Sustainable Livestock Farming with Oil Seed Crops and Their By-Products

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ABSTRACT

The increasing human population and food shortage are fueling the demand for alternative feed resources for animals not meant for human consumption. Oil seeds and their derivatives are suitable options to meet the escalating global demand for animal feed proteins; camelina is one of them. Camelina sativa (CS), an ancient oilseed crop belonging to the Brassicaceae family, is known for its resistance to drought and cold, as well as its various uses for meal, oil, and other products. However, it also has some anti-nutritional factors (ANF) that can limit its use as animal feed. These ANFs can be reduced by various methods, such as enzyme addition, heat treatment, fermentation, or genetic engineering. CS and its by-products can affect animal metabolism, especially lipid metabolism and hormone levels, and can also improve the fat profile of meat and milk products, making them more suitable for human consumption and health. CS and its by-products achieved weight gain and protected dietary PUFAs, but decreased bio-hydrogenation intermediates. Small ruminants fed CS-supplemented diets produced meat with a suitable fat profile for human consumption. Feeding with CS seeds and derivatives decreased milk fat concentration, yield, and fat-corrected milk. Camelina forage, however, increased the milk fat percentage. The effects of CS and its by-products on milk fatty acid composition were contradictory. CS meals may improve the composition of milk products, making them healthier for humans. Researchers need to determine how CS meals can be used in dairy ewe and goat diets at different life stages.

Introduction

The world population is steadily increasing, which has led to increasing concerns about food security for human beings (31). Critics have targeted the ruminant production system for competing for feed supplies that could be used for human consumption. Ruminants have a lower feed conversion ratio than monogastric animals, which, combined with their higher environmental footprint, raises concerns (36, 68, 105). Ruminants, on the other hand, are important for livestock sustainability because they can consume crop residues and by-products that are not suitable for human consumption while also producing high-quality milk and meat (64). Milk and milk products, meat, and meat products have been reported to provide 25% of the total dietary energy intake and account for half of the saturated fatty acids (SFA), the primary source of monounsaturated fatty acids (MUFA), n-3 polyunsaturated fatty acids (PUFA), and trans-fatty acids for humans (107).

Enriching the animal diet could improve animal health and increase the contribution of milk and meat to the dietary intake of beneficial FAs (6, 90, 107). However, in several countries, forages have low protein levels, and they import high-protein resources, such as soybeans, which is costly. To address these issues, research on alternative feed resources has gained attention. The use of alternative feed resources is determined by their nutritional composition, animals, price, and environmental impact (1, 18, 81, 95). Agro-industrial byproducts are a promising source of alternative feed.

Soybean, rapeseed, canola, sunflower, cottonseed, groundnut, linseed, chia, palm kernel, and hempseed are commonly used oil- seeds, and their by-products after processing during oil extraction contain high volumes of nutrients and bioactive compounds. During the production process, manufacturers obtain a substantial byproduct in the form of oilseed cakes and meals. The nutritional composition of these byproducts varies a lot and can affect the health, production, and performance of animals. The nutritional makeup of these byproducts varies considerably, which can have a significant impact on the health, productivity, and performance of animals.

Camelina sativa (L.) Crantz has garnered attention from scientists worldwide as a potential source of healthy and nutritious ingredients for use in both food and feed. The positive agronomic traits, such as excellent environmental adaptability, drought resistance, cold tolerance, pest and pathogen resistance, a shorter life cycle, and tolerance to other environmental stresses, result in a reduced need for inputs, making it advantageous for farming (65, 72).

Camelina sativa (CS) seeds, oil, and cake are exceptional sources of beneficial fatty acids (FA), particularly long-chain PUFA. In addition to being an energy source for high-producing animals, CS seeds and their derivatives have the ability to decrease methane emissions, which is a major contributor to environmental pollution as a greenhouse gas (94, 100). Unlike other oilseed plants, CS also contains anti-nutritional factors (ANF) that can impair the performance of animals if included in large amounts in their diets (75). However, after oil extraction, CS meal showed a lower amount of crude fat and an increased amount of crude protein and amino acids (23).

The amino acid profile of the supplemented SC shows a more significant effect on the mRNA expression levels of the selected genes that are relevant to ewes' immune systems (20). Moreover, new CS varieties and the application of technologies for their processing have lowered the antinutritional content (35, 75). Researchers have discussed the effects of CS seeds, oil, and their by-products in ruminants, swine, poultry, and other animals (7, 70, 83, 98, 110). Nevertheless, the effects of CS seeds and their derivatives on feed intake, rumen digestion, fermentation, milk production, meat production, and composition are unclear because of conflicting results and the limited availability of research on small ruminants.

The present review aims to provide a comprehensive overview of the available literature on the general characteristics and nutritional composition of CS seeds and their derivatives as alternative feed sources, along with their use in the feeding of small ruminants, including their impact on the overall health and performance of small ruminants, such as feed intake, digestion, metabolism, milk production, composition, and milk by-product quality.

Use of Oil Seeds and Its By-Products in Animal Nutrition

There is a growing interest in identifying locally generated alternative protein feed sources to replace soybean meal in livestock production due to issues such as resource depletion, population growth, unsustainable consumption habits, rising demand for animal-sourced food, and climate change (4, 78).

The world's top cultivated seeds are soybeans, sunflowers, rapeseed and canola (102). Additionally, the world market has camelina, linseed, cotton, coconut, hempseed and pumpkin as noteworthy oilseeds (85). In animal nutrition, oilseeds are primarily utilized to provide various vegetable oils. The oil industry now provides protein-rich byproducts for livestock feed, in addition to oil. This is due to the abundance of byproducts accessible after extraction of oil. Cakes and meals are byproducts produced after the majority of the oil has been extracted from oilseeds. Oilseed cakes and meals may serve as an alternate protein source to meet the growing demand for protein-rich foods. Indeed, the worldwide need for animal protein is predicted to double by 2050 (73).

Soybean meal (SBM), a significant protein source, is commonly included in feed mixer rations (16) to boost the protein composition of diets. SBM has a CP concentration of 42-50%, which contains a major part as rumen-degradable protein (43). Nonetheless, as SBM is in popular sources, the price has risen, resulting in increased total feed costs. Furthermore, expanded soybean cultivation and enhanced commercial crop production are typically connected with negative environmental outcomes (54).

Rapeseed meal (RSM), which is the post-pressing leftover, is generated at 39 million metric tonnes per year (48), mostly used as animal protein feed (104). However, other dietary components (phenolics, glucosinolates, lignocellulosic fibre and phytates) impede the direct utilisation of RSM. This might harm protein solubility, digestion, and the production of toxic compounds. This has restricted both the species of animals that can be offered RSM and the percentage of RSM in overall diet. Ruminants, for example, may tolerate RSM due to their complicated digestive systems (97), It can only be used in up to 50% of swine feed and is not suggested for poultry (106). These limits have reduced the price of RSM low as compared to the more desirable SBM.

Canola meal (CM), a byproduct of canola oil extraction, has tremendous potential as animal feed since it comprises 35-40% protein, somewhat less than SBM (25), but much more B-vitamins and minerals. However,

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CM is a significantly lower-valued feed than SBM due to its high fibre and anti-nutrient concentration. Its use is confined to ruminant animals, and in some markets, it is applied straight to the soil as fertiliser (32). Anti-nutrients found in CM, such as phenolic chemicals and glucosinolates, might impair cattle growth performance (58). The overall fiber content in CM is on average 31.7 percent of dry biomass, which is greater than in SBM (61). Non-ruminant animals digest fibres poorly, particularly hemicellulose.

Sunflower meal (SFM) contains a significant protein level (about 30% to 50%) (27) e.g. albumins (17-30%), globulins (mostly helianthin protein), and other small proteins, such as oleosins (38). SFM peptide isolates are free of harmful ingredients and have a lower level of anti-nutritional components than other protein-rich alternatives such as mustard meal (glycosylates), SBM (trypsin inhibitors), or cotton meal (gossypol) (39).

Camelina is sometimes called false flax or gold of delight, is a Brassicaceae family oilseed crop. This crop's enormous potential is also being used to produce a stable feed for its variety of applications and to enhance dryland agriculture (49). Camelina has a comparable nutritious profile as CM, with high amounts of protein and fibre, but it is not as excellent a source as SBM, which contains more protein and less fibre. The oil extraction process yields identical meals, but the ejected camelina meal has significantly more fat and less protein, whereas the solvent-extracted meal contains less fat and more protein. This is particularly notable since the high quantities of glucosinolates in camelina meal are a major obstacle to its use in animal feeds, particularly for pigs. Lowering the glucosinolates by thermal processing, fungus fermentation, or genetic manipulation to develop low-glucosinolate variants may increase the nutritional value of camelina meal (29). In this review we will discuss the details of camelina usage in animal nutrition.

Discovery and Distribution

Bu In Auvervier and Switzerland, CS was cultivated as far back as 4000 BCE (41) the Iron Age (100 CE-250 BCE) (52) and evidence of extensive planting across northern Europe from Southern Scandinavia (103) to central Asia (eastern Turkey). The CS was grown for food and oil production, and it was widely accessible by the late Bronze Age (1200 BCE), according to archaeological sites (15). The cultivation of CS decreased throughout the Middle Ages but increased during the past century in northern, central, and eastern Europe, and the Balkans (51). False flax name was given to CS because it was probably brought to the Americas as a weed with flax (76). The CS is successfully farmed in the USA (34), and Canada (42). It tolerates heat stress with the following mechanism; increased root prospection and changes in the organic acid exudation are signs that camelina adopts a more acquisitive strategy (28).

General Characteristics

The CS is a heavily branching plant that is 20–80–100 cm in length morphologically. Its basal leaves form a rosette, and it has a taproot and whole or dentate leaves (62). The blooms have four nectaries and yellow petals, and terminal inflorescences. The fruits are tiny silicles with many seeds (11, 82), each of which has a high oil content (36 to 47 % (55). The positive agronomic traits of this oilseed can be very useful in agriculture, which is now developing into a significant issue for the environment and ecosystems (82). Due to their excellent environmental adaptability, CS crops can help to mitigate this problem. They can withstand drought, cold, pest and pathogen attacks, and other environmental stresses, which reduces the number of inputs needed for their maintenance, particularly irrigation, fertilizer, and pesticides (5, 7). In dry and semi-arid environments, its short life cycle (85–100 days), robust root structure, and resistance to cold weather make it a suitable choice for crop rotation, reducing fallow time and offering an alternative to monoculture (111).

Crop rotation and intercropping are said to have positive effects on the environment, including reducing weed growth, increasing soil organic matter, and reducing erosion (10, 22, 53). The CS possesses nectareous blooms (112). Cultivating CS increases agricultural productivity by increasing the diversity of insects and by giving them a healthy environment (forage, nectar, nesting, etc.) (62). The CS stands out for its wide range of applications in addition to its advantages for ecology and its agronomic traits. Due to the high protein content of the seed meal (60, 83) and the excellent nutritional value of the seed oil (80), studies are also being conducted to investigate its potential application in animal and human feed. Finally, in this context of climate and global change, CS crops can play a significant role in lowering the consumption of fossil fuels, the use of land, and the production of greenhouse gases, thereby assisting in the development of circular and sustainable agriculture that does not harm ecosystems or biodiversity (66, 93).

Factors Affecting *Camelina Sativa*

Factors affecting the production of CS include biotic (weed, insects, disease) and abiotic (temperature, water, salt (NaCl and KCl). The findings of a study (108) show that salt (NaCl and KCl) stress significantly lowers the speed, percentage and index of germination, shoot length, root length, vigor index, root shoot ratio, and seedling fresh weight of the salt-treated CS seeds. At the highest levels of salt concentration (5g/L), the fresh weight of seedlings dropped as seedling length fell with increasing

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salinity levels. Although CS is resistant to various external factors compared to other plants still some factors need to be considered, which are shown in figure 1.

The CS seed vegetable oil is extracted by different methods which has been displayed in Figure 2.

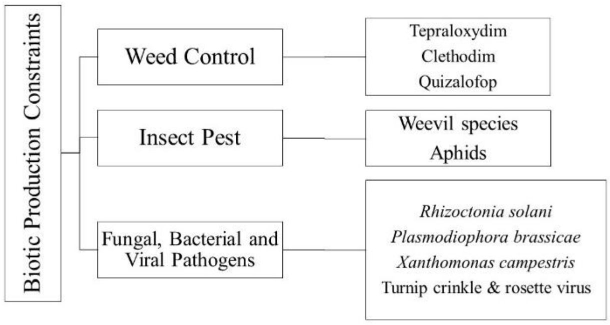

Figure 1. Biotic production constraints for Camelina Sativa Extraction of oil from *Camelina sativa*.

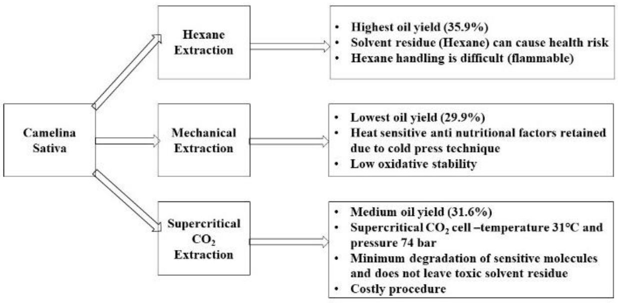

Figure 2. Different methods of oil extraction from *Camelina Sativa.*

Combinations of both methods are most often used for economic reasons since the pressing process leaves a significant amount of residual oil in the oil cakes and meals, which can be extracted by solvent extraction. There is another method of oil extraction which is instant controlled pressure drop (DIC), when using solvent extraction, DIC pre-treatment combined with Accelerated Solvent Extraction (ASE) enabled the extraction of 10.8% more oil from CS seeds compared with untreated seeds. Bouallegue et al. (9) stated that the best way to extract CS oil is by DIC pretreatment since it increased CS oil yields, speeds up the extraction process, and valorized pressing meals. Indeed, CS and its byproducts contain moisture (6-11.4%), dry matter (88.2-94%), crude protein (19.35-41.1%), NE_L (2.20-2.58 Mcal/kg), ADF (11.1-22.53%) and NDF (22.7-39.9%) based on dry matter (83).

Nutritional Characteristics of *Camelina Sativa*

The CS stands out from other oilseed crops thanks to its appealing nutritional profile. Understanding this profile is essential to comprehending both the promise of this crop in terms of human and animal nutrition, as well as the difficulties experienced in increasing its nutritional features. The CS seeds have a high amount of oil, with a weight percentage of oil content ranging from 38% to 43% (113). Particularly interesting is the fatty acid makeup of this oil. Alpha-linolenic acid (ALA), an omega-3 fatty acid, is the major form of polyunsaturated fatty acid (PUFA) found in abundance in it (63). CS oil contains PUFAs in a larger proportion than many other oilseed crops, at around 35% of the total fatty acids (44).

Because the human body is unable to produce omega-3 fatty acids, it is necessary to consume them in the diet (92). They have been associated with several health advantages, including lowering heart disease risk and inflammation, enhancing mental health, and promoting growth and development (14, 84). CS oil is a good plant-based source of these vital nutrients due to its high omega-3 level.

In addition to having a lot of oil, CS also has a lot of protein. It has been discovered that the leftover seed meal contains up to 40% protein after oil extraction (46). This protein-rich meal might be used as a healthy ingredient in livestock feed, creating sustainable animal farming techniques (33). Additionally, the oil of CS is high in tocopherols, a class of chemicals sometimes called vitamin E (50). Strong antioxidants like vitamin E shield cells from the harm that free radicals may do (69). Additionally, it is essential for immunological performance, cell communication, and other metabolic activities (87). The CS oil's high tocopherol concentration increases its nutritional value and extends both the stability and shelf life of the oil (86).

The CS's high plant sterol content is another beneficial nutritional characteristic. These substances, often referred to as phytosterols, have been demonstrated to prevent cholesterol absorption in the stomach, hence assisting in the reduction of blood cholesterol levels (56). Consuming meals high in plant sterols may improve heart health since eating high cholesterol-free diets lowers the chance of developing heart disease (45).

The CS is distinguished for its higher nutritional profile when compared to other oilseed crops. For example, CS oil, one of the most popular vegetable oils, has a much greater omega-3 concentration than canola oil (59). Furthermore, its protein level is equivalent to that of soybean meal, a key ingredient in livestock feed (47).

The CS is a desirable choice for initiatives to improve the quality and quantity of oilseed crops because of its overall nutritional characteristics. Nevertheless, despite its promise, there are still obstacles standing in the way of completely reaching this potential, such as genetic restrictions, agronomic problems, and legal barriers (79). Along with its positive aspect, some anti-nutritional factors are also present in it, which are described in the anti-nutritional factor part.

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Anti-Nutritional Factors

There is a significant difference in protein content between different types of CS. In contrast to the Alba variety, whose autumn and spring values did not surpass 39 g 100 g of DM, some of them had values greater than 45 g 100 g of DM in both sowing times (75). With the high protein content of CS, some ANF also come with them to reduce their digestibility which has been elaborated below.

Trypsin Inhibitor: The presence of trypsin inhibitor (TI) in CS seeds has not received much attention up to this point, even though it is known that they negatively impact protein digestion by blocking the proteinase enzymes (2, 12). This calls for careful consideration when selecting the types to be used as a source of protein in the diets of fish and mammals (17, 40). Like, Budin et al. (12) and Almeida et al. (2), Pozzo et al. (75) likewise found a broad range in TI content. The mean results, however, were lower than those mentioned in the earlier investigations. Regarding Luna, the greatest value observed for the spring Spanish CCE29 was about three times higher than the lowest. The figures for Luna and Przybrodzka, on the other hand, that were lower than 7.0 TIU mg^{1} during spring sowing indicated that their addition to feed, at the proper proportion, would be safe (75). The lowest level of TI was likewise found in the Luna and Przybrodzka meals, and the planting season does not appear to have an impact on their quantity.

Glucosinolates: Secondary metabolites called glucosinolates (GLSs), which include sulphur, are mostly found in the Brassicaceae family of plant species. They are the primary cause of CS meals' exclusion from animal feed. Genetic and environmental variables have been implicated in variations in the quantity and pattern of GLSs (91, 101). The GLSs were between 25.66 to 38.94 µmol/g. The cultivars CCE36, CCE26, and Pearl (in both sowing seasons) had the maximum GLS content (> 36 µmol/g), but Luna and Przybrodzka's meal had the lowest amount (26.5 µmol/g). Between the two planting dates, all varieties showed equivalent levels of GLSs, however only the Spanish varieties CCE26, CCE29, CCE32, and CCE40 and Celine showed discernible changes (75). The GLS pattern showed variations amongst the kinds as well. The literature found three primary GLSs: GLS9 (glucoarabin), GLS10 (glucocamelinin), and GLS11 (91). With a content of around 65 per cent of the total glucosinolates, GLS10 was as predicted the most prevalent glucosinolate in all kinds (data not shown), and following Russo and Reggiani (89), the quantity of GLS9 was frequently greater than GLS11. Only Przybrodzka (75), one of the other types examined in this study, had a significant aliphatic GLS chain elongation that resulted in a greater concentration of GLS11 than GLS9. Despite being less common, several genotypes have previously been shown to have more GLS11 than GLS9 (3, 88). Some scientists linked this unusual pattern to winter biotypes, hybrids, or wild species of CS (3, 91). Brassicaceae are known for their tendency to create GLSs with elongated chains, however longer aliphatic chains are thought to reduce the likelihood of hazardous chemicals being produced during the breakdown process.

Sinapine: A meal may acquire an unpleasant odour and flavour when sinapine (96), a choline ester of sinapic acid, is present in large proportions. Which, in turn, may have an impact on its flavour and the standard of animal products. With average values of 3.65 and 3.88 µg/mg for the two sowing dates, the sinapine in this study varied from 2.92 g µm/g (Ligena in spring sowing) to 5.03 µg/mg (Pearl in autumn sowing) (75). Sinapine was found at a level comparable to that reported for CS by Amyot et al. (3) and Juodka et al. (47), although it was much lower than that of other Brassicaceae species, whose median values ranged from 12 to 15 µg/mg (57, 114). Therefore, it might be concluded that sinapine side effects should not arise in the tested CS varieties.

Phytic acid: Due to its potent chelating abilities with nutritionally significant cations (Ca, Fe, Mg, Zn), phytic acid (PA), another ANF present in CS meal, can be a cause of the problem. The PA quantity in the different cultivars under investigation varied from 24.96 to 33.62 µg/mg in the fall planting (75). The amount of PA reported by Zubr and Matthäus (114) is consistent with the quantity and significant heterogeneity. In general, the amount of PA was a little bit lower in spring sowing than in fall sowing, with Alba, Cypress, and Celine being the exceptions. Different methods to reduce ANF have been summarized in Figure 3.

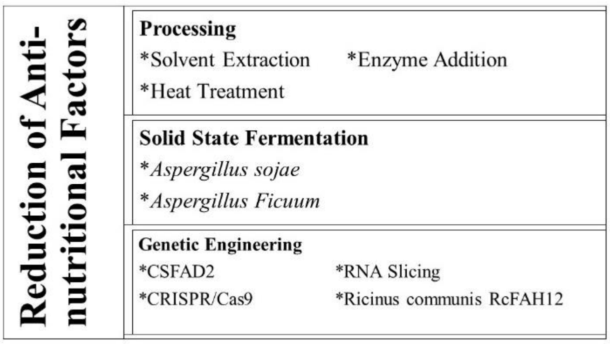

Figure 3. Reduction of Anti-Nutritional Factors of *Camelina Sativa*.

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Use of *Camelina Sativa* and Its by-products in Small Ruminants

Effect of Camelina sativa and by-products on Feed Intake, rumen digestion and metabolism in small Ruminants: Dry matter (DM) is the primary component in the preparation of animals' rations, and the DM intake and digestibility are crucial factors influencing animal performance. In high-producing animals, sufficient DM intake (DMI) is critical to provide adequate nutrients. Additionaly, the use of natural, safe, and sustainable intervention options, such as the incorporation of oils, oil-seed plant, and by-products has the potential to contribute to the safe production of animal products. Current evidence regarding the effects of CS and its by-products on the DMI of small ruminants is inconclusive. Noci et al. (67) studied the effects of various plant seeds, including CS seeds, linseed (LS), and NaOH-soaked CS, NaOH-soaked linseed, as well as oils such as camelina sativa oil (CO), linseed oil, and ethanolamine-reacted CO, and rumen-protected saturated fats (SF), on lambs. The DMI increased with the oil-supplemented diets compared to the seeds supplementation. However, the CS-supplemented diets reduced DMI compared to the linseed diets. The DMI was higher in the CS diet than in the NaOH-treated seeds. Similarly, DM, organic matter (OM), neutral detergent fiber (NDF), and fat digestibility were similar among the treatments compared to the control; however, crude protein (CP) digestibility increased, while ash digestibility increased in all treatments compared to the control. Similar to large ruminants (78), DM and OM digestibility was higher in CS-supplemented diets than in linseed-supplemented diets. Compared with the oil-supplemented diets, DM, OM, and CP digestibility decreased in seed-supplemented diets.

Studies also reported the effect of CS seeds cake (CSC) (12% in concentrate) and dried distiller grains (DDGS) (12% in concentrate) on blood serum metabolic, hormonal, and FA profile in the lactating ewes. Compared to the control, CSC supplementation reduced the levels of triglycerides, glucose, free fatty acids, and insulin. Blood urea nitrogen, alanine transaminase (ALT), aspartate transaminase (AST), leptin, and T3 levels remained unaltered among all treatments. However, T4 concentration increased with CSC and DGGS diets, thus reducing the T3/T4 ratio. This increase in insulin and T4 concentrations could be the result of increased metabolism and oxidation of lipids in the liver and muscles (83). Similarly, the serum fatty acid profile showed no change in saturated fatty acid (SFA), unsaturated fatty acid (UFA), MUFA, PUFA, n-3, n-6, n-6/n-3, medium-chain FA, or long-chain FA compared to the control diet. However, DGGS resulted in higher levels of MUFA, PUFA, and n-6 FA. Based on the available literature, the effects of CS seeds on the DMI in small ruminants are unclear. Studies have shown that supplementing the diet with CS and its by-products can cause changes in metabolism, particularly lipid metabolism and hormone levels. More research is needed to fully understand and optimize DM intake, digestion, and metabolism of the animals fed diets containing CS and its by-products.

Effect of the Camelina products on meat production, carcass traits, and tissue composition: Diet composition and supplementation can lead to changes in the rumen environment, microbial community and fermentation (30, 109). The presence of GSLs in CS is a concern when used as a replacement for protein and fat sources in ruminant diets, because they can have toxic effects on thyroid function and cause metabolic imbalances. However, Noci et al. (67) reported similar average daily gain (ADG), total intramuscular adipose tissues in the muscles of animals fed plant seeds or oils. Carcass weight and perirenal fat increased with oil supplementation compared with in those seeds. However, the results remained similar for the CS products (seeds vs oil). However, CS amides increased liver and kidney weights compared to the LS diets fed animals. Ramírez et al. (77) also reported no change in the average weight gain and ADG when compared the diet containing 50% CS meal (CM) in replacement of soybean to the fibrous diet containing a small amount of CM and other fibrous diets without grains and soybean, and control diet containing soybean and grains. The fibrous diet resulted in higher DMI in comparison to the CM and the control group. However, the lower feed intake compensated for the price in the CM and control diets. This higher feed intake in fibrous diet fed group could be the result of less energy supply by the fibrous diet, which was 20% lower than that of the other two diets.

Carcass traits such as hot carcass weight, cold carcass weight, dressing percentage, chilling loss, and pH at the time of slaughter and 24 h after slaughtering remained similar with diet having 50% soymeal-replaced with CM and fibrous diet (containing CS husk) compared to the control diet. The total fat, lean meat, and bone percentage remained similar among all diets. Similarly, after seven days of storage of meat, muscle color, cooking loss, dripping loss, Warner-Bratzler shear force (WBSF), and thiobarbituric acid reacting substances (TBARS) did not change among the treatments; however, pH was slightly higher in fibrous diet meat, which may be owing to the lower glycogen content of the muscle (74, 77). While studying the effect of CM (8% inclusion in the ration) and CS hay (45% inclusion in diet) reported an increase in fatty acid (n-3 FA, MUFA, PUFA) in the muscles from yearling and lamb meat compared to the control diet. Both animal type and storage period affected the oxidative stability of lipids and meat color. Researchers have reported a lower amount of vitamin E in the muscles of animals supplemented with CM and CS hay. Therefore, fortification with vitamin E is recommended to prevent color change during display and change in cooked meat color to off-white when long-term storage under semi-frozen conditions is required. The CS diet supplementation results in higher muscle fat; therefore, vitamin E supplementation is required to protect essential fats from oxidation.

Partial replacement (50%) of soybean meal (SBM) with CM and concentrates without grain and SBM offered to lightweight lambs for fattening resulted in altered FA composition in the muscles. Collectively, total SFA increased with partial replacement of CM and decreased with the fibrous diet compared to the control. However, CM replacement resulted in higher cis-MUFA compared to the fibrous diet, which produced higher MUFA trans-isomers, mainly the 18:1 isomer. Total CLA increased with a fibrous diet and remained similar for CM supplementation compared to the control (37). Noci et al. (67) reported a decrease in SFA with the supplementation of NaOH-treated CS, however, SFA remained unchanged with all the other treatments in intramuscular fat. The CS also resulted in higher MUFA content. The NaOH-treated seeds resulted in higher PUFA and n-3 FA compared to oil supplementation, whereas n-6 remained similar among all treatments. The PUFA/SFA ratio was similar for CM and CO and higher for LS. Seed supplementation resulted in a lower n3/n-6 ratio, which was significantly lower in the LS than in the CS seeds. NaOH-treated CS seeds supplementation resulted in an increase in cis-9 trans-11 CLA levels in subcutaneous adipose tissue and intramuscular fat. Thus, the health-beneficial FA can be increased efficiently within the muscles with NaOH-treated CS seeds or LS seeds, which can easily be processed on-farm. The use of CS and its by-products resulted in comparable outcomes for weight gain and a more substantial protection of dietary PUFA, but it decreased the incorporation of bio-hydrogenation intermediates. However, meat from animals fed diets supplemented with CS and its by-products showed a fat profile that is suitable for human consumption.

Effect of the Camelina products on the milk yield and Composition in Small Ruminants: The utilization of dietary oilseeds or their by-products affects milk production and composition, which is dependent on the inclusion level, derivative type, concentration of USFA, and composition of the basic diet (Table 1). Supplementation of dairy ewes with CS seeds at three different inclusion levels (6%, 11%, and 16%) did not change the milk yield, energy-corrected milk yield, fat-corrected milk yield, milk fat, or milk protein yield. In chemical analysis, the fat percentage decreased at the higher inclusion rate (16%), which also resulted in a decrease in the total solids percentage, while protein, lactose, and solid not fat remained similar among all treatments compared to the control (19). Similar results were reported by Szumacher-Strabel et al. (99), who studied the inclusion of CSC at rates of 10% and 20%, respectively, in the feed compared to the control (0%). The addition of 12% CSC resulted in similar results (26). Dairy ewes supplemented with CS forage (CF) had higher milk DM, fat, and lactose percentages than the control, while protein and ash contents remained unaltered (24).

Table 1. Effect of the Camelina sativa and its by-products on the production and composition of milk in small ruminant's.

Treatment	Inclusion rate (%, DM Basis)	Milk Production (g/d)	Lactose (g/d)	Protein (g/d)	Fat (g/d)	Lactose (%)	Protein (%)	Fat (%)	References
Control	0%[x]	1181	58.64	71.91	64.89	4.89	5.99	5.41[a]	(99)
CSC	10%	1316	58.23	70.65	61.22	16.13	5.89	5.10[ab]	
CSC	20%	1272	58.19	71.30	55.68	15.75	5.94	4.64[b]	
Control	0%[x]	1705		89.15	99.76	4.94	5.21	5.89[a]*	(19)
CSS	6%	1857		97.76	105.74	5.00	5.28	5.71[ab]	
CSS	11%	1874		101.26	107.1	5.04	5.43	5.85[a]	
CSS	16%	1887		98.60	99.75	5.02	5.23	5.35[b]	
CFD						4.62[a]	3.72	4.33[a]	(24)
Control						4.54[b]	3.61	4.11[b]	
CS seeds	12%		5.75[y]	3.92	3.93[b]				(26)
Control	0%		5.98	4.08	5.28[a]				

CSC= Camelina seed cake; CSS= Camelina Sativa Seeds; CFD = Camelina Forage Diet
[x] = % in concentrate (DM basis)
[y]= Chemical composition presented as g/kg.
[a,b,c,]= Values with superscripts describe the significant difference (P<0.05).

Table 2. Effect of the Camelina sativa and its by-products on the composition of milk and meat fatty acids in small ruminants.

Treatment	Inclusion rate (%, DM Basis)	SFA (%)	MUFA (%)	PUFA (%)	CLA Cis-9, trans-11 (%)	Total CLA (%)	n-3 (%)	n-6 (%)	n-6/n-3	Reference
Meat Fatty acids Composition										
Control	0%^{x}	0.26	0.23	0.10^{b}	0.71 $^{b,\,y**}$		22.60^{b,y**}	81.41^{y}	1.22^{y**}	
CSC	10%	0.28	0.26	0.14^{a}	4.12^{a}		33.97^{a}	109.22	0.95	(21)
CSC	20%	0.30	0.28	0.14^{a}	6.14^{a}		38.07^{a}	107.27	0.83	
CSM	12%	33.34^{a**}		15.44^{b}	0.28^{b}	0.57^{b}				
FIBD	6%	31.12^{b}		18.29^{a}	0.79^{a}	1.07^{a**}				(37)
Control	0%	32.60^{ab}		17.27^{ab}	0.18^{b}	0.46^{b}				
Milk Fatty acids Composition										
Control	0%^{z}	76.01^{a}	19.78^{d}	4.12^{d}	0.45^{d}		0.77d	2.91^{d}	3.78^{a}	
CSS	6%	69.93^{b}	24.68^{c}	5.19^{c}	0.68^{c}		1.05^{c}	3.46^{c}	3.30^{b}	(19)
CSS	11%	66.69^{c}	26.68^{b}	6.44^{b}	1.03^{b}		1.24^{b}	4.14^{b}	3.34^{b}	
CSS	16%	60.75^{d}	30.90^{a}	8.11^{a}	1.65^{a}		1.44^{a}	4.91^{a}	3.41^{b}	
Control	0%^{x}	71.88	20.93^{c}	4.02^{b}	0.62^{b}		1.05^{c}	2.76	0.26^{a}	
CSC	10%	66.86	23.43^{b}	4.96^{a}	1.07^{a}		1.53^{b}	3.08	0.20^{b}	(99)
CSC	20%	60.85	28.59^{a}	5.43^{a}	1.10^{a}		1.87^{a}	3.06	0.16^{c}	
Control	0%	68.36^{b}	27.53^{a}	4.11^{a}		0.53^{a}	0.99	2.33		(26)
CSC	12%	65.48^{a}	29.57^{b}	4.95^{b}		1.53^{b}	0.96	2.15		
Control		62.41	16.26	5.34^{b}	0.71^{b}		0.94	3.40^{b}		(24)
CFD		61.55	16.29	5.35^{a}	0.91^{a}		0.93	3.42^{a}		

CSM=Camelina Sativa Meal; FIBD= Fibrous Diet; CH=Camelina Hay; CSS=Camelina Sativa Seeds; CSC= Camelina Seed Cake; CFD= Camelina sativa Forage Diet; FA=Fatty Acids; SFA= Total Saturated FA; MUFA= Mono-Unsaturated FA; PUFA= Poly-Unsaturated FA; n-3=Total n-3 FA, n-6=Total n-6 FA; CLA= Conjugated linoleic Acid
[1]= % on DM basis otherwise stated; x=%age of concentrate; [y]= Values presented as mg/100g; [z] = As fed basis
[a,b,c,*,**]= Values with superscripts describe the significant difference (* = P<0.05, ** = P<0.001)

Increasing levels of CS seeds resulted in a linear decrease in short-chain FA, SFA, and SFA/USFA and a linear increase in long-chain FA, MUFA, PUFA, n-6, and n-3 FAs. The n-6/n-3 ratio decreased with CS seeds supplementation (Table 2). Similarly, α-linolenic acid cis-9, trans-11 (C18:2), and trans-10, cis-12 (C18:2) also increased with CS seeds supplementation. Overall, when the health-promoting index was evaluated, it increased in all treatments. Similar to the supplementation of CS seeds, the antioxidant enzymes and total oxidant capacity of milk increased, indicating the stability of milk for a longer duration. In addition, biomarkers for oxidative stress also remained similar among the 6% and 11% treatments, with a slight increase in blood and a decrease in milk with 16% group (19). Dairy ewes supplemented with CF had similar milk fat SFA, MUFA, short-chain SFA, and n-3 fatty acids. Total MUFA, CLA, total n-6, and total n-3 FA increased and long-chain SFA decreased with CS seeds' inclusion in diet. Compared to other CS seeds and cake, CS forage inclusion in diets resulted in a higher increase in total n-6 FA and n-6/n-3, however, their content remained at favorable levels. Overall, forage supplementation resulted in higher quality fatty acid production.

Szumacher-Strabel et al. (99) also reported an increase in all the health-beneficial fatty acids in ewe's milk with supplementation of 10% and 20% CSC compared to the control. In addition, thrombogenic and atherogenicity indices increased. However, dairy ewes supplemented with CF did not show any change in the atherogenic index, thrombogenic index, hypocholesterolemic FA, or hypercholesterolemic FA. Similar to previous results in other ruminants, CSC supplementation resulted in increased trans-MUFA, which should be considered when supplementing CSC.When CSC is used in amounts of 10–20%, it causes considerable alterations in the fragrance of ewe milk. Sheep fed CSC milk lost the general dairy aroma. It has a distinct lack of freshness in its scents. Regardless of the quantity of CSC supplied in the feed, pasteurization of the tested milk intensified the dairy fat, and cooked odors. With an increase in the quantity of CSC in the feed and after pasteurization, the level of total volatiles increased significantly (13).

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At present, only a single study is available on goats, where 12% supplementation of CSC in dairy goats resulted in no difference in DM, protein, fat, and mineral content of milk compared to the control. Compared to the control, goats fed the diet supplemented with CSC showed a change in the FA composition of the milk. The MUFA, PUFA, cis-9, trans-11 (C18:2), and CLA levels significantly increased, and SFA decreased in milk from CSC supplementation compared to the control (71). Feeding with CS seeds and its derivatives reduced milk fat concentration and yield, as well as the production of fat-corrected milk. However, camelina forage led to an increase in the milk fat percentage. Nevertheless, all other milk production and composition parameters remained unchanged in small ruminants fed diets containing CS and its by-products. However, the effects of CS and its by-products on the fatty acid composition of milk are unclear. Further studies are needed to evaluate the impact of different doses of SC and its derivative doses on milk production and composition.

Effect of the Camelina products on the milk by-products in small ruminants: Supplementation with 12% CSC was advantageous in terms of the FA profile of milk fat, leading to a greater proportion of MUFA, trans-MUFAs, and PUFA, including CLA. Milk from sheep with higher concentrations of bioactive ingredients is beneficial for the creation of yoghurt. Both immediately and 21 days after storage, yoghurt generated from CSC-supplemented milk showed the same beneficial variations in FA content. In addition, these bioactive components did not alter the color, acidity, and consistency or sensory characteristics (consistency, taste, and smell) of yogurt produced from CSC-supplemented milk compared to the control (26).

Cheese composition changes with the milk source and its composition (8). Caciotta cheese produced from the milk of ewes supplemented with CF showed no change in texture or color between the two treatments. Additionally, cheese produced from this milk did not show any difference in caciotta cheese DM composition and fatty composition, except for n-6 and n6/n-3, which remained higher in cheese similar to that of milk. Sensory properties, such as goat hardness, solubility, odor, taste, and overall liking, increased with the CF diet. However, all other studied sensory parameters remained similar among treatments (24). Similarly, the kefir produced from the milk of dairy goats supplemented with 12% CSC (% of DM in concentrate) showed no difference compared to the control diet milk kefir. However, similar to the milk composition, the incorporation of MUFA, PUFA, and CLA increased in kefir. Sensory parameters such as the taste, consistency, and aroma of kefir also remained similar between the two treatments (71). In a nutshell, CS and its by-products improve the composition of milk products, making them more suitable for human consumption and health.

Conclusion

In conclusion, to improve animal nutrition and overall farm sustainability, incorporating oilseed plants into livestock production systems presents a promising strategy. This review has revealed the numerous advantages of incorporating oilseed-based products, such as camelina, soybeans, sunflower seeds, and canola into the diets of livestock. These feedstuffs supply all the important nutrients to the animals and they also demonstrate the potential for reducing environmental impact by decreasing the use of conventional protein sources. Due to its nutritional advantages, environmental flexibility, and potential to enhance general health and performance, *Camelina sativa* has promise as a great resource for small ruminant feed. It has outstanding agronomic characteristics, a high oil content, and beneficial nutritional qualities, making it a good choice for sustainable agriculture and nutrition improvement. It is a potential oilseed that is a strong option for sustainable agriculture and nutrition improvement due to its high amounts of tocopherols, high levels of protein, and beneficial plant sterols. In order to fully realize its potential, one must take into account some anti-nutritional variables that are present in it. Small ruminants may benefit from the usage of CS and its byproducts in terms of dry matter intake, metabolism, meat output, and carcass characteristics. The addition of CS and its byproducts to the diets of small ruminants had no discernible impact on milk basic composition. Nevertheless, it does have favorable effects on fatty acid profiles, perhaps improving the quality of dairy products for ingestion without significant sensory changes. Additional research is required to examine the best doses, how they affect animal performance, the standard of animal products, and long-term impacts. Smilarly, to identify how to utilize CS meal as an alternative feed ingredient in the diets of developing dairy ewes and dairy goats at various life phases, further studies are required.

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Not applicable.

Animal Welfare

Not applicatble.

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