A review of the prospects of *Camelina sativa* L. in different cropping pattern as a potential feed source for the poultry industry

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Abstract

Camelina sativa L. is imperative oilseed crop of Brassicaceae family, and fitted best in different farming systems followed by farmers in agricultural countries. The byproducts of *Camelina sativa* L. (cake, seeds, oil) have immense use in different industries includes food, cosmetics, biofuel and animal feed industry. The seeds of *C. sativa* L. contains significant proportion of α-linolenic acid (C18:3n-3; ALA), oil in seeds and cake up to 36.7%, 36.8% and 22.7%, respectively. Further, tocopherol contents ranges up to 900 mg/kg of camelina oil. Thus, the processed byproducts of *C. sativa* L. improved n-3 polyunsaturated fatty acids and ALA of broiler meat. In addition, fatty acids profiling significantly decreased the n-6/n-3 ratio, thus addition of camelina cake in broiler feed also improved the human nutrition. However, increased proportion of camelina seeds in poultry feed showed non-significant improvement on broiler health and meat quality. Some studies reported the negative effects of camelia cake (> 10%) on meat feed digestibility subsequently lowers the broiler growth attributes. The carcass related qualities of chicken were similar to the birds. And, the addition of camelina did not improved the efficacy of sensory organs of poultry chicken. The present review indicate the prospects of camelina plants in agricultural farming system and its possible benefits to poultry feed industry. However, a comprehensive research on the appropriate concentration of camelina byproducts in poultry feed industry should be carried out in future for promising results.

Keywords**:** Camelina, Poultry, feed, fatty acid, *C. sativa* L.

I. Introduction

Camelina sativa (C. sativa L.) is a dicotyledonous and self-pollinated plant that belongs to the Brassicaceae family. It has a short growing period and a central position amongst other oilseed crops in the world. The stem of *C. sativa* L. has hairs, and it is similar to the herbaceous plants. Camelina plants produce small, yellow flowers which turn pear-shaped, ranging from 16 to 115 silicles per plant, with a diameter of 4-5 mm and 10-20 seeds according to genetics and optimal circumstances of growth at the time of seed maturation (Zanetti et al., 2021). As silique ripens, they turn from green to yellow-reddish, eventually drying out entirely at maturity. *C. sativa* plants have the potential to attain a final height of 0.65 to 1 meter and may develop as many as 30 lateral branches. *C. sativa* is an indigenous plant species in Europe and Southwest Asia. Its ancient history can be traced back to 4000 BCE, with the earliest findings in Scandinavia dating back to 1800 BCE (Sydor et al., 2022). Evidence suggests the presence of *C. sativa* in Eastern Turkey during the period of 700 to 900 and from the Eneolithic to the Bronze Age in Romania. This indicates that *C. sativa* was grown for its potential for oil production (Zanetti et al., 2021). Until the mid-20th century, *C. sativa* was periodically cultivated; therefore, this oilseed plant emerged as a significant source of vegetable oil in European countries (Mondor and Hernandez-Alvarez, 2021). It has drawn much attention in the last ten years, primarily in scientific research to enhance *C. sativa* seed production. *C. sativa* may vary from different varieties in production potential, higher weight, lower levels of anti-nutritional elements, and better-quality lipids (Zanetti et al. 2021).

II. Possibilities of *C. sativa* cultivation in different cropping patterns

C. sativa is a promising oilseed crop for sustainable cultivation because it requires relatively less agricultural inputs (Obour et al., 2015). The drought-resistant quality makes it significant amongst other oil seed crops. Further, *C. sativa* plants require 50% less water than other oilseed crops. They also stated that *C. sativa* effectively withstands low temperatures and stress, whereas antimicrobial phytoalexin production helps to resist various plant diseases and pest attacks. Thus, *C. sativa* could be established as a primary crop in marginal soil during the autumn and spring (Zanetti et al., 2021).

In addition, *C. sativa* can be grown twice in a whole season by adopting the approach of a double cropping system, which will modify the C. sativa status from a common crop to a cash crop (Zanetti et al., 2019). Gesch et al. (2014) stated the use of Camelina as a cover crop provides additional economic benefits to farmers with a high yield of the main crop. Meanwhile, the cultivation of *C. sativa* in summer increases the insect population, which helps in flower setting (Groeneveld and Klein, 2014). Other researchers reported the potential of C.

sativa with soybean, maize, and sunflower in winter (Zanetti et al., 2019). Likewise, Berti et al. (2015) stated the sowing of *the C. sativa* crop along with different pulses (peas, soybean, and lentils) in mixed cropping enhances the C. sativa yield (Gollner et al., 2010). Furthermore, the adoption of mixed cropping in advanced agricultural countries is increasingly observed by Gollner et al. (2010). Less weed crop completion was reported in mixed cropping systems, which reduces the crop input cost and improves the net economic benefits (Zanetti et al., 2021). Furthermore, the absence of herbicides did not affect the growth and yield of C. sativa significantly (Leclere et al., 2019). On the other hand, low *C. sativa* yield was obtained from mixed cropping with cereals primarily owing to intense crop competition (Leclere et al., 2019). Besides, further studies are necessary to maximize the potential of *C. sativa* L. and other oilseed crops (Zafar et al., 2019; Yadav et al., 2022).

III. Chemical properties of *C. sativa* seeds and its products

C. sativa seeds contain a wide range of (36.5 to 40.2%) lipid contents (Singh et al., 2023). The predominant fatty acid consists mainly of polyunsaturated (PUFA), constituting 55% of the total fatty acids (Table 1).

Table 1: Chemical properties of *Camelia sativa* L. (dry mass basis)

Properties	**Unit**	**Seed**	**Meal**	**Cake**
Moisture	%	6.57-11.40	6-8.85	7.2-9.11
Dry biomass	%	88.5-93.40	91.15-94	90.90-92.8
CP	%	27.00-34.00	26.5-41.1	38-42
Gross energy	Kcal/kg	5139	5429	50.57-51.97
CF	%	-	-	12-16.92
ADF	%	14.67-15.1	11.1-19.3	17.2-22.53
NDF	%	28.6-30.24	23.3-39.9	25.4-38.3
References		(Hurtaud et al., 2007; Ryhänen et al., 2007; Peng et al., 2014; Zaj˛ac et al., 2020)	(Hurtaud et al., 2007; Moriel et al., 2011; Aziza et al., 2013; Lawrence et al., 2016; Brandao et al., 2018)	(Kahindi et al., 2014; Woyengo et al., 2016, 2018)

CP: crude protein, CF: crude fiber, ADF: acid detergent fiber, NDF: neutral detergent fiber.

The primary fatty acid in the n-3 series is alpha-linolenic (C18:3 n-3), comprising 33% of the total fatty acids. In contrast, the primary fatty acid in the n-6 series is linoleic acid (C18:2 n-6), accounting for 19% of the total fatty acids. *C. sativa* seeds have a beneficial ratio of n-6/n-3 ranging from 0.63 to 0.65. Similar to all plants of this family (Brassicaceae), they also have erucic acid (C22:1 n-9); however, it has been reported to be relatively low (<5%). More*over,* the protein content of *C. sativa* seeds varies from 24.5% to 30% of their total weight (Singh et al., 2023). Further, the chemical properties of *C. sativa* are listed in Table 2.

Table 2: Amount of different fatty acids present in *Camelia sativa* L. seeds and its by-products

Fatty acid (%)	**Seed**	**Meal**	**Cake**	**Oil**
Myristic (C14:0)	0.09-0.2	0.17	0.13-0.14	0.06
Pentadecylic (C15:0)	-	-	0.05-0.06	-
Palmitic acid, (C16:0)	5.1-10.3	9.12-9.19	7.19-7.46	5.2-7.00
Palmitoleic (cis-9 C16:1)	0.1-0.9	0.32-0.52	-	0.08
Stearic (C18:0)	2.19-2.81	2.27-2.9	-	2.2-3.08
Elaidic (trans-9 C18:1)	12.14-19.00	-	-	10.57-19.37
Oleic (C18:1)	11.9-15.57	17.71-21.7	-	15.10-18.70
Linoleic (C18:2)	13.5-20.9	24.35-28.8	-	16.00-19.60
Linolenic (C18:3)	28.6-41.3	24.2-46.3	-	28.00-38.10
Arachidic (C20:0)	1.2-1.8	1.17	-	1.22-2.33
Eicosenoic (C20:1)	13.3-25.4	10.1-13.3	-	11.60-15.1
Gondoic (C20:1 n-9)	11.9-15.57	11.23-13.3	10.18-10.56	10.56-15.19
Behenoic (22:0)	0.3-6.2	-	0.36-0.38	0.26-0.44
Erucic (C22:1 n-9)	1.6-4.2	0.77	2.84-3.32	1.6-4.2
Lignoceric (C24:0)	0.013-0.2	-	0.25-0.28	0.13-0.28
Nervonic (C24:1 n-9)	0.57-0.7	-	0.64-0.8	0.48-0.80
Total SFA	0.04-13.13	9.67-9.86	-	10.2-11.3
PUFA	31.0-37.7	33.5-33.87	-	31.6-34.6
Total MUFA	51.8-57.4	-	-	55.2
References	(Budin et al., 1995; Bonjean and Goffic,	(Hurtaud et al., 2007; Quezada et al., 2012;	(Smit and Beltranena, 2017)	(Shukla et al., 2002; Abramoviˇc and

	1999; Zubr and Matthäus, 2002; Abramoviˇc and Abram, 2005; Hurtaud et al., 2007; Wu and Leung, 2011; Quezada and Cherian, 2012; Yang et al., 2016; Raczyk et al., 2016; Berti et al., 2016 Krzyzaniak et al., 2019; Sarramone et al., 2020; Ebeid et al., 2020)	Cappellozza et al., 2012; Aziza et al., 2013; Petre et al., 2015)		Abram, 2005; Hrastar et al., 2009; Moser and Vaughn, 2010; Katar, 2013; Toncea et al., 2013; Hixson et al., 2014; Bayat et al., 2015; Belayneh et al., 2015; Jurcoane et al., 2017)

The seeds of *C. sativa* are rich in essential amino acids (leucine, arginine, valine, phenylalanine, lysine, and isoleucine) and non-essential (glutamic acid, glycine, alanine, and aspartic acid) amino acids. In addition to protein, *C. sativa* meal is an excellent source of antioxidant compounds, including flavonoids, phenolic acids, gamma- and alpha-tocopherols, xanthophylls, phytosterols, and alpha-tocopherols. These compounds stabilize oil and prevent oxidation of PUFAs, thus extending its shelf life. They also play an essential role in determining the color and flavor of *C. sativa* oil. Additionally, *C. sativa* seeds contain 4.15-4.31% ash and a significant amount of phosphorous, potassium, sulfur, calcium, and magnesium (Sydor et al., 2022).

Besides, the camelina seeds used to extract oil through oil extraction technique whereas the cake is used for poultry feed industry. Chemically, this cake comprises 5.9% ash contents, 28% oil and 35% protein, which improve the poultry feed nutrition (Halmemies-Beauchet-Filleau et al., 2018; Sydor et al., 2022).

IV. Uses other than feed: Agrochemicals, food, biofuel, biopolymers and cosmetics

C. sativa L. have significant industrial applications (Popa et al., 2017). It can be used in biofuel, biopolymers and cosmetics. In the field of agrochemicals, *C. sativa* oil is considered highly valuable for the development of novel compounds. Using quaternary ammonium hydroxide in reaction with *C. sativa* oil has formed ammonium bio-ionic liquids, yielding 86% to 93%. These products were evaluated as adjuvants for sulfonylurea herbicides and against storage pests like confused flour beetle (*Trogoderma granarium*), khapra beetle and larvae (*Tribolium confusum*), and granary weevil (Sitophilus granaries). Experimental results showed significant activity in both situations, emphasizing *C. sativa* oil's potential for these applications (Sydor et al., 2022).

1. Biodiesel:

C. sativa seeds used for the manufacturing of biodiesel, which is comparatively more sustainability than the mineral diesel fuel with reduced emission of CO and other harmful gases (Yilbaşi et al., 2022). The fatty acid methyl esters derived from *C. sativa* oil are more environmentally friendly than that of oil extracted from rapeseed and soybean (Moser, 2012; Soriano and Narani, 2012; Lebedevas et al., 2013; Arshad et al., 2022). Despite its favorable characteristics, *C. sativa* biodiesel also has some drawbacks: *C. sativa* contains a high content of iodine, elevated cloud filter pours point, a large Conradson carbon residue, and a pronounced susceptibility to oxidation, although it has an antioxidant property (Schütze, 2021). To mitigate these drawbacks, a possible solution would be to mix *C. sativa* oil with 50% with other vegetable oil to achieve the recommended iodine level (Karcauskiene et al., 2014). Another essential method is to use *C. sativa* oil as a biofuel, which might involve reducing the high proportion of unsaturated fats through genetic evolution (Hernando et al., 2017). The adhesive properties of camellia oil are optimal for producing pressure-sensitive adhesives when combined with other epoxidized oils to make biopolymers, resins, paints and varnishes (Ahmad et al., 2023). In addition, researchers are synthesizing a range of hydrophilic oil-based monomers by utilizing epoxidase *C. sativa* oil. They are also extending their investigation to explore the combination of polyethylene glycol (PEG) and dimethacrylate in C. sativa oil, which is protected by nanostructured substances known as polyhedral oligomeric silsesquioxane (Singh et al. 2023).

2. Cosmetics:

Cosmetic industry have significant use of different vegetable oils (Arshad et al., 2022). The anti-oxidative properties of *C. sativa* helps to serves as an occlusive or soothing skin-conditioning agent without posing any significant toxicity risks (Saraf et al., 2022). Additionally, the fatty acids extracted from refined *C. sativa* oil are major source of fragrance (Popa et al., 2017). These substances can potentially enhance *C. sativa* oil's economic divergence and sustainability in the market, although more research is still required (Sydor et al., 2022).

3. Food

The presence of high amount of n-3 polyunsaturated fatty acids (PUFA) in *C. sativa* oil improves human health. In addition, lipid decreasing properties of *C. sativa* oil promoted the breakdown of large lipoproteins into smaller ones that regulated the metabolism of blood lipids. In resulting, *C. sativa* oil provides protection against cardiovascular disease and improves liver function (Musazadeh et al., 2022). In a recent study, Faustino et al. (2016) developed a milk-fat alternative through oil extracted from *C. sativa*.

4. Animal feed

There are immense utilization of C. sativa plants and its byproducts as an animal feed in livestock (Cherian, 2012). Many researchers reported different byproducts of camelina plants a suitable option as soybean meal (Riaz et al., 2022). Camelina-seed-cake has high nutritional profiling (Sydor et al., 2022). Therefore, the previous studies reported promising outcomes of incoportaing the camelina-seed-cake in feed of different poultry animals (Zhu et al. 2021; Juodka et al. 2022). Besides high PUFA along with essential amino acids, various studies reported various disadvantages of camelina addition in animal feed (Cherian, 2012; Sydor et al., 2022). Therefore, further research necessitate to find the optimum percentage of the byproducts of *C. sativa* L. in feed to enhance the poultry animal performances and meat quality characteristics (Juodka et al., 2022).

V. Disadvantages with promising solutions

Less seed weight and oil contents in Camelina seeds is due to its decreased seed size (Zanetti et al., 2017). It makes the seeds of *C. sativa* less favorable than those of other Brassicaceae family plants. Moreover, *C. sativa* carries various plant secondary metabolic products, including phytic acid, glucosinolates, sinapine, condensed tannins, and trypsin inhibitors. Glucosinolates are characterized as beta-thioglucoside N-hydroxy sulfate with cross chains and sulfur-linked beta-D-glucopyranose. Epithionitriles, nitriles, isothiocyanates, and thiocyanates are byproducts of camelina seeds and develop toxicity, impaired growth, thyroid dysfunction, infertility as well as gastrointestinal mucosal irritation that leads to necrosis (Russo and Reggiani, 2012). Phytic acid constitutes the primary organic phosphorus found in plant seeds. It mixes with minerals to produce complexes that change them into insoluble and organically inaccessible forms (Schlemmer et al., 2009).

C. sativa L. is also a source of sinapine that has a bitter taste, which makes it less palatable to animals. Furthermore, mixed with poultry food results in a fishy flavor and unpleasant smell (Sydor et al., 2022). Tannins prevent the digestion of specific enzymes, precipitate proteins, and decrease the absorption of vitamins and minerals. Furthermore, it combines with vitamin B12, thereby reducing its absorption. However, they are recognized as health-improving elements in plant-based foods and beverages due to their antimicrobial, antimutagenic, and anticarcinogenic qualities (Amarowicz et al., 2010).

On the contrary, the drawbacks mentioned earlier could be addressed through different approaches, i.e., artificial hybridization, an easy way to get hybrid plants. Precise or bulk breeding techniques could be used to manage segregation generation. In *C. sativa* breeding, the single-seed descent approach was used to promote the generation and achieve homozygosity (Vollmann and Eynck, 2015). Besides, mutations also improved the genetic traits of camelina seeds. This approach has effectively altered the composition of fatty acids (Singh et al., 2023). After being treated with EMS, *C. sativa*'s sensitivity to an acetolactate synthase inhibitor is decreased, resulting in resistance to sulfosulfuron, imazethapy, and flucarbazone (Walsh et al., 2012). Another important method for improving breeding programs is the formation of double haploids from distinct microspores or other cultures (Vollmann and Eynck, 2015).

Moreover, the gene sequences of Arabidopsis [*Arabidopsis thaliana* (L.) Heynh.] and Camelina are highly identical. As a result, fully developed tools for genetic engineering enable effective interbreeding and trait improvement (Sydor et al., 2022). Genetically, agrobacterium-mediated floral dip transformation has been established to enhance various traits such as oil and seed yield (Rao, 2019). Furthermore, *C. sativa* treated with EMS exhibits mutant seed lines that have changed the structure of their fatty acids. It allows the targeting of particular genes using CRISPR/Cas9 technology (Zanetti et al., 2021)

VI. The use of Camelina sativa L. in poultry industry

1. Broiler poultry species digestibility

The digestibility of nutrients in the digestive tract may decrease when birds are administered a diet containing *C. sativa* or its derivatives (Zajac et al., 2020; Sydor et al., 2022). 15% Camelina seeds decreased the energy metabolism of broilers in the early phase of growth, leading to a lower efficiency of lipid metabolism (Zajac et al., 2020). This was primarily due to the substantial amount of non-starch polysaccharides (NSP, mostly water-soluble) present in *C. sativa* seeds (Singh et al., 2023). The high presence of water-soluble NSP gave more digestible viscosity and is considered a significant factor in reducing fat metabolism (Amerah et al., 2014). Different enzymes significantly lowered the impact of trypsin inhibitors and glucosinolates, which improve the amino acid digestion (Woyengo et al., 2016). Furthermore, infrared studied showed less fiber and ash percentage and high ether, protein and dry matter content with addition of radiation to *C. sativa* seeds in feed (Zajac et al., 2021). Compared to the control group, the broiler chicken meals supplemented with 15% of these micronized seeds showed a significant increase in nutrient digestibility, particularly for organic matter and crude protein. Nevertheless, more research is needed to understand the most effective methods for integrating *C. sativa* derivatives into poultry diets to maximize their nutritional value and minimize their adverse effects.

2. Live performances

Various research experiments indicated different mixing percentages (5%-10%) of *C. sativa* seeds into broiler chicken feed remained non-significant to enhance broiler growth and meat (Ciurescu et al., 2016). However, Ciurescu et al. (2007) reported increased daily weight using C. sativa seeds in poultry feed (**Table 3**). In addition, the use of *C. sativa* up to 15% in poultry feed improved broiler performance and yield (Zajac et al., 2020). Moreover, *C. sativa* seeds have been shown to have a positive impact on the daily weight gain, death rate, and FCR of chickens, particularly during the finisher period, when provided to their diet at a rate of 15% after they have been irradiated and micronized (Zajac et al., 2021). The current findings suggest that *C. sativa* seeds provide nutritional advantages and beneficial impacts on the actual performance of broiler chickens. It has been demonstrated that *C. sativa* oil has minimal or negligible levels of antinutritional compounds compared to cake or seeds. Consequently, it is unsurprising to observe that the addition of *C. sativa* oil in the food of broiler chicken did not result in any significant effects on how they performed in comparison to those that are associated with ordinary oil sources (Singh et al., 2023).

Table 3. Efficacy of *Camelina sativa* L. feed on growth attributes of different poultry animals.

Poultry animal	**Feed type**	**Level of *C. sativa* used (%)**	**Experimental duration (days)**	**Body weight (g)**	**Weight gain (g)**	**Feed intake (g/birds)**	**Feed conversion ratio (kg/kg)**	**Reference**
Chicken	Cake	5	42	+54.37	+54.43	+312.8	+0.11	(Aziza et al., 2010)
Chicken	Oil Cake	4 10	22-42	- -	-22 -122	-50 -116	-0.04 +0.09	(Orczewska-Dudek et al., 2019)
Chicken	Oil Seed	2.5 5	11-42	+63.82 -31.86	- -	+87.8 +134.85	-0.01 +0.08	(Ciurescu et al., 2016)
Quail	Cake	15	35	+3.35	+2.38	+31.27	+0.00013	(Bulbul et al., 2015)
Turkey	Cake	15	1-28	-56	-	+4	+0.12	(Frame et al., 2007)
Chicken	Seed	10	7-42	-116.8	-122.13	-250	+0.01	(Ciurescu et al., 2007)
Chicken	Oil	3	22-49	+61	-	-	-0.03	(Orczewska-Dudek and Pietras, 2013)
Chicken	Cake	10	1-21	-60	-	-71	+0.03	(Pekel et al., 2015)
Chicken	Cake	8	23-42	-35.69	-22.17	-17.5	+0.01	(Anca et al., 2019)
Chicken	Cake	10	42	-	+107.5	+3.13	+0.10	(Pekel et al., 2009)
Chicken	Cake	16	42	+508.5	+12.2	+0.7	-	(Oryschak et al., 2020)

Numbers in columns indicated the variation among the control treatment; significant difference found $p < 0.05$.

The 5% *C. sativa* cake used with poultry feed improves the weight gain of broiler chicken (Aziza et al., 2010), feed conversion ratio (FCR), and food consumption rate, particularly in male chickens (Singh et al., 2023). At the same time, incorporating 10% into broiler chicken gives different results (Orczewska-Dudek and Pietras, 2019). However, Pekel et al. (2015) reported notably low performance in FCR, feed intake, and weight gain. As estimated, elevating the inclusion level of *C. sativa* meal in chicken's diet up to 20% resulted in further retardation of growth, FCR, and feed intake of chickens (Pekel et al., 2015). The pattern remained unchanged when poultry species other than chickens were examined. For example, Frame et al. (2007) found that augmenting the proportion level of *C. sativa* cake in their diet, ranging from 5% to 20%, had adverse effects on daily weight, leading to reduced duction intake in feed. Moreover, high feed consumption was observed with 15%-20% *C. sativa* cake, while birds fed with 20% *C. sativa* cake demonstrated an increased value of FCR. Meanwhile, 15%-20% usage of *C. sativa* cake showed non-significant effects on weight gain and FCR in ducks. However, Juodka et al. (2022) reported a considerable decrease in FCR compared to the control groups, suggesting a possible palatability problem. The experimental results showed that various *C. sativa* products have diverse effects on actual performance (such as weight gain, FCR, and food intake) in distinct broiler chicken species. Influence on live performance is significantly affected by certain aspects, such as the degree of inclusion, the extent of feeding, and a specific variety of *C. sativa* seeds, suggesting that a 10% threshold seems preferable.

3. Carcass traits

Experimental studies show that the addition of *C. sativa*-based products in dietary food of broiler species can significantly affect carcass traits. The details are as follows:

***C. sativa* seeds:** Researcher reported the *C. sativa* seeds used up to 15% did not affect the carcass traits of broiler chicken (Ciurescu et al., 2016). This could be explained by the short nutritional period (21 days) of research or the low level of anti-nutrients in the *C. sativa* plant (Zajac et al., 2020).

***C. sativa* oil:** The use of *C. sativa* oil ranging from 2.5% to 6% showed similar effects as observed with camelina seeds and these were identical to the control groups, where no camelina byproducts were used (Orczewska-Dudek and Pietras 2019).

***C. sativa* oil:** According to given studies, 2.5-10% use of *C. sativa* cake remained non-significant to the carcass characteristics of poultry chickens (Aziza et al., 2010; Orczewska-Dudek and Pietras, 2019). The group-fed control diet significantly outperformed the broiler chickens regarding carcass, breast, slaughter, and leg weight.

Besides carcass weight and yield, adding 15% or 20% *C. sativa* cake to the duck's diet did not affect carcass characteristics (Juodka et al. 2022). Anti-nutritional compounds have the potential to affect the uptake of nutrient nutrients or decrease growth adversely. This, in turn, directly correlates to carcass attributes such as yields, quality, and proportions. According to research on *C. sativa* cake in broiler poultry chickens (Cullere et al., 2023), it is not recommended to include 15% of readily available *C. sativa* in the diet because it lowers the carcass weights along with slaughter when compared to the control. The detrimental impacts on carcass traits were not identified when optimized *C. sativa* varieties (low linoleic acid and low glucosinolates) were considered. Depending on the exact parameters of live performance, adding *C. sativa*-based products to poultry feed had varying impacts on carcass traits (feeding period and level of inclusion). Furthermore, due to a diet containing *C. sativa* seeds or cake, most observations on carcass traits were directly correlated with nutritional intake and growth. These factors make it recommended to avoid the administration of elevated quantities of *C. sativa*-derived products in poultry diets during the initial phase since young birds are especially vulnerable to anti-nutritional compounds (Aziza et al., 2010).

4. Meat quality

Including 5-10% *C. sativa* seeds in chickens' diets showed no significant effect on the biochemical structure of breast meat of chicken (Juodka et al., 2022). Increasing the concentration of *C. sativa* seeds up to 15% will significantly reduce breast meat's ash and lipid content in subsequent broiler chicken (Zajac et al., 2020). The addition of *C. sativa* seeds (> 10%) to poultry feed was found to enhance the digesta viscosity, which is essential for the digestion of nutrients, especially fat, as it is a prerequisite for live performance (Amerah et al., 2014). On the other hand, the poultry diet with 3% *C. sativa* oil showed more protein levels in breast meat, while the diet with 6% *C. sativa* oil did not affect protein levels. Polyunsaturated fatty acids (PUFA) play a role in catalyzing the activation of uncoupling proteins in mitochondria.

This process may significantly lessen the amount of nutritional energy in the animals administered with high amounts of PUFA, such as *C. sativa*, thus making it preferable to use that energy, particularly for protein deposition (Pietras and OrczewskaDudek, 2013). Incorporating 3% and 10% *C. sativa* cake into broiler poultry's diet resulted in chest meat with a chemical structure comparable to the control groups (Untea et al., 2019; Orczewska-Dudek and Pietras, 2019). Conversely, in the context of broiler quails, and incorporating 15% *C. sativa* cake into the diet of broiler chicken can impact the chemical combination of elements of quail's chest meat. The group with readily accessible *C. sativa* lines, i.e., Calena, exhibited higher water and lower lipid content. On the other hand, the two different groups utilizing enhanced *C. sativa* varieties (linoleic acid and low glucosinolates) showed intermediate values. Based on the limited research of available data, it can be concluded that broiler feed containing *C. sativa* by-product may alter the meat's approximate composition, particularly when the amount of *C. sativa* in dietary products.

5. Fatty acids

The Food and Agriculture Organization in the United Nations suggests consuming less saturated fatty acids for a balanced diet (Singh et al., 2023). In this regard, the fatty acid composition and profile of animal products, particularly food, is crucial. The oil content of *C. sativa* is significantly high in monounsaturated (MUFA) and polyunsaturated (PUFA) at approximately 30% and 50% of total fatty acids, respectively. Thus, the dietary administration of *C. sativa* in poultry chicken can modify the proportion of FA in meat, which lowers the amount of saturated fatty acid (SFA) and increases the amount of unsaturated fatty acid. The administration of *C. sativa* seed primarily affects the n-6 and n-3 polyunsaturated amino acids in chicken breast meat. This inclusion resulted in low saturated fatty acid especially stearic acid (C18:0). These outcomes were due to elevated levels of eicosapentaenoic acid (EPA: C20:5 n-3), alpha-linolenic acid (ALA: C18:3 n-3), docosapentaenoic acid (DPA: C22:5 n-3), arachidonic acid (AA: C20:4 n-6) and docosahexaenoic acid (DHA: C22:6 n-3) in broiler's chest meat. As the inclusion level increased, a decrease in total n-6 PUFA and an increase in total n-3 PUFA were examined. An increase in the incorporation level of *C. sativa* seeds subsequently increased the extent of alteration in the fatty acid proportion (Ciurescu et al., 2016). Furthermore, it was observed that the breast meat of chicken had higher concentrations of EPA, ALA, AA, DHA, and DPA along with lower concentrations of C18:0. As predicted, elevated levels of dietary incorporation of *C. sativa* oil determine similar yet more favorable outcomes specifically at levels of 4% and 6% (Orczewska-Dudek and Pietras, 2019).

6. Sensory traits

Adding 3% or 6% *C. sativa* oil to the diets of broiler chickens did not affect the sensory characteristics of the grilled meat (Nayef and Zangana, 2019). In contrast, including *C. sativa* oil at a concentration of 4% in broiler chicken meals enhanced breast juiciness. Furthermore, no significant effect of applying 10% *C. sativa* cake on the descriptor (Orczewska-Dudek and Pietras, 2019). Similar results were reported by Ryhänen et al. (2007), who found no variations in flavor, moisture content, and taste of chicken grown with 5010% *C. sativa* cake. Furthermore, the chicken breast meat had comparatively high tenderness compared to the control groups (Ryhänen et al., 2007).

Genetics, food, and processing methods of feed impact the sensory characteristics of poultry meat. Nevertheless, incorporating *C. sativa*-derived products into the feed of different poultry species gave promising results about meat tenderness and juiciness while leaving flavor, taste, and aroma unaffected. However, the impact of *C. sativa* seeds and its by-products on sensory traits of chicken is not well studied (Orczewska-Dudek and Pietras, 2019).

VII. Conclusion:

C. sativa by-products are imperative to enhance poultry feed efficiency. However, a high concentration of *C. sativa* by-products in broiler poultry diets significantly increases digesta viscosity, negatively impacting digestibility. The literature reviewed indicated that 10% is the critical limit for the sustainable use of *C. sativa* by-products in poultry feed. Further, additions of some supplements such as copper, carbohydrase, or micronized *C. sativa* seeds (treated with infrared irradiation) can enhance the digestion of essential nutrients and improve the overall performance of the poultry and chicken industry. Interestingly, the 2.5% to 20% addition of *C. sativa* derivatives did not significantly affect carcass attributes features. The proximate composition of poultry meat slices remained constant. The fatty acid concentration was significantly affected by *C. sativa*-based feed. However, the difference in sensory traits could be possible by increasing the range of *C. sativa* oil and cake above 10% in poultry feed. However, the intensity of sensory characteristics depends on the duration and time of feeding, along with the composition of the diet. Further investigation is required to identify the sustainable limit of *C. sativa*-based by-products in the poultry feed industry to improve the broiler meet, proximate characteristics, and nutritional quality.

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