign oil imports. This review aims to thoroughly assess the potential of *Camelina* oil, including its chemical composition and role as a new edible oil source for Ethiopia.

## 2 Methodology

The sources for this review were drawn from published papers across various reputable and curated academic databases. Comprehensive meta-analyses, research papers, reviews, and working papers were primarily sourced from platforms such as Scopus and Web of Science, which provide high-quality and peer-reviewed literature. Google Scholar was used in a complementary role to broaden the scope of the search and to identify additional relevant studies, including regionally published and grey literature that may not be indexed in Scopus or Web of Science. A systematic literature search was conducted using the following search strategy across databases: (“*Camelina*” OR “*Camelina sativa*”) AND (“oil” OR “edible oil” OR “vegetable oil”) AND (“chemical composition” OR “fatty acid profile” OR “nutritional value”) AND (“agronomic traits” OR “adaptability” OR “Ethiopia”). Boolean operators were adapted slightly to each database's syntax (e.g., using field-specific tags in Scopus and Web of Science).

The inclusion criteria were: (1) studies published in English, (2) peer-reviewed journal articles, review papers, and working papers from credible institutions, (3) papers focused on the chemical composition, nutritional aspects, or agronomic traits of *Camelina sativa*, and (4) studies published between 2013 and 2024. The exclusion criteria included: (1) articles unrelated to the scope of the review, (2) non-scientific reports or blog content, and (3) duplicated records. The initial search yielded 202 studies. After screening titles and abstracts for relevance and applying inclusion/exclusion criteria, 61 full-text articles were reviewed in detail (Fig. 1). Reference management and duplicate removal were done using Mendeley. Grey literature, such as FAO reports and institutional theses related to Ethiopia's edible oil sector, were included when relevant

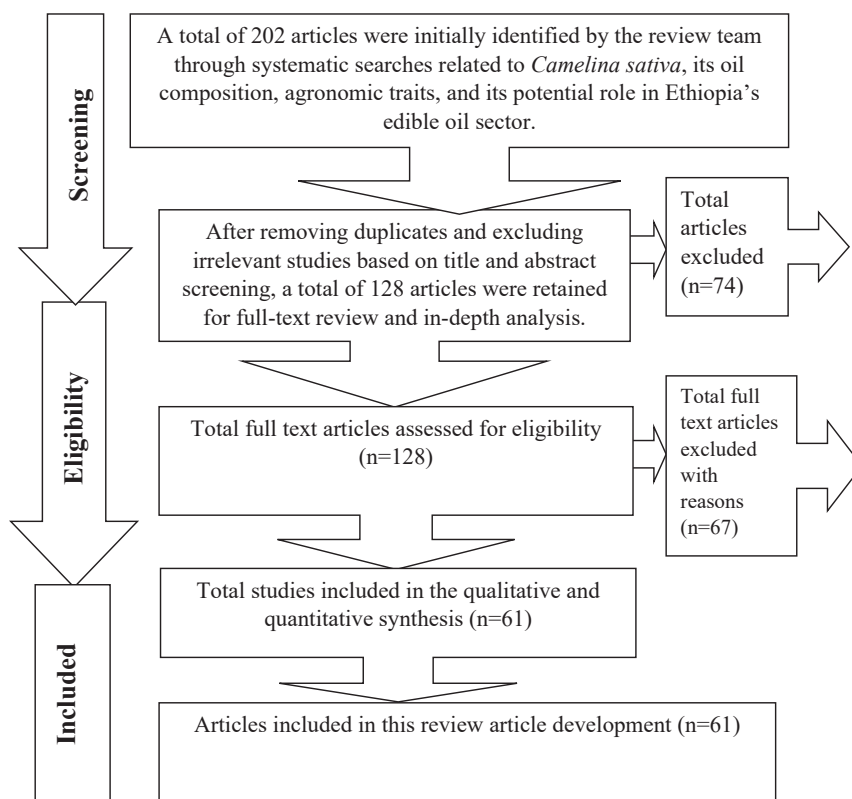


Fig. 1 Flowchart of the literature search, screening, and selection process for studies on *Camelina sativa*.

and cited accordingly.

### 3 Agronomic and Environmental Benefits of Camelina Cultivation

#### 3.1 Adaptability of Camelina to Ethiopian climate and soil

Camelina demonstrates exceptional adaptability to Ethiopia's climate and soil conditions, particularly due to its drought resistance and low input requirements. This hardy oilseed crop thrives in environments with irregular rainfall or prolonged dry seasons. Unlike many conventional oilseed crops that demand intensive irrigation and fertilization, Camelina thrives with minimal inputs. Figure 2 illustrates the Camelina plant and seed, whose small and resilient nature contributes to the crop's adaptability by requiring limited water, fertilizer, and pest control—making it well-suited for low-input farming systems<sup>16, 17</sup>. Such characteristics make it a suitable option for Ethiopian farmers, especially in areas where access to agricultural inputs is limited or soil fertility is low. Furthermore, Camelina's short growing season allows it to fit into various farming cycles, maximizing land use efficiency and improving resilience to climate variability. Its ability to thrive in marginal areas and adapt to unfavorable environmental conditions sets it apart from several other conventional oilseed crops<sup>7, 9</sup>.

Camelina is a cool-season crop that germinates at low temperatures of 34 to 36°F (1 to 2°C) and produces small, self-pollinating yellow flowers with four petals arranged in a raceme upon maturity. The stems of the plant may be smooth or hairy, branching, and eventually turning woody<sup>5</sup>. The crop's small seeds, less than 1/16 inch in diameter with a ridged surface, allow for a double cropping strategy, enabling farmers to cultivate it twice in a single season and transforming its status from a common commodity to a cash crop<sup>5, 18</sup>. Camelina's shorter life cycle, compared to other crops in the Brassicaceae family, facilitates the planting of a second crop, which may also help reduce nematode populations due to its high glucosinolate content<sup>19</sup>. Moreover, the combined use of Camelina with other crops like lentils, peas, and soybeans enhances agricultural biodiversity, reduces soil erosion, and minimizes nitrate and phosphorus loss without compromising the growth or yield of primary crops<sup>4, 20</sup>. While nitrogen fertilizer can boost Camelina production, with applications of 90 to 100 kg of nitrogen per hectare increasing yields significantly for both winter and summer varieties<sup>3, 21</sup>, its overall cultivation could improve economic resilience and food security in Ethiopia's semi-arid regions.

#### 3.2 Environmental sustainability

Camelina contributes significantly to environmental sustainability due to its low carbon footprint and reduced



Fig. 2 Camelina plant and seed<sup>61)</sup>.

need for fertilizers and pesticides. As a hardy, drought-resistant crop, Camelina requires minimal inputs compared to traditional oilseed crops, which often rely heavily on chemical fertilizers and pest control<sup>22)</sup>. Its ability to thrive in nutrient-poor soils means that farmers can cultivate Camelina without the environmental burden associated with synthetic fertilizers, thus minimizing soil degradation and reducing greenhouse gas emissions associated with fertilizer production and application. Furthermore, Camelina's natural resistance to pests can lower the reliance on chemical pesticides, promoting a healthier ecosystem and reducing potential harm to beneficial organisms in the soil<sup>22, 23)</sup>.

In addition to its low input requirements, Camelina plays a vital role in crop rotation systems, enhancing soil conservation and agricultural biodiversity. When integrated into crop rotations, Camelina can help break pest and disease cycles, reducing the prevalence of soil-borne pathogens and promoting healthier crops<sup>24, 25)</sup>. Its high glucosinolate content also acts as a bio-fumigant, aiding in the management of nematodes and other soil pests. This crop improves soil structure and health, contributing to increased organic matter and nutrient availability in subsequent crops. By planting Camelina as part of a diversified cropping system, farmers can enhance soil fertility, reduce erosion, and improve overall ecosystem resilience, making it a sustainable choice for modern agricultural practices<sup>25, 26)</sup>.

#### 4 Chemical Composition of Camelina

*Camelina sativa* meal is rich in various antioxidant components, including flavonoids, phenolic acids, gamma- and alpha-tocopherols, xanthophylls, and phytosterols. These compounds play a crucial role in stabilizing the oil, thereby extending its shelf life<sup>20)</sup>. Notably, Camelina oil

contains significantly higher levels of thiamin, with concentrations reaching 18  $\mu\text{g/g}$  compared to rapeseed at 8  $\mu\text{g/g}$  and flaxseed at 6  $\mu\text{g/g}$ . Additionally, Camelina seeds boast substantial amounts of phosphorus, potassium, sulfur, calcium, and magnesium, along with an ash content ranging from 4.15% to 4.31%<sup>27)</sup>. Furthermore, research by Faten & El Habbasha<sup>27)</sup> highlights that Camelina meal contains 13% residual oil, 6% ash, 12% crude fiber, 30% crude protein, 27% non-nitrogenous matter, carbohydrates, and other vitamins.

According to Delver & Smith<sup>28)</sup>, the amino acid profile of Camelina meal is comparable to that of soybean and canola meals. The four most comparable common amino acids identified in both Camelina and soybean meals are glutamate, aspartate, arginine, and leucine. Additionally, a study by Razmaité et al.<sup>21)</sup> reported the compositional values for Camelina, hemp, and flaxseed seeds, revealing sugar content at 3.76%, 2.33%, and 3.16%; protein content at 23.35%, 22.17%, and 21.51%; and fat content at 34.28%, 30.95%, and 31.87%, respectively. Among traditional oil sources, Rahman et al.<sup>29)</sup> found that *Camelina sativa* L. exhibited a comparable total phenolic content of 11.69 mg/g and a total flavonoid content of 6.81 mg/g. Furthermore, the mean Vitamin E profile of Camelina oil was compared to that of canola, sunflower, soybean, and crambe oilseeds, revealing a total tocopherol concentration ranging from 800 to 900  $\mu\text{g/g}$ <sup>27)</sup>. However, the high levels of unsaturated fatty acids in Camelina oil can lead to the production of oxidation products during free-radical chain reactions in the presence of oxygen. These compounds are responsible for oxidative rancidity, discoloration, and deterioration of sensory and nutritional qualities<sup>30)</sup>.

Vegetable oils contain important fatty acids, encompassing all classes of saturated fatty acids (SFAs), monounsaturated fatty acids (MUFAs), and polyunsaturated fatty acids (PUFAs)<sup>31)</sup>. However, the specific composition of fatty

acids varies depending on the parent plant. According to the data presented in Table 1, Camelina oil is particularly rich in polyunsaturated fatty acids, especially n-3 and n-6 PUFAs. Therefore, while Camelina oil can be a valuable addition to the diet, it is generally not recommended for daily use as the primary cooking oil; instead, it should be incorporated as a supplement alongside other PUFAs. *Camelina sativa* seed oil is characterized by low levels of saturated fatty acids (10.2–16.1%)<sup>9, 32, 33</sup> and moderate levels of monounsaturated fatty acids (5.06–6.05%), primarily consisting of palmitic acid<sup>34, 35</sup>. The lipid content of *C. sativa* seeds varies significantly, ranging from 36.5% to 40.2%, with polyunsaturated fatty acids constituting 54.6% to 55.2% of the total fatty acids<sup>9, 32, 36, 37</sup>.

Reports indicate that eicosenoic acid levels in Camelina oil range from 11.60% to 19%, which contributes to its susceptibility to autoxidation, making it less suitable for food applications. In comparison to other commonly used vegetable oils, Camelina oil contains erucic acid at a concentration of 1.6% to 4.2%, below the permissible limit of 5%, thereby minimizing the risk of adverse health effects

such as elevated triglycerides and free fatty acids<sup>9, 38</sup>. Erucic acid is often regarded as a limiting factor in vegetable oils, impacting their suitability for human consumption<sup>39</sup>. Additionally, Camelina oil contains gondoic acid, which is rare in most vegetable oils, with concentrations reported between 10.56% and 15.19%<sup>9, 32, 37</sup>. While common vegetable oils like olive, corn, and sunflower oil typically have less than 1% linolenic acid, soybean and rapeseed oils contain around 8%, and flaxseed oil has up to 60%. In contrast, Camelina oil exhibits high levels of unsaturated fatty acids, with linoleic acid (18:2) concentrations ranging from 16.00% to 19.60% and linolenic acid (18:3) concentrations between 28.00% and 38.10%. Furthermore, due to its high content of eicosenoic acid (11.51% to 19%), Camelina oil is a source of medium-chain fatty acids (MCFAs), which are typically found only in palm and coconut oils in Europe, thus making it a unique addition to the range of plant-based oilseed options<sup>9, 32, 39–41</sup>.

**Table 1** Polyunsaturated composition of Camelina (*Camelina sativa* L.).

Fatty acids	Concentration (%)	Reference	Fatty acids	Concentration (%)	Reference
Myristic (C14:0)	0.10	(38)	Arachidic (C20:0)	1.37	(35)
	0.22	(40)		1.22–2.33	(9, 60)
	0.14	(35)		1.11	(38)
	0.06	(9, 34)		4.60	(41)
Palmitic acid, (C16:0)	6.05	(35)	Eicosenoic (C20:1)	11.60–15.1	(9)
	5.2	(9, 34)		13.4	(40)
	5.90	(41)		11.51	(35)
	5.06	(32)		19	(39)
Palmitoleic (cis-9 C16:1)	0.11	(35)	Gondoic (C20:1 n-9)	10.56–15.19	(9, 37)
	0.80	(41)		14.6	(32)
	2.2–3.08	(60)		11.51	(35)
Stearic (C18:0)	2.69	(32)	Behenoic (22:0)	0.27	(9, 35)
	2.2–3.08	(9, 34)		0.26	(40)
Elaidic (trans-9 C18:1)	10.57	(9)	Erucic (C22:1 n-9)	1.6–4.2	(9, 38)
	12.40	(34)		2.20	(35)
Oleic (C18:1)	19.81	(35)	Lignoceric (C24:0)	0.13–0.28	(9, 60)
	16.27	(38, 40)		0.28	(37)
Linoleic (C18:2)	16.00–19.60	(9, 35)	Total SFA	10.2–11.3	(9)
	16.7	(32, 40)		13.40–14.13	(33)
	17.90	(41)		16.1	(32)
Linolenic (C18:3)	28.00–38.10	(9, 35)	PUFA	55.2	(9, 37)
	36.1	(32, 40, 41)		54.6	(32)
	37.33			55.12	(36)

## 5 Nutritional Importance of Camelina

### 5.1 Camelina oil in human nutrition

The growing interest in the health benefits of various nuts, seeds, and oils has led to a significant increase in consumer demand for oils derived from these sources, primarily due to their rich content of essential fatty acids. Among these, *Camelina sativa*, often referred to as “fake flax” or “gold of pleasure,” has emerged as a promising oilseed crop. Recognized as a novel source of vital fatty acids, particularly omega-3 fatty acids, Camelina holds considerable potential for both human consumption and animal feed products<sup>32, 34</sup>. Supplementary Camelina meal boasts a sucrose content of 5.5%, which is notably higher than that of flaxseed (2.8%) but slightly lower than rapeseed (6.8%). Furthermore, Camelina contains significantly lower levels of oligosaccharides alongside a fair proportion of monosaccharides and disaccharides, rendering it easily digestible and a readily available source of energy for the human body<sup>27, 42</sup>. Recent studies by Razmaité et al.<sup>21</sup> have highlighted that Camelina seeds exhibit superior levels of protein, oil, and sugar compared to dehulled hemp and flax seeds, reinforcing its nutritional value.

Camelina oil is distinguished by its unique properties, including high levels of tocopherols and eicosenoic acid, which contribute to its remarkable stability against oxidation. These compounds are capable of scavenging free radicals and may help prevent a range of diseases in humans, exhibiting potential antiviral, antibacterial, anti-tumor, and anti-mutagenic effects. Moreover, they may promote skin elasticity, support cell regeneration, and enhance overall health<sup>39, 43</sup>. The presence of phenolic compounds in Camelina oil and meal further emphasizes its health benefits; these compounds are recognized as significant food metabolites capable of preventing various pathologies, including cancer, neurological disorders, and cardiovascular diseases. Polyphenols act as reducing agents by transferring atoms or electrons, chelating metal ions, and limiting the activity of oxidases, thereby showcasing intriguing antioxidant properties in Camelina oil<sup>29, 44</sup>.

The high concentration of n-3 PUFAs in Camelina oil, particularly  $\alpha$ -linolenic acid, has been linked to promoting neurological development and overall health<sup>27</sup>. Furthermore, Camelina oil has been shown to facilitate lipid reduction by converting large lipoproteins into smaller ones, effectively managing blood lipid metabolism, enhancing liver function, and providing protection against cardiovascular diseases<sup>18</sup>. Additionally, Camelina serves as a valuable source of vitamins B1, B3, and B5, which play essential roles in brain function and maintaining a healthy appetite<sup>27</sup>.

A study by West et al.<sup>33</sup> found that dietary supplementation with transgenic *Camelina sativa* seed oil, enriched with docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), was equally effective as fish oil in boosting

long-chain omega-3 fatty acid levels. Similarly, Estakhr & Ranjbar<sup>45</sup> reported that Camelina seed supplementation improved the oxidative stability of milk samples, resulting in higher-quality milk suitable for human consumption when integrated into a grass-silage-based diet. Beyond its nutritional advantages, Camelina offers potential industrial applications, including low-emission biodiesel fuels, eco-friendly paints, coatings, and cosmetics<sup>7, 34</sup>. This multifaceted potential underscores Camelina's role not only as a nutritionally rich food source but also as a sustainable resource for various industries.

### 5.2 Camelina meal in animal nutrition

Camelina seeds are utilized not only in the oil extraction process but also in the production of meal, which serves as a valuable ingredient in various animal feed industries. These seeds and their by-products can effectively replace traditional protein sources in ruminant diets with minimal adverse effects<sup>9, 28</sup>. The oil content derived from Camelina seeds is rich in lipids, particularly PUFAs, which are essential energy sources for high-producing animals. The high levels of n-3 and n-6 fatty acids found in Camelina oil are particularly noteworthy, as they contribute to improved animal health and product quality, such as enhanced milk and meat nutritional profiles. Furthermore, the digestion of Camelina seeds and their derivatives results in minimal methane production, making them an environmentally friendly option for animal fodder<sup>46</sup>. This reduced greenhouse gas emission is particularly significant in the context of sustainable agriculture, where minimizing the carbon footprint of livestock production is a growing priority.

The versatility of Camelina seeds extends beyond their nutritional benefits. They can be incorporated into various animal feed formulations, making them suitable for different species, including poultry, swine, and ruminants. This adaptability is especially important as the agricultural industry seeks to diversify protein sources and reduce reliance on conventional feed ingredients, such as soybean and corn, which are often associated with higher environmental impacts<sup>5, 28</sup>. Additionally, Camelina meal is relatively high in fiber, which can aid in digestion and improve gut health among livestock. Research also indicates that the use of Camelina meal can enhance the overall feed conversion ratio, leading to more efficient growth rates in animals. This efficiency is critical for livestock producers aiming to maximize productivity while minimizing costs<sup>9, 28, 46, 47</sup>. Furthermore, the unique composition of Camelina meal can support animal welfare by providing a balanced diet that meets the nutritional needs of livestock, ultimately promoting better health and productivity. As the demand for sustainable and nutritious feed options continues to grow, Camelina seeds represent a promising alternative that aligns with the evolving practices in modern animal husbandry<sup>28, 48</sup>.

Despite these advantages, the inclusion of *Camelina* meal in animal feed is sometimes limited by the presence of anti-nutritional factors<sup>49)</sup>. However, Alhomodi et al.<sup>50)</sup> suggested an innovative solution involving fungal fermentation of *Camelina* meal to mitigate these drawbacks. Given the current deficiency of n-3 polyunsaturated fatty acids in human diets, feeding livestock with *Camelina* seed, cake, or oil presents an opportunity to enhance the nutritional quality of animal products. For instance, studies indicate that chickens fed a diet rich in *Camelina* meal exhibited increased total protein levels in their breast flesh<sup>51)</sup>. Moreover, research by Yenİçerİ et al.<sup>37)</sup> found that the duodenum of chickens on a *Camelina* diet had higher total omega-6 fatty acid levels compared to those fed other meal types. In a significant finding, Cherian<sup>52)</sup> reported that broiler chickens fed a diet containing 10% *Camelina* meal had omega-3 fatty acids in their meat and eggs increase by two to 2.5 times compared to those on a control diet based on maize and soybeans. This suggests that incorporating *Camelina* meal into the diets of laying hens can substantially enhance the nutritional quality of their eggs<sup>53)</sup>.

Furthermore, a study by Zajaç et al.<sup>54)</sup> highlighted the positive effects of adding micronized full-fat *Camelina*, flax, or sunflower seeds at a 15% level in broiler diets, showing improved performance and nutrient utilization. Specifically, broiler chickens experienced an average weight gain increase of 9% when fed *Camelina* and flax seeds, and a 6% increase with sunflower seeds. *Camelina* can also be effectively substituted in ruminant diets, providing a superior fatty acid and amino acid profile with reduced anti-nutritional effects<sup>9)</sup>. Research by Pikul et al.<sup>55)</sup> demonstrated that goats fed diets supplemented with *Camelina sativa* cake exhibited higher levels of beneficial fatty acids in their milk. Additionally, studies by Alhomodi et al.<sup>50)</sup> and Riaz et al.<sup>9)</sup> indicated that feeding *Camelina* meal to dairy cattle improved the fatty acid composition of milk, decreasing saturated fatty acids while increasing polyunsaturated fatty acids. Supporting this, supplementary research by Hixson et al.<sup>56)</sup> and Koskela et al.<sup>57)</sup> found that various fractions of *Camelina sativa* significantly enhanced the levels of polyunsaturated fatty acids in fish body composition, leading to improved weight gain and growth performance. These findings collectively underscore *Camelina*'s potential to enhance animal nutrition while promoting sustainable farming practices.

## **6 Camelina Potential as a New Vegetable Oil Source in Ethiopia**

Ethiopia's oilseed industry plays a vital role in generating foreign exchange profits and sustaining the livelihoods of stakeholders across the value chain. Oilseeds such as sesame, soybean, and Niger seed account for approximate-

ly 17% of the country's agricultural exports, ranking third in terms of foreign exchange earnings, just behind cut flowers and coffee<sup>58)</sup>. Despite this contribution, Ethiopia faces a significant challenge: the demand for edible oils is high, but local production falls dramatically short of meeting domestic needs, with around 95% of the country's vegetable oil supply being imported<sup>12, 59)</sup>. This dependence not only strains the nation's foreign currency reserves but also exposes the economy to global price fluctuations, affecting the stability of domestic food prices.

To alleviate the burden on consumers, the Ethiopian government has implemented subsidies for edible oil imports; however, this approach is neither sustainable nor economically viable in the long term. Such subsidies place a significant strain on the nation's foreign exchange reserves and expose the economy to global price fluctuations, which can lead to unpredictable price changes in the local market. Recognizing these challenges, the government has initiated a strategic shift by actively promoting investment in the edible oil manufacturing sector to enhance local production capabilities<sup>59)</sup>. This initiative aims to not only reduce reliance on imported oils but also to stimulate the domestic economy and create job opportunities within the agricultural and manufacturing sectors. By facilitating both domestic and foreign businesses to import and supply edible oils to the local market using their foreign currency reserves, the government is fostering an environment conducive to investment in local oilseed processing. This move not only seeks to stabilize the edible oil market but also creates an opportunity to transition towards a more self-sufficient oilseed industry, ultimately bolstering food security and reducing vulnerability to international market dynamics<sup>12)</sup>.

Despite the current shortfall in oilseed production, there are ambitious plans to develop new edible oil sources capable of fulfilling up to 60% of the nation's demand. This will involve ramping up agro-industries and edible oil processing facilities to enhance long-term oilseed production<sup>59)</sup>. A critical aspect of this agroecological transition involves encouraging the diversification of oilseed crops, which can improve overall crop production in alignment with varying agricultural conditions. Crop diversification not only stabilizes revenue streams from exports but also mitigates volatility in earnings, thereby increasing farmers' incomes<sup>58)</sup>. In this context, Alemaw & Gurmu<sup>12)</sup> note that oils from peanuts, sunflowers, olives, and palm are among the vegetable oils imported for domestic consumption. However, the establishment of several vegetable oil manufacturers has revealed a lack of sufficient raw materials. These facilities primarily package, refine, and distribute imported crude palm or soybean oil, underscoring the need for locally sourced alternatives. Estimates indicate that these operations can save up to 20% on foreign exchange costs, but they still rely heavily on imports to meet

demand.

Introducing *Camelina sativa* L. to Ethiopia's oilseed sector could be a transformative step towards reducing the country's reliance on imported edible oils. This oilseed crop is particularly promising due to its adaptability to various climates and the availability of both winter and spring varieties, which enhances its cultivation prospects. Camelina is well-suited for marginal areas due to its short growing season, low input requirements, and resilience to both biotic and abiotic stresses<sup>9, 35, 41</sup>. Moreover, Camelina is increasingly recognized as a valuable oilseed crop rich in omega-3 fatty acids, yet its full potential for food applications remains largely untapped, especially in Ethiopia and other African regions<sup>8</sup>. The introduction of Camelina could significantly impact Ethiopia's edible oil landscape. By cultivating Camelina at scale, the country can begin to fulfill a substantial portion of its domestic edible oil needs, thereby reducing the volume of imported oils. This reduction would not only save foreign exchange reserves but also enhance food security and stabilize local food prices. Additionally, Camelina oil has unique nutritional benefits, particularly its high content of omega-3 fatty acids, which are crucial for human health. Incorporating Camelina oil into cooking and food preparation could improve nutritional profiles in local diets, addressing common deficiencies.

Furthermore, the Camelina meal, a by-product of oil extraction, can serve as a high-protein feed supplement for livestock, enhancing the nutritional quality of animal products such as milk and meat. This dual-use potential serving both human consumption and animal feed positions Camelina as a strategic crop that can contribute to a more resilient agricultural economy<sup>9, 28</sup>. Despite these advantages, the successful integration of Camelina into Ethiopia's agricultural system will require targeted investments in research and development to optimize cultivation practices and processing technologies. It is crucial to develop improved seed varieties, establish efficient supply chains, and create awareness among farmers about the agronomic benefits and market potential of Camelina. Educational programs can also inform consumers about the nutritional benefits of Camelina products, encouraging local consumption and fostering a market for these goods.

The introduction of *Camelina sativa* L. into Ethiopia's agricultural landscape presents a multifaceted opportunity to enhance the oilseed sector, promote sustainable farming practices, and improve nutritional health among the population. By leveraging the unique qualities of Camelina, Ethiopia can work towards greater self-sufficiency in edible oils, significantly reducing its dependence on imports. This strategic move not only bolsters the agricultural economy but also fosters a resilient food system capable of meeting the needs of its growing population. Ultimately, the promotion and development of Camelina could serve as a cornerstone for Ethiopia's agricultural and economic future, en-

suring a more sustainable and nutritious food supply for all Ethiopians.

In general, Camelina's emergence as a nutritionally rich oilseed crop is underpinned by its unique chemical composition and its agroecological adaptability across diverse environments. These two foundational attributes not only explain its growing appeal in health-conscious markets but also support its viability in regions with challenging agronomic conditions, such as Ethiopia. While Camelina's historical background and commercial uses provide important context, these aspects are addressed primarily to demonstrate how its nutritional properties and ecological resilience translate into practical value chains. For instance, its utility in animal feed and industrial products stems from the same biochemical traits such as high omega-3 content and oxidative stability that make it attractive for human consumption. By aligning Camelina's agronomic potential with its compositional strengths, this review underscores how Ethiopia can leverage these attributes to reduce edible oil imports, diversify crop production, and improve food security in a sustainable manner.

## 7 Challenges and Opportunities in Camelina Oil Commercialization in Ethiopia

### 7.1 Challenges in Camelina oil commercialization in Ethiopia

The commercialization of Camelina oil in Ethiopia faces several significant challenges, primarily in the areas of supply chain development, market penetration, and regulatory hurdles. The existing supply chain for oilseed crops is often underdeveloped, marked by inadequate infrastructure for processing, storage, and transportation. This inadequacy leads to high post-harvest losses and increased costs for producers, ultimately affecting profitability and market competitiveness. Additionally, the market for Camelina oil is relatively new and not well established, making it difficult for farmers and processors to penetrate the existing edible oil market, which is largely dominated by traditional crops such as sesame and soybean. Furthermore, regulatory challenges, including inconsistent policies on oilseed production, import tariffs on competing products, and insufficient quality standards for local oils, can impede the commercialization of Camelina oil. These hurdles create uncertainty for investors and producers, making it difficult to establish a stable market for Camelina oil. To effectively address these challenges, a concerted effort from government agencies, industry stakeholders, and agricultural organizations is essential. Collaborative initiatives can help create a more robust supply chain and facilitate market access for Camelina oil.

## 7.2 Opportunities in Camelina oil commercialization in Ethiopia

Despite the challenges, there are significant opportunities for Camelina oil commercialization in Ethiopia that can be leveraged to drive growth in the sector. The increasing awareness of the health benefits associated with omega-3 fatty acids and the rising demand for healthier edible oils create a favorable market environment for Camelina oil. This trend can position Camelina as an attractive alternative for health-conscious consumers. Moreover, Ethiopia's commitment to reducing its reliance on imported oils presents an opportunity for local production initiatives. By emphasizing domestic cultivation of Camelina, the country can enhance its self-sufficiency in edible oil production. With the right branding and marketing strategies, Camelina oil can be positioned as a premium product in the Ethiopian market, capturing the interest of consumers seeking quality edible oils.

Furthermore, as global trends shift toward sustainable and environmentally friendly agricultural practices, Camelina oil known for its low input requirements and resilience to climate change aligns well with these values, enhancing its appeal in both domestic and international markets. To fully realize the potential of Camelina oil, support for smallholder farmers is essential. Implementing capacity-building programs focused on training farmers in best agricultural practices, pest management, and post-harvest handling can significantly improve yields and oil quality. Additionally, collaboration between government agencies, non-governmental organizations, and the private sector is crucial for creating an enabling environment for Camelina oil commercialization. Such partnerships can facilitate research and development efforts aimed at improving Camelina varieties suited for Ethiopian conditions, increasing productivity, and enhancing market competitiveness. By leveraging these opportunities while addressing the existing challenges, Ethiopia can capitalize on Camelina oil's potential to contribute to food security, economic development, and sustainability in the agricultural sector.

## 8 Conclusion and Future Prospects

This review underscores Camelina as one of the most economically viable oilseed crops, particularly due to its numerous nutritional applications and potential as a novel source of essential fatty acids, especially omega-3 and alpha-linolenic acid. Camelina oil stands out not only for its appeal in health-conscious diets but also for the intriguing functional qualities of Camelina meal, which is rich in antioxidants and phytochemicals valuable constituents that enhance its nutritional profile. The oil extracted from Camelina seeds can serve various purposes, including as a dietary supplement for humans and as a high-quality ingre-

redient in animal feed, owing to its rich composition of essential fatty acids and amino acids. Moreover, Camelina exhibits numerous advantages over traditional oilseed crops, such as its adaptability to diverse climatic conditions, low input requirements, and natural resistance to pests. These characteristics present significant agrotechnical and industrial benefits, making Camelina an economically viable crop for countries like Ethiopia, where sophisticated technological infrastructure may be limited.

Despite Ethiopia's diverse climate and extensive agricultural land, the potential for increased oilseed production remains largely untapped. The industry holds substantial prospects for enhancing the nation's oilseed export rate, generating income, and meeting domestic food demand. However, there are notable challenges, including underdeveloped supply chains, limited market access, and insufficient research on Camelina's properties and applications in the Ethiopian context. While many scholars acknowledge Camelina oil as a rich source of omega-3 fatty acids that could effectively replace conventional vegetable oils, there is a pressing need to advocate for its integration into Ethiopia's agricultural landscape and dietary practices. Additionally, Camelina could serve as a sustainable alternative to fish or seafood, particularly in regions where access to these products is limited or economically unfeasible.

To realize these prospects, it is essential to raise awareness among policymakers, farmers, and consumers about the benefits of Camelina cultivation and consumption. Support for smallholder farmers is crucial, as many may lack the resources and knowledge needed for successful Camelina production. Capacity-building initiatives focused on best practices and sustainable farming methods can help unlock the crop's potential. Future research should prioritize identifying and developing high-yielding Camelina varieties that are well-suited to Ethiopia's diverse agroecological zones. In addition, evaluating and refining cost-effective and scalable post-harvest processing techniques such as cold-pressing and oil refining methods adapted to local conditions will be vital for value addition and market competitiveness. Furthermore, research efforts should prioritize optimizing cultivation techniques and processing methods specific to Ethiopia's agroecological context. Collaboration between government, NGOs, and the private sector can facilitate investments in the necessary infrastructure and regulatory frameworks to support Camelina oil commercialization. By promoting Camelina as a key component of the national agricultural strategy, Ethiopia could enhance its food security, diversify its agricultural output, and pave the way for a more resilient and sustainable oilseed industry. Addressing the existing challenges while leveraging the significant opportunities presented by Camelina oil can contribute to the development of a thriving agricultural sector, ultimately benefiting both local farmers and consumers. Embracing Camelina as a viable

alternative can not only reduce the country's reliance on imported edible oils but also contribute to the overall economic growth and sustainability of Ethiopia's agricultural landscape.

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### Author Contribution

Banchiywsen Kidane: conceptualization, data organization, writing—original draft, and editing, Wesena Hunde: organization, review, proofreading, editing, final approval, and Markos Makiso Urugo: review, proofreading, editing, final approval, and supervision, Fikadu Tessema: review, proofreading, editing, final approval, and supervision, Tilahun A. Teka: review, proofreading, editing, final approval, and supervision.

### Conflict of Interest

The authors declare no competing interests.

### Availability of Data and Materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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