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CAMELINA SATIVA AS A SUSTAINABLE AND FEASIBLE FEEDSTUFF FOR LAYING POULTRY: A REVIEW*

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Review paper

Abstract: *Camelina sativa* is a promising oilseed crop with unique characteristics, including rapid growth, drought and frost tolerance, low input requirements, and resistance to pests and diseases. It offers diverse applications in both feed and non-feed sectors, primarily due to its high levels of *n*-3 polyunsaturated fatty acids (PUFA) and antioxidants. However, the presence of secondary plant metabolites in camelina restricts its use in poultry nutrition. These compounds may inhibit some digestive enzymes, increase digesta viscosity, and affect nutrients absorption, potentially compromising bird health and product quality. Various techniques, such as heat treatment, multi-enzyme supplementation, and copper supplementation, have been employed to mitigate the negative effects of these antinutritional compounds. Inclusion at high levels (>10%) of camelina by-products in poultry diets has been found to decrease nutrients digestibility and laying performance. Nonetheless, the inclusion of camelina by-products, particularly oil, in the diets resulted in comparable or improved egg quality. The egg yolk fatty acid profile exhibited a higher content of PUFA, reducing the *n*-6/*n*-3 ratio, thereby enhancing the nutritional value of eggs. Sensory evaluations showed no significant differences in product quality among diet groups. This review highlights the feeding value of camelina by-products and provides a comprehensive overview of the existing literature, focusing on digestibility, performance, and egg quality evaluation in laying poultry diets.

Key words: false flax, feeding, inclusion level, live performance, egg quality, fatty acids, sensory analysis

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Introduction

In recent years, there has been a growing emphasis on identifying sustainable and economically viable alternatives to conventional feed sources in poultry production. The conventional feed sources, predominantly composed of soybean and corn, encounter challenges such as environmental impacts, price volatility, and limited availability. Consequently, in the last 20 years, researchers have explored alternative feed ingredients with the aim of maintaining good performance levels *(Rokka et al., 2002; Cherian et al., 2009; Kakani et al., 2012; Aziza et al., 2013; Lolli et al., 2020; Orczewski-Dudek et al., 2020; Cullere et al., 2023; Singh et al., 2023)*. One promising candidate in this regard is *Camelina sativa* (L.) Crantz, commonly known as camelina or false flax, an oilseed crop that has gained attention for its potential as a sustainable and feasible feedstuff for laying poultry.

Camelina sativa belongs to the Brassicaceae family and is recognised for its high oil content, ranging from 30% to 45%. This oil content is particularly rich in essential omega-3 fatty acids (FA) (*Singh et al., 2023*). Additionally, the cultivation of camelina requires fewer resources, such as water and fertilisers, in comparison to other traditional oilseed crops, rendering it an environmentally friendly option (*Zanetti et al., 2021*). As a hardy crop, camelina can thrive in marginal lands, thereby reducing the strain on prime agricultural areas. Additionally, camelina cultivation entails a low carbon footprint due to reduced pesticide and fertiliser applications, which contributes to sustainable farming practices (*Zanetti et al., 2021; Mondor and Hernández-Álvarez, 2022*). Moreover, incorporating camelina in poultry feed has the potential to decrease reliance on traditional feed ingredients, thereby fostering greater economic viability in poultry production.

These characteristics have generated increased interest in exploring the utilisation of camelina as a feed ingredient for laying poultry. The nutritional composition of camelina as is (seed) or as derived products (meal and oil) makes them highly valuable for their inclusion in poultry diets. They possess a favourable balance of amino acids, including essential amino acids that play a crucial role in optimising egg production and quality. Furthermore, by-products derived from camelina serve as a good source of energy, vitamins, and minerals, augmenting their potential as a feedstuff for laying poultry (*Pietras et al., 2012; Orczewska-Dudek et al., 2020*). The high presence of omega-3 fatty acids in camelina by-products can also have a positive influence on egg quality by enriching the eggs with these beneficial nutrients (*Pietras et al., 2012; Orczewska-Dudek et al., 2020*). The incorporation of camelina in laying poultry diets has demonstrated improvements in egg production, egg weight, feed conversion ratio, and shell quality (*Cherian et al., 2009; Kakani et al., 2012; Pietras et al., 2012; Bulbul and*

Ulutas, 2015; Aziza et al., 2013; Cherian and Quezada, 2016; Lolli et al., 2020; Orczewska-Dudek et al., 2020). The oil of camelina is rich in omega-3 FA, thus camelina inclusion in layers diet increases the omega-3 FA in eggs. Moreover, its ingredients have been shown an overall improvement in the egg's nutritional profile (*Rokka et al., 2002; Cherian et al., 2009; Pietras et al., 2012; Aziza et al., 2013; Cherian and Quezada, 2016; Panaite et al., 2016; Orczewska-Dudek et al., 2020*).

Despite its potential, the utilisation of camelina in laying poultry diets does present certain challenges. Antinutritional factors, such as glucosinolates and erucic acid, necessitate attention to ensure the safe inclusion of camelina in feed formulations (*Russo and Reggiani, 2012*). Strategies, including genetic modification and processing techniques, have been employed to mitigate the presence of these undesirable components. Genetic engineering techniques have been utilised to develop camelina varieties with reduced levels of undesirable components. By targeting specific genes involved in the synthesis or regulation of glucosinolates and erucic acid, researchers have successfully developed genetically modified camelina plants with altered profiles of these compounds. Through the use of gene editing tools or the introduction of genes from other plant species, the expression of key enzymes involved in the synthesis of undesirable components can be suppressed or modified, leading to reduced levels in the resulting crops (*Vollmann and Eynck, 2015; Zanetti et al., 2021*).

Processing methods play a crucial role in reducing or eliminating undesirable components in camelina. Various techniques have been employed to detoxify or modify the composition of seed and meal. These techniques include heat treatment (*Zajac et al., 2021*), and enzymatic treatments (*Woyengo et al., 2016*). For instance, heat treatment can effectively reduce glucosinolates content. The use of these strategies, whether individually or in combination, aims to mitigate the presence of glucosinolates and erucic acid in camelina, thereby improving the safety and suitability of camelina as a feedstuff for livestock.

Apart from being a potential feed ingredient, offers a range of non-feed uses. These non-feed uses of camelina have gained attention due to its unique properties and potential environmental benefits. Some of the notable non-feed uses of camelina are: *Soil amendment and phytoremediation*: camelina plants have deep root systems that can help improve soil structure and reduce soil erosion. Additionally, camelina has the ability to extract heavy metals from contaminated soils, making it suitable for phytoremediation purposes to restore polluted sites (*Berti et al., 2017*). *Nutraceuticals and functional foods*: camelina oil contains omega-3 fatty acids, including alpha-linolenic acid, which is beneficial for cardiovascular health and inflammation reduction. It can be used as an ingredient in nutraceuticals and functional foods, such as supplements, health drinks, and fortified food products, to provide the health benefits associated with omega-3 FA (*Zubr, 2009; Faustino et al., 2016*). *Cosmetics and personal care products*: camelina oil is rich not only in omega-3 FA, but also in antioxidants, and vitamin

E, which are beneficial for healthy skin and hair. It can be incorporated into cosmetic formulations, including creams, lotions, serums, and hair care products, to provide moisturising, nourishing, and protective properties (*Arshad et al., 2022*). *Biofuel production*: camelina oil is suitable for biofuel production. The oil can be processed into biodiesel, which is a renewable and environmentally friendly alternative to fossil fuels. Camelina-based biodiesel has shown promising results in terms of lower greenhouse gas emissions (*Lebedevas et al., 2012*). *Green chemicals and bioplastics*: camelina oil can serve as a renewable feedstock for the production of green chemicals and bioplastics. The oil can be transformed into various chemical intermediates used in the manufacturing of biodegradable plastics, resins, coatings, etc… (*Balanuca et al., 2015; Kim et al., 2015*). These non-feed uses of camelina highlight its versatility and potential as a sustainable crop with applications in various industries. However, this article provides a comprehensive and critical review of research conducted on camelina and its by-products for utilisation in laying poultry feeding. The review presents valuable insights into the feeding value of camelina by-products and encompasses an extensive survey of the existing literature pertaining to their incorporation in laying poultry diets, focusing on aspects such as digestibility, performance, and egg quality.

Layer Digestibility

Most studies have revealed that nutrients and energy digestibility is reduced if poultry diets contain camelina seeds or cake, with some exception. *Varzaru et al. (2014)* included camelina seeds (2%) together with other oilseeds (linseed and fenugreek seeds at different inclusion levels) in laying hens' diets. The outcomes of the study revealed that the diets supplemented with 2% camelina seed and 5% linseed did not affect the digestibility coefficient of amino acids, except phenylalanine and arginine. However, digestibility coefficients of the amino acids decreased in the group supplemented with 2% camelina seed, 2% linseed, and 1% fenugreek seed.

As regards the use of camelina cake, when low inclusion level (1% or 2%) was used, crude protein and amino acids (except tyrosine, cysteine, glycine, and serine) digestibility did not vary in laying hens (*Peñagaritano et al., 2019*). Such low inclusion levels were not able to highlight the known negative effects of glucosinolates (5.73 μmoles/g) and erucic acid (4.01%) present in the cake. Using the same camelina cake inclusion level as in the previous work (2%), but supplementing the diet with exogenous enzymes (12.5 g/100 g feed) and copper (150 mg/kg feed), the apparent faecal digestibility of amino acids was significantly improved, however, showing an effect not entirely attributable to camelina cake (*Varzaru et al., 2019*). In contrast, increased inclusion level of camelina cake (up to 10%) in the diets of laying hens not only decreased the digestibility of crude protein, but also reduced the apparent metabolisable energy content of the diet (*Aziza et al., 2013*). The reason relates not only to the presence of glucosinolates but also to that of non-starch polysaccharides, which interfere with available nutrients by forming complexes and inactivating digestive enzymes (*Acamovic et al., 1999*).

Layer performance

The effect of the dietary inclusion of camelina by-products on layer poultry productive performance is presented in Table 1. The dietary inclusion of 10% camelina seeds improved hens egg production by 5.1%, and also increased the feed intake by 9.44 g/bird/day compared to the control group. The study did not report the feed conversion ratio (FCR) or feed efficiency, however average egg weight was lowered for group-fed camelina seeds compared to the control group (*Cherian and Quezada, 2016*).

Table 1. Effect of the dietary inclusion of camelina by-products on layer poultry productive performance

Species	Matrix	Bird age, wk	Feeding, wk	Inclusion, %	FI, g/d/bird	FCR	Egg production, %	Egg weight, g	Ref.
Hen	Control			0	116±7.04	2.20±0.32	87.6±4.62	61.4±2.31	1-9
	Seed	48	16	10	128**	-	92.8*	60.4*	1
	Oil	23	4	1.5, 3	119	2.68	83.7	60.2	2
		26	7	4	116	1.99	91.0	61.1	3
	Cake	26	7	10	118	2.02	89.8	61.3	
		24	12	10	-	-	95.6*	56.5	4
		58	11.4	5, 10, 15	102	-	77.1**	61.6	5
		29	12	5, 10	-	-	95.3	59.0*	6
		60	6	2	116*	2.05*	88.8*	64.7*	7
		21	30	10, 20	118	2.21	-	62.0	8
		58 & 60	6 & 4	2		1.98*	86.8	64.6	9
Quail	Control			0	38.1	3.81	86.8	11.5	10
	Cake	8	8	5, 10, 15, 20	35.2*	3.70	84.2**	11.3	

(Mean value of species-specific control diets ± Standard deviation)*;* wk: weeks; Ref.: references; 1: *Cherian and Quezada (2016);* 2: *Pietras et al. (2012);* 3: *Orczewska-Dudek et al. (2020);* 4: *Aziza et al. (2013);* 5: *Cherian et al. (2009);* 6: *Kakani et al. (2012);* 7: *Panaite et al. (2016);* 8: *Lolli et al. (2020);* 9: *Varzaru et al. (2019);* 10: *Bulbul and Ulutas (2015);* *P<0.05, **P<0.01 or P<0.001 vs control within study.

In studies conducted by *Pietras et al. (2012)* and *Orczewska-Dudek et al. (2020)*, the impact of incorporating camelina oil into the laying hen diet at levels of 1.5%, 3%, and 4% was investigated. As expected, the inclusion of camelina oil did not significantly affect performance and production parameters, which remained comparable to the control group. It should be noted that camelina oil does not contain antinutritional compounds that could negatively impact bird performance and production. In laying quails, a small amount of camelina oil (0.39% of the diet), in replacement of the soybean oil, significantly increased the egg weight after 6 weeks of administration (*Dalle Zotte et al., unpublished data*). These findings highlight the potential of camelina oil as a beneficial dietary component for layers.

As for the dietary inclusion of camelina cake, the results on laying hens generally revealed good egg production and quality. When the 5% or 10% inclusion level was applied, no differences in live performances were observed (*Cherian et al., 2009; Kakani et al., 2012; Orczewska-Dudek et al., 2020*), except for a lower egg weight ($P<0.05$) compared to the control diet (*Kakani et al., 2012*). However, literature results are nonuniform, as at 10% inclusion level the egg production increased by 8% compared to the control diet without affecting the eggs weight (*Aziza et al., 2013*).

The upper limit for including camelina cake is still unclear, as the limited studies conducted so far have presented conflicting data. Indeed, whereas the 15% inclusion level significantly reduced egg production (<19%; $P<0.01$) (*Cherian et al., 2009*), the 20% did not negatively affect feed intake, FCR and egg production (*Lolli et al., 2020*).

Considering that the supplementation of Cu in the laying hens' diet has been shown to reduce the concentration of antinutritional compounds, particularly glucosinolates, either through absorption from the intestinal lumen or through their transformation into other by-products (*Panaite et al., 2016; Varzaru et al., 2019*), further research has been conducted by enriching diets with Cu when camelina cake was included, without exceeding 200 ppm concentration, as higher levels can lead to gizzard degeneration, consequently reducing feed intake (*Kim et al., 1992*). Therefore, the result of two studies which tested the dietary inclusion of camelina cake at 2% showed promising results when Cu was supplemented. In the first study, the diets also contained linseed cake (5%) and 3 of them were supplemented with increasing Cu concentrations (75, 100, 150 mg/kg feed). As a result, FCR decreased linearly and egg production increased with Cu concentration (*Panaite et al., 2016*). In the second study (*Varzaru et al., 2019*), a control diet was compared with a diet containing camelina cake (2%) and linseed cake (5%), supplemented with Cu (150 mg/kg feed) and cellulolytic enzyme (12.5 kg/100 g feed) fed to laying hens. The findings revealed that the inclusion of these supplements also led to improvements in FCR, confirming the enhancement of the nutrient utilisation by the hens. however egg production and egg weight were comparable to those in the control group.

A study investigated the inclusion of camelina cake (5%, 10%, 15%, or 20% inclusion level) in diets for laying quails (*Bulbul and Ulutas, 2015*), whose eggs are commercially sold as table eggs in many countries. Quails layers fed with a 15% or 20% inclusion level reduced their feed intake and lowered their egg production, but the lower inclusion levels did not affect their performances, resulting comparable to the group fed a control diet. Significantly lower digestibility of ether extract and energy, and lower egg weight, were recently observed when a 15% camelina cake inclusion level was tested in laying quails, which were fed the camelina-containing diet from their pullet stage; however, the same inclusion level did not affect feed intake, FCR, egg production, and egg weight when camelina cake inclusion only covered the laying period (*Dalle Zotte et al., unpublished data*), thus suggesting the possibility of considering the inclusion of camelina cake in diets for laying quails as a promising alternative ingredient to conventional raw materials.

Egg quality

The inclusion of camelina by-products into layers diet can positively modify the various egg quality traits, playing an important role on consumer satisfaction and on profitability of the production chain (Tables 2-5).

The effect of the dietary inclusion of camelina in layers on the egg physical traits is depicted in Table 2. The inclusion of camelina seeds at 10% in laying diets seems too high, as it negatively affected albumen weight and yolk weight and colour (*Cherian and Quezada, 2016*). On the contrary, the use of camelina oil gave good results, since at 1.5% and 3% inclusion levels it was able to increase the yolk proportion (*Pietras et al., 2012*), and at 4% inclusion it also intensified the yolk colour (*Orczewska-Dudek et al., 2020*).

Table 2. Effect of the dietary inclusion of camelina by-products on egg physical traits of layer poultry

Species	Matrix	Bird age, wk	Feeding, wk	Inclusion, %	Yolk weight, g	Yolk, %	Yolk colour†	Albumen weight, g	Albumen, %	Shell weight, g	Shell thickness, mm	Haugh unit	Shape index, %	Ref.
Hen	Control			0	15.5± 1.75	25.6± 2.22	4.97± 2.11	38.2± 1.30	63.2± 2.18	7.24± 1.41	0.39± 0.03	74.4± 10.1	-	1-7
	Seed	48	16	10	15.3	25.4	5.40	38.4*	63.5	6.76	0.43	68.7	-	1
	Oil	23	4	1.5, 3	13.8*	22.9	-	40.2	66.8	6.28	0.36	87.0	-	2
		26	7	4	16.6	27.2	2.90**	37.1	60.7	7.44	0.38	-	-	3
	Cake	26	7	10	16.6	27.0	2.93**	37.6	61.4	7.13	0.38	-	-	3
		24	12	10	12.8*	22.7*	5.63*	37.0	65.5	6.56	0.41	77.1	-	4
		58	11.4	5, 10, 15	16.3*	26.4*	6.50**	39.1	63.4*	6.23	0.42	-	-	5
		29	12	5, 10	-	-	-	-	-	-	0.40	75.0	-	6
		21	30	10, 20	-	-	-	-	-	6.21	0.37	-	-	7
Quail				Control	5.80	51.38	4.30	4.45	38.7	1.25	0.21	65.1	78.0	8
	Cake	8	8	5, 10, 15, 20	5.50	53.1	6.73	4.54	40.2	1.25	0.21	62.29	77.5	

(Mean value of species-specific control diets ± Standard deviation); wk: weeks; Ref.: references; †Roche yolk colour fan; 1: *Cherian and Quezada (2016);* 2: *Pietras et al. (2012);* 3: *Orczewska-Dudek et al. (2020);* 4: *Aziza et al. (2013);* 5: *Cherian et al. (2009);* 6: *Kakani et al. (2012);* 7: *Lolli et al. (2020);* 8: *Bulbul and Ulutas (2015);* *P<0.05, **P<0.01 or P<0.001 vs control within study.

The camelina cake inclusion level resulted in contradictory results. Some authors observed no significant differences in the physical traits of hen eggs with 5% (*Cherian et al., 2009*) or 10% (*Kakani et al., 2012; Lolli et al., 2020*) camelina cake supplementation. Others, observed that a 10% dietary inclusion increased (*Orczewska-Dudek et al., 2020*) or reduced the yolk colour, together with the yolk weight (*Aziza et al., 2013*). The worst results were found by *Cherian et al. (2009)* who observed that the inclusion of camelina cake at 10% or 15% significantly reduced the yolk weight, yolk colour, yolk and albumen proportions compared to the control group. It is likely that the contrasting data on yolk colour depend on the defatting level of the camelina cakes, since the higher the oil content, the higher the pigments in the diet. Quail eggs are also affected by the inclusion of the camelina cake, and the 15% inclusion level (with cake containing 12.7% oil) showed a significant increase in yolk a* and b* values (*Dalle Zotte et al., unpublished data*).

Research on the impact of camelina dietary inclusion in laying hens on egg chemical composition is limited (Table 3). However, two notable studies conducted by *Pietras et al. (2012)* and *Orczewska-Dudek et al. (2020)*, which tested 1.5%, 3% camelina oil, and 10% camelina cake or 4% camelina oil, respectively, provided insights into this aspect. Both studies did not observe significant differences in the chemical composition of the eggs, compared to the hens receiving the control diet. This result is expected, as negligible changes in egg proximate composition are observed when the laying hen's diet is nutritionally balanced.

Table 3. Effect of the dietary inclusion of camelina by-products on chemical composition (%) and cholesterol of laying hen egg yolk

Species	Matrix	Bird age, wk	Feeding, wk	Inclusion, %	Water, %	Protein, %	Lipids, %	Cholesterol, g/kg	Ref.
Hen	Control			0	52.6±0.36	15.8±0.01	32.1±0.01	9.63±0.01	1-2
	Cake	26	7	10	52.9	16.0	33.2	9.76	1
	Oil	26	7	4	53.7	15.9	33.3	9.34	
		23	4	1.5, 3	51.1	15.9	33.2		2

(Mean value of species-specific control diets ± Standard deviation); wk: weeks; Ref.: references; 1: *Orczewska-Dudek et al. (2020);* 2: *Pietras et al. (2012).*

Considering the FA profile of camelina, whose seeds contain an average of 54% PUFA, of which 36% are *n*-3 FA, and the *n*-6/*n*-3 ratio is approximately 0.5 (*Dalle Zotte et al., unpublished data*), studies have focused on the extent to which eggs are enriched with *n*-3 fatty acids as a result of the dietary inclusion of camelina (Tables 4 and 5). Only one study addressed the effect of the seed inclusion (10%) on laying hens and, as expected, laid eggs were significantly higher in *n*-3 PUFA and lower in *n*-6/*n*-3 ratio (*Cherian and Quezada, 2016*).

Table 4. Effect of the dietary inclusion of camelina by-products on main fatty acid classes (% fatty acid methyl esters) of laying hen egg yolk

Species	Matrix	Bird age, wk	Feeding trial, wk	Inclusion, %	SFA	MUFA	PUFA	*n*-6	*n*-3	*n*-6/*n*-3	Ref.
Hen	Control			0	35.6±2.14	49.8±3.39	16.7±6.24	14.2±5.64	1.61±0.72	8.79±4.03	1-7
	Seed	48	16	10	34.1	52.0	-	10.8	3.12*	2.45*	1
	Oil	52	3	5	-	-	21.4	14.6	6.83	2.14	2
		23	4	1.5, 3	39.8**	49.2*	10.5**	8.43**	2.08**	4.27**	3
		26	7	4	35.7	45.1**	19.0**	13.6	4.65**	2.92**	4
	Cake	26	7	10	35.8	45.3**	18.9**	13.4	4.14**	3.23**	
		24	12	10	33.0*	43.4*	23.6**	19.2	4.39*	4.37*	5
		58	11.4	5, 10, 15	33.3**	50.9**	-	13.3**	2.74**	4.85**	6
		60	6	2	32.6*	-	30.4*	25.7	5.11*	5.02*	7

(Mean value of species-specific control diets ± Standard deviation); wk: weeks; Ref.: references; SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; 1: *Cherian and Quezada (2016);* 2: *Rokka et al. (2002);* 3: *Pietras et al. (2012);* 4: *Orczewska-Dudek et al. (2020);* 5: *Aziza et al. (2013);* 6: *Cherian et al. (2009);* 7: *Panaite et al. (2016);* *P<0.05, **P<0.01 or P<0.001 vs control within study

Table 5. Effect of the dietary inclusion of camelina by-products on fatty acid profile (% FAME) of laying hen egg yolk

Species	Matrix	Bird age, wk	Feeding, wk	Inclusion, %	C16:0	C18:0	C16:1	C18:1 *n*-9	C18:2 *n*-6	C18:3 *n*-3	C20:4 *n*-6	C22:5 *n*-3	C22:6 *n*-3	Ref.
Hen	Control			0	27.5± 2.14	8.07± 1.20	4.16± 1.04	43.7± 4.53	11.8± 4.44	0.31± 0.23	1.68± 0.16	0.05± 0.04	0.98± 0.45	1-7
	Seed	48	16	10	25.8	7.78	5.99	45.5**	9.38	1.53*	1.31*	0.27*	1.25*	1
	Oil	52	3	5	23.8	9.32	1.93	39.6	13.8	5.02	-	-	1.81	2
		23	4	1.5, 3	31.4**	7.81	4.17*	45.0**	6.75**	0.72**	1.62**	-	1.35**	3
		26	7	4	27.9	7.24**	2.99	42.2	11.9	2.86**	1.58	0.05	1.75*	4
	Cake	26	7	10	28.0	7.22**	3.80	42.2	11.7	2.65**	1.55	0.05	1.63*	
		24	12	10	23.9*	8.15	3.71*	39.7*	17.2*	3.05*	1.48*	0.16	1.17	5
		58	11.4	5, 10, 15	25.3**	7.80	3.68**	46.7**	12.1**	1.42**	1.16**	-	1.32**	6
		60	6	2	-	10.5	-	33.8	21.7*	1.90*	-	0.21*	2.79*	7

(Mean value of species-specific control diets ± Standard deviation); wk: weeks; Ref.: references; 1: *Cherian and Quezada (2016);* 2: *Rokka et al. (2002);* 3: *Pietras et al. (2012);* 4: *Orczewska-Dudek et al. (2020);* 5: *Aziza et al. (2013);* 6: *Cherian et al. (2009);* 7: *Panaite et al. (2016);* *P<0.05, **P<0.01 or P<0.001 vs control within study

Since the seed is currently used for the extraction of oil for non-livestock purposes, researchers have focused more their study on the use of the cake, which is a by-product (of the oil) and therefore a more sustainable foodstuff. However, camelina oil could be an interesting dietary ingredient for poultry layers, since low amounts (1.5% or 3%, *Pietras et al., 2012*; 4%, *Orczewska-Dudek et al., 2020*) are able to significantly decrease SFA and MUFA contents in yolk lipids, in favour of the PUFA content, enriching eggs with C18:3 *n*-3 and C22:6 *n*-3 FA.

When using camelina cake instead of its oil, similar results on the FA profile of eggs were found, however closely dependent on the dietary inclusion level, and for the cake, depending on its lipid content. Thus, PUFA and *n*-3 FA increased in eggs of hens fed diet containing 2% (*Panaite et al., 2016*), 5% (*Cherian et al., 2009*) 10% (*Cherian et al., 2009; Kakani et al., 2012; Aziza et al., 2013*), 15% (*Cherian et al., 2009*) camelina cake, indicating that camelina products are a viable dietary source of *n*-3 FA for poultry, able to enrich eggs with *n*-3 FA. Furthermore, the *n*-6/*n*-3 PUFA ratio was halved or even reduced by 4 times in egg yolk lipids from hens fed camelina seeds or oil or cake compared to the control group.

Camelina has a mustard-like taste, and hens fed cruciferous plants could eggs presenting off-odours or off-flavours, often described as fishy. However, none of the three studies which performed sensory tests or consumer tests on eggs coming from hens fed 5% camelina oil (*Rokka et al., 2002*), either 4% camelina oil or 10% camelina cake (*Orczewska-Dudek et al., 2020*), or 5 or 10% extruded and defatted camelina cake (*Kakani et al., 2012*) reported such adverse effects.

Conclusions

Camelina exhibits potential as a valuable feed ingredient for layer poultry due to its rich content of antioxidants, favourable amino acids, and desirable fatty acid profiles, which contribute to high-quality egg production. However, the presence of antinutritional compounds in camelina limits its utilisation in poultry nutrition, particularly at higher inclusion levels (>10%), as it hinders nutrient absorption and utilisation. Inclusion of camelina (seed or cake) in diets with reduced glucosinolates levels, or supplemented with exogenous enzymes and copper has shown improved nutrient digestibility and productive performance in laying poultry. The 10% inclusion level of camelina cake could represent a compromise, to have unaltered FRC, oviposition rate and egg quality traits, and to provide eggs with excellent fatty acid profile. Further research is however needed to fix the optimal camelina cake inclusion level, the optimum lipids content in camelina cake (degree of defatting) and to optimise the processing methods in poultry diets to improve sustainability and product quality.

Camelina sativa, održiva i upotrebljiva hrana za kokoši nosilje: pregled

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Rezime

Camelina sativa je perspektivna uljarica sa jedinstvenim karakteristikama, koje uključuju brzi porast, otpornost na sušu i mraz, niske zahteve u smislu input-a, kao i otpornost na štetočine i bolesti. Nudi raznovrsnu primenu u sektoru proizvodnje hrane za životinje, kao i u sektoru koji nije za životinje, prvenstveno zbog visokog nivoa *n*-3 polinezasićenih masnih kiselina (PUFA) i antioksidanata. Međutim, prisustvo sekundarnih biljnih metabolita u kamilini ograničava njenu upotrebu u ishrani živine. Ova jedinjenja mogu inhibirati neke digestivne enzime, povećati viskozitet digeste i uticati na apsorpciju hranljivih materija, potencijalno ugrožavajući zdravlje živine i kvalitet proizvoda. Za ublažavanje negativnih efekata ovih antinutritivnih jedinjenja koriste su različite tehnike, kao što su termička obrada, dodatak multi-enzimima i dodatak bakra. Utvrđeno je da uključivanje u visokim nivoima (>10%) nusproizvoda kamiline u ishranu živine smanjuje svarljivost hranljivih materija i učinak nosivosti. Bez obzira na to, uključivanje nusproizvoda kamiline, posebno ulja, u ishranu rezultiralo je istim ili poboljšanim kvalitetom jaja. Profil masnih kiselina u žumancu je pokazao veći sadržaj PUFA, smanjujući odnos *n*-6/*n*-3, čime se povećava nutritivna vrednost jaja. Senzorne procene nisu pokazale značajne razlike u kvalitetu proizvoda među grupama na ishrani. Ovaj pregledni rad naglašava hranidbenu vrednost nusproizvoda kamiline i pruža sveobuhvatan pregled postojeće literature, fokusirajući se na svarljivost, performanse i procenu kvaliteta jaja u ishrani kokoši nosilja.

Ključne reči: lažni lan, ishrana, nivo uključivanja, proizvodne performanse, kvalitet jaja, masne kiseline, senzorna analiza

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