Obtaining eggs enriched in polyunsaturated fatty acids (PUFA). 1. Use of vegetable sources rich in PUFA as functional ingredients in laying hens diets: A review

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ABSTRACT

The concern of consumers regarding the role of the polyunsaturated fatty acids (PUFA) for human health has been increasing steadily over the past decades. There is scientific evidence on the opportunity of enriching foods in PUFA by feeding the hens with oleaginous plants or with their by-products. Both the seeds, meal and cakes can increase the PUFA level in the foods obtained from poultry. Recent research shows that the poultry meat and eggs, produced by birds fed flaxseeds, camelina and rapeseeds, have high PUFA levels. This fact enhanced the interest for their use, and for the use of their by-products in laying hens diets. This review gives information on the feeding value of the flaxseeds, camelina and rapeseeds, together with their by-products, as well as a survey of the literature on their use in poultry feeding to produce foods beneficial to consumer health.

Keywords: Laying hens; PUFA sources; eggs and meat; fatty acids.

INTRODUCTION

Research results shown that the main factors triggering many of the non-infectious diseases, including obesity, cardiovascular and degenerative diseases are caused by the imbalanced diet and lifestyle (Bosma-den Boer et al., 2012; Chakma and Gupta, 2014). Thus, the "consumption" of pharmaceuticals increased, as the easiest manner of dealing with these nutritional and lifestyle disturbances. Within this context, the modern consumers seek to replace the pharmaceuticals by "functional foods", which, besides their nutritional value, also provide health benefits (Bigliardi and Galati, 2013).

Siro et al. (2008) defined functional foods as *such "foods that can bring physiological benefits and/or reduce the risk of chronic diseases beyond the*

basic nutritional functions, may look as the conventional foods and may be consumed as part of the normal diet". The interest for the consumption of functional foods increased much over the past two decades (Siro et al., 2008) as the consumers became increasingly aware of the health benefits (Bachl, 2007; Niva and Mäkelä, 2007; Chrysochou, 2010; Szakály et al., 2012). Many studies (Yashodhara et al., 2009; Kromhout et al., 2011; Jump et al., 2012) proved that the polyunsaturated fatty acids (PUFA), particularly those of the omega-3 (n-3) family, through functional foods, have several beneficial effects: cardiovascular protection, anticancer protection, lower the blood triglycerides and the blood pressure, enhance immunity, and their role in growth, development and maturation of the central nervous system.

The functional poultry products refer to poultry eggs and meat enriched in ingredients that have a positive influence on human health. The birds have the capacity of using beneficial dietary ingredients in their physiological and metabolic processes and to store them in their end products (eggs and meat). The poultry products can be enriched in functional ingredients by feeding the birds with ingredients rich in fatty acids, vitamins and antioxidants. Among consumers, eggs and meat are the most popular functional foods, rich in omega-3 fatty acids, vitamin E, selenium and carotenoids. (Rymer and Givens, 2005; Givens and Gibbs, 2008; Poureslami et al., 2010; Vlaicu et al., 2017 c).

The egg is a food which has proteins with high biological value, because the amino acids profile is similar with that of the proteins from the human body. The egg proteins have a biological value higher than those of the meat proteins (Layman and Rodriguez, 2009). The egg yolk contains essential fatty acids, vitamins and minerals necessary for the proper functioning of the human body (Drenjancevic et al., 2017). Enriching the eggs in particular active principles is easier because of the higher fat content of the egg yolk than of the poultry meat (Perić et al., 2011).

The poultry meat is rich in proteins, it has a low content of fat, being a healthier choice because of the lower content of fatty acids, therefore of a better saturated to unsaturated fatty acids ratio (De Smet and Raes, 2004). However, in the attempt to optimise the fatty acids composition of the poultry meat, previous studies reported that the fatty acids supply of the foods is reflected differently in the muscle tissues (Rymer and Givens, 2005; Poureslami et al., 2010). Furthermore, the poultry meat is available to large scale consumption, at more affordable prices than the red meat (Drenjancevic et al., 2017; Turcu et al., 2018).

The purpose of this paper was to synthesize the studies on i) fatty acids importance and metabolism; ii) nutritive characteristics (chemical composition and fatty acids profile) of various vegetable sources rich in PUFA, such as flaxseeds, camelina, rapeseeds and their by-products (meals

and cakes); iii) impact of feeding these vegetable sources on layers performance, and their effects on egg products.

Fatty acids

In terms of growth and development of the body, lipids are those that contain the essential fatty acids needed. It is already well known that essential fatty acids act as precursors for long chain derivatives used by the cell membrane. In addition, they are responsible for the synthesis of prostaglandins and hormone substrates which are directly involved in the regulation, reproduction, immunity and blood flow of cells. The fatty acids (FA) are common structural units of the lipids and consist of three elements: carbon (C), hydrogen (H) and oxygen (O) fitted on a carbon chain with a terminal carboxyl group (-COOH). Biochemically, the FA are carboxyl acids with unbranched aliphatic chain, which can be saturated or unsaturated. The classification of fatty acids is made according to the length, number of carbon atoms, 4-6 carbon atoms (short chain); 8-12 carbon atoms (medium chains); >12 carbon atoms (long chain) and by the position and configuration of the double link. The most common FA are aliphatic monocarboxylic with normal saturated or unsaturated chain, with an even number of atoms (4 to 26). Table 1 shows the classification of the main saturated and unsaturated fatty acids.

Table 1. Main saturated and unsaturated fatty acids (after Hăbeanu et al., 2011)

Common name	Number of carbon atoms	Number and position of the double bond
Saturated		
Palmitic	16	0
Stearic	18	0
Unsaturated		
Palmitoleic	16	1 (Δ^{9})
Oleic	18	1 (Δ^{9})
Linoleic (LA)	18	2 ($\Delta^{9, 12}$)
Linolenic (ALA)	18	3 ($\Delta^{9, 12, 15}$)
Arachidonic (AA)	20	4 ($\Delta^{5, 8, 11, 14}$)
Eicosapentaenoic (EPA)	20	5 ($\Delta^{5, 8, 11, 14, 17}$)
Docosaxehaenoic (DHA)	22	6 ($\Delta^{4, 7, 10, 13, 16, 19}$)

The general formula of the saturated FA is $CH_3 (CH_2)_nCOOH$, and of the unsaturated FA, is C_n: Δ^m, where: n = number of carbon atoms, and Δ^m = position of the double link(s). The saturated FA have the maximal number of hydrogen atoms, while the monounsaturated FA (MUFA) have a double link, and the polyunsaturated FA (PUFA) have two or more double links.

The PUFA can be further subdivided according to the place of the double link in relation with the methyl end of the chain.

The saturated FA have a perfectly straight structure of the chain, while the unsaturated fatty acids usually have a curved shape of the chain, unless they have a trans configuration.

Fatty acids metabolism

The PUFA classify in two families: omega-6 (n-6) and omega-3 (n-3), depending on the position of the first double link within the carbon chain, i.e., where the hydrogen atoms are missing (Alais and Linden, 1991). The metabolism and role of the omega-6 and omega-3 PUFA differ in the living organism and are called essential fatty acids (EFAs) because they cannot be synthesized by the organism, and must therefore be acquired largely through the diet (Naudet et al., 1992; Simopoulos, 1999).

The omega-6 FA are mainly represented by the linoleic acid (LA) and arachidonic acid (AA), while the omega-3 FA are mainly represented by the alpha-linolenic acid (ALA), the eicosapentaenoic (EPA) and docosahexaenoic (DHA) acids. Each of these PUFA families have a precursor: ALA for n-3 family and the linoleic acid (LA) for the n-6 family (Naudet et al., 1992). The configuration of ALA and LA, with the double link in the hydrocarbon chain was previously explain schematic by Dubois et al., (2007).

The importance of the dietary omega-3 PUFA-rich products relies in the fact that both essential LA and ALA (precursors with 18 carbon atoms) can be metabolised in the human organism into AA and DHA (fatty acids with 20-22 carbon atoms in the chain) following enzymatic processes of catalysis using elongase, Δ6 and Δ5-desaturase (Simopoulos, 2001; Meyer et al., 2004; Simopoulos, 2016). The limiting factor of omega-6 and omega-3 PUFAs metabolism is Δ6-desaturase enzyme (Figure 1).

The final conversion into docosapentaenoic acid (DPA) and into docosahexaenoic acid (DHA) is not yet clear, but it seems that Δ4-desaturase plays and important role (Holman, 1998). DHA biosynthesis takes place in the mitochondrial membranes, while AA, EPA and DPA biosynthesis takes place in the endoplasmic reticule (Infante and Huszagh, 1998).

The EFAs are transformed into substances called eicosanoids, with the help of cyclooxygenase (COX) and lipoxygenase (LX) enzymes. Many studies reported that during their biosynthesis, the LA, ALA and oleic acids compete for the same Δ6-desaturase, and that ALA acts as inhibitor n-6 PUFA metabolism (Cooke 1991; Emken et al., 1994; Schmitz and Ecker, 2008). The two PUFA families, omega-6 and omega-3, compete for the desaturation and elongation enzymes (Brody, 1999; Simopoulus, 2001) and have distinct physiological properties, as well as antagonistic actions

(Simopoulus, 2018). The omega-3 FA produces anti-inflammatory derivatives, while the omega-6 FA generates inflammatory metabolites. The n-6: n-3 ratio must reflect a dietary balance between the two eicosanoid families to avoid the "pro-inflammatory status", and the "immuno-deficient status"(Lehr et al., 1991; Abeywardena et al., 1992; Abeywardena and Head, 2001).

The need for a balanced dietary n-6: n-3 ratio is basic for human health; this ratio varies from 2:1 to 1:1 in the traditional Mediterranean diet, to 15:1 in the European diet, and 16.74:1 in the North American diet. The optimal dietary n-6: n-3 ratio must be 1-4:1 (Simopoulus, 2001; 2008).

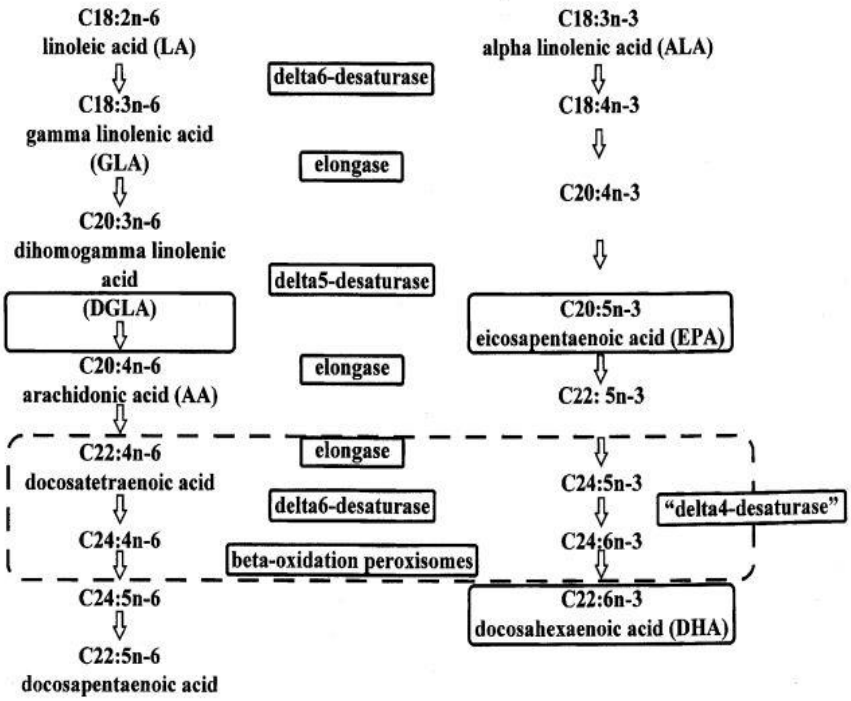

Figure 1. Desaturation and elongation of omega-6 and omega-3 fatty acids (Simopoulos, 2008)

Most plant seeds, the corn, sunflower, safflower and soybean oils are rich LA sources. ALA can be found in green plants, and in the flaxseed, rapeseed, chia and nut oils (Sinclair et al., 2002). AA can be predominantly found in the cereal phospholipids, in meat, milk and eggs. EPA and DHA exist in the fish oil, particularly from the fat fish (Simopoulus, 2008).

Vegetable sources rich in PUFA used in poultry feeding

The classical poultry feeds based on cereal grains and soybean meal supply mostly omega-6 PUFA and a small amount of omega-3 PUFA, composition that reflects in the poultry products too. The modern nutrition must develop feeding strategies which to deliver high quality products and a good health state for the animals and man.

In order to remain competitive, poultry production uses compound feeds whose ingredients are selected from a range of similar products, according to the market price and local availabilities, knowing that the cost of feeds accounts for 65-75% of the total production costs.

The knowledge about diverse, safe and quality feeds must be improved, while the composition and intake of feeds are important segments. At the same time, feed availability for man and animals is insufficient, which calls for the full use of the existing resources and for the identification of unknown and/or less used ones.

The current feeding strategies focus on the evaluation of the omega-3 PUFA-rich sources for poultry feeding and their subsequent effects on product quality.

Some feed sources, such as the flaxseeds, camelina, rapeseeds, chia, hemp seeds, nut, sunflower and their by-products (meals, cakes and oils), or the buckthorn, grapeseed and pumpkin seeds meals are true pools of nutrients (fatty acids, amino acids, polyphenol compounds) more or less used in poultry feeding.

Given the need to increase the available sources of feeds for animals, and the therapeutic properties of some natural bioactive compounds of these sources/by-products, and the current trend of using various food supplements in human nutrition, it is necessary to know and use efficiently these feed resources.

The great disadvantage of these sources/by-products is that they have a variable content of nutrients and a production potential limited by the existence of antinutritional factors.

The purpose of this paper is to review the studies conducted over the past fifteen years on the nutritional characteristics (chemical composition and fatty acids profile) of flaxseed, camelina and rapeseeds, and their by-products (meals and cakes), as well as to evaluate the productive and quality effects of using these products as rich PUFA sources in layer hens feeding.

Chemical composition and fatty acids profile of the studied sources

 # Flaxseed and flaxseed by-products

The flax (*Linum usitatissimum L.*) is a rich source of proteins (22%), oil (34%) and alpha-linolenic acid (ALA, 50% oil). The dietary flaxseeds and his by-products given to layers produces eggs or meat enhanced in n-3 fatty acids (Caston and Leeson, 1990; Ajuyah et al., 1991; Hargis and Van

Elswyk, 1993; Leeson and Summers, 2005). The protein from flaxseeds is rich in some essential amino acids (arginine, aspartic acid and glutamic acid), but also has its limiting amino acids (lysine, methionine and cysteine) (Chung et al., 2005). The flaxseeds and by-products (meals, cakes) have a huge potential of use in poultry production being rich in lipids, proteins, soluble fibres, phenolic compounds and lignans, particularly secoisolariciresinol diglycoside, with antioxidant effect (Shahzad, 2006; Gutiérrez et al., 2010; Amin and Thakur, 2014).

However, the flaxseeds contain several antinutritional factors that may depress poultry performance, depending on the dietary level and form of administration i.e. seeds or by-products (Ajuyah et al., 1991; Lee et al., 1995; Alzueta et al., 2003). Compared to other poultry feed ingredients, flaxseeds have rather large amounts of non-amylose-polysaccharide, NSP (about 165.2 mg/g, of the total fat), 46% being water-soluble (Jia et al., 2009). The chemical composition of the flaxseeds and by-products differ according to the genotype, environmental conditions, oil extraction methods and technologies, etc. (Coskuner and Karababa, 2007; Shim et al., 2014).

The literature studies investigated (Table 2) shows that flaxseeds have a crude protein content in the range of 17.90-23.44%, 31.16-45.20% ether extractives, 6-29.07% fibres 2.66-3.75% ash (Bozan et al., 2008; Pekel et al., 2009; Mueller et al., 2010; Cherian and Quezada 2016; Panaite et al., 2017).

The flaxseed meal displays the largest variations of the chemical composition, which depend on the oil extraction process. The crude protein content was in the range of 29.97-43.30%, ether extractives 1.13-15.69%, crude fibres 8.33-12.94% and 3.87-6.40% ash (Mueller et al., 2010; Panaite et al., 2016; Vlaicu et al., 2017; Olteanu et al., 2017; Vlaicu et al., 2018).

The flaxseed cakes have 27.78-40.90% crude protein and 7.55-13.00% ether extractives (Mueller et al., 2010; Ahmad et al., 2017) depending on the variety and method of processing.

Table 3 shows reports of previous studies on the fatty acids composition of the flaxseeds (El-Beltagi et al., 2007; Quezada and Cherian 2012; Aziza et al., 2013; Rahimi et al., 2013; Cherian and Quezada 2016; Panaite et al., 2017), meals (Quezada and Cherian 2012; Panaite et al., 2016; Vlaicu et al., 2018) and cakes (Halle and Schone, 2013).

The fatty acids profile of the flaxseeds (Table 3) shows that among the saturated fatty acids, the palmitic acid (C16:0) dominates, with values of 5.70-9.54%, followed by the stearic acid (C18:0) 2.76-4.15%. The monounsaturated fatty acids are dominated by the oleic acid (C18:1n-9) with proportions of 15.61-23.33%, while the eicosenoic acid (C20:1n-9) was detected in low proportions (0.37%) by Aziza et al., (2013). The total proportion of unsaturated n-6 fatty acids varied between 12.10-29.60%,

with the linoleic acid (C18:2n-6) dominating, 14.52-29.60%, while the eicosadienoic acid (C20:2n-6) was detected in amounts of 0.11-0.17% (Quezada and Cherian 2012; Panaite et al., 2017).

The main characteristic of the flaxseeds, unique for this source, is the large amount of n-3 polyunsaturated fatty acids, 37.00-87.90%, the linolenic acid (C18:3n-3) dominating, with values of 37.00% (Rahimi et al., 2013) to 60.80% (Vlaicu et al., 2019). The variable proportion of linoleic acid in the flaxseeds depends on the cultivation and growing conditions (Wakjira et al., 2004).

The flaxseed meal contains 3.95-12.85% palmitic acid and 1.27-3.69% stearic acid (Panaite et al., 2016; Vlaicu et al., 2018). Quezada and Cherian (2012) suggested that the quantitative and qualitative differences of the fatty profile can be attributed to the extraction process of the oil. Among the monounsaturated fatty acids, the oleic acid (C18:1n-9) was determined in proportions of 15.88-23.31%, while the eicosenoic acid was determined in low proportions, 0.52% (Quezada and Cherian, 2012). The total proportion of n-6 polyunsaturated fatty acids varied between 10.22-27.30%, dominated by the linoleic acid, 10.22-26.64%, while the eicosadienoic acid was determined in low proportions, 0.17% (Panaite et al., 2017). The total proportion of n-3 polyunsaturated fatty acids varied between 39.50-68.57%, dominated by the linolenic acid (C18:3n-3), with 39.29-68.57%.

The flaxseeds and by-products are functional foods because of their nutritional composition and content of bioactive compounds (alpha-linolenic acid, lignans and polysaccharides, other than starch), with positive effects in the prevention of diseases such as diabetes, arteriosclerosis or cancer (Valencia et al., 2006; Williams et al., 2007; Bozan and Temelli, 2008; Bilek and Turhan, 2009; Toure and Xueming 2010).

 # Camelina and camelina by-products

Camelina sativa is an oleaginous plant from the *Brassica* (*Cruciferae*) family, also known as „false flax" or „gold of pleasure" (Zubr, 1997), that has gained interest as an alternative biofuel source (Ayasan, 2014). The seeds and by-products from oil extraction have a high content of fat and a special structure of the lipids, of omega n-3 essential fatty acids (Schieber et al., 2001; Toncea et al., 2013; Ayasan, 2014; Woyengo et al., 2016). In addition, it is noted that the oil has high natural antioxidants and tocopherols (Aziza et al., 2010a; Quezada and Cherian, 2012), which confers increased stability and increased resistance to oxidation (Habeanu et al., 2011). Besides the outstanding quality of the fat of these sources, it is also noticeable for the protein and essential amino acids content (Berti et al., 2016).

Table 2. Chemical composition of flaxseed and by-products investigated

Item	Dry matter, %	Crude protein, %	Ether extract, %	Crude fiber, %	Crude ash, %	References
Flax Seed	nd	17.90	33.60	nd	3.90	Bozan et al., 2008
	93.68	23.44	38.84	6.00	3.48	Pekel et al., 2009
	nd	21.34	nd	6.21	2.66	
	92.60	23.40	45.20	nd	3.50*	Mueller et al., 2010
	92.70	23.30	44.00	nd	3.38**	
	nd	19.00	42.00	nd	nd	Cherian and Quezada 2016
	94.00	22.00	40.50	6.50	2.99	Ahmad et al., 2017
	94.46	20.86	31.16	29.07	3.75	Panaite et al., 2017
Flax Meal	89.20	39.80	1.13	nd	6.34**	Mueller et al., 2010
	90.30	43.30	1.67	nd	6.40*	
	89.25	32.99	9.42	11.99	4.65	Panaite et al., 2016
	90.94	35.55	10.79	9.60	5.60	Olteanu et al., 2017
	90.46	29.97	15.69	11.16	3.87	Vlaicu et al., 2017
	90.40	33.00	0.50	9.50	6.00	Ahmad et al., 2017
	90.71	39.35	12.22	8.33	4.97	Vlaicu et al., 2018
Flax cake	nd	27.78	nd	7.02	3.40	
	87.40	40.90	12.40	nd	6.30*	Mueller et al., 2010
	91.40	36.90	7.55	nd	6.19**	
	89.70	32.20	13.00	9.50	5.20	Ahmad et al., 2017

*Brown linseed, **Yellow linseed; nd=not determined.

Table 3. Fatty acids profile of investigated flaxseed and by-products

Item	Fatty acids (% of total FAME)									References
	C16:0	C18:0	C18:1n-9	C18:2n-6	C18:3n-3	C20:1n-9	C20:2n-6	Σn-6 PUFA	Σn-3 PUFA	
Flax Seed	7.10	3.70	22.00	18.30	48.20	nd	nd	12.10	87.90	El-Beltagi et al., 2007
	5.81	3.47	15.61	14.52	60.08	nd	0.17	14.52	60.08	Quezada & Cherian, 2012
	5.70	4.12	22.50	29.60	37.00	nd	nd	29.60	37.00	Rahimi et al., 2013
	9.54	2.76	23.33	19.78	43.07	0.37	nd	20.06	43.23	Aziza et al., 2013
	5.81	3.47	15.61	14.52	60.08	nd	nd	14.52	60.08	Cherian & Quezada, 2016
	5.95	4.15	17.38	16.13	54.51	nd	0.11	17.07	54.77	Panaite et al., 2017
Flax Meal	12.85	3.69	23.31	18.71	39.29	0.52	nd	19.39	39.50	Quezada & Cherian, 2012
	7.70	3.07	18.54	26.64	42.96	nd	0.17	27.30	42.93	Panaite et al., 2016
	3.95	1.27	15.88	10.22	68.57	nd	nd	10.22	68.57	Vlaicu et al., 2018
Flax Cake	5.90	2.90	22.10	17.10	51.50	nd	nd	nd	nd	Halle and Schone, 2013

C16:0, Palmitic; C18:0, Stearic; C18:1n-9, Oleic; C18:2n-6, Linoleic; C18:3n-3, α-Linolenic; C20:1n-9, Eicosenoic; C20:2n-6, Eicosadienoic; Σn-6 PUFA sum n-6 PUFA; Σn-3 PUFA sum n-3 PUFA; nd= not determined.

However, the presence of components such as glucosinolates, non-starch polysaccharides, erucic acid, etc., can have adverse effects of poultry performance, thus limiting the dietary level (Ryhanen et al., 2007; Pekel et al., 2009).

The nutrient content of the camelina seeds and by-products varies with the genotype, cultivation and growing conditions, soil quality, etc. (Zubr, 2003).

Table 4 shows that the camelina seeds have 24.50-27.00% crude protein, 22.11-38.90% ether extractives, 11.40-33.30% fibres and 3.20-4.27% ash (Peiretti et al., 2007; Peiretti and Meineri, 2007; Cherian and Quezada 2016; Ciurescu et al., 2016).

The camelina meal has 33.03-46.90% crude protein, 4.82-13.55% ether extractives, 8.40-11.90% crude fibre, and 4.97-6.50% ash (Peiretti and Meineri, 2007; Cherian et al., 2009; Pekel et al., 2009; Aziza et al., 2010 a, b; Cherian, 2012; Kakani et al., 2012; Thacker and Widyaratne, 2012; Dharavath et al., 2016). The camelina cakes have 28.16-38.10% crude protein, 4.68-22.49% ether extractives (Gheorghe et al., 2014; Dharavath et al., 2016) and 5.25% ash (Dharavath et al., 2016). Table 5 shows the fatty acids composition of the camelina seeds and by-products (meals, cakes).

Among the saturated fatty acids, camelina seeds have 2.16-9.00% palmitic acid and 1.04-2.80% stearic acid. Among the monounsaturated fatty acids, the oleic acid is in a proportion of 14.92-17.54%, while the eicosenoic acid is in a proportion of 2.02-15.57%. Some studied determined 1.72% - 5.02% erucic acid (Ropota et al., 2010; Ciurescu et al., 2016; Dharavath et al., 2016). The *Brassicaceae* family plants naturally contain variable amounts of erucic acid (≥ 40% of the total fatty acids (Schuster and Friedt, 1998; Tripathi and Mishra, 2007). The erucic acid is part of the omega-9 family. It oxidizes hardly in the organism and because of this, it accumulates in the cardiac muscle, particularly, producing myocardia lipidosis. Thus, the intake of large amounts of erucic acid leads to delayed development, to impaired performance and health of monogastric animals. Just as for the rapeseed, the progresses achieved in biotechnologies *via* techniques of genetic modification, succeeded to eliminate the antinutritional factors, the erucic acid, included, from the camelina seeds, thus improving the quality and suitability of their use for monogastric animals feeding. The n-6 family accounts for 21.66-23.15% of the total polyunsaturated fatty acids, dominated by the linolenic acid, with 18.01-23.15%, while the eicosadienoic acid was determined in amounts of 1.47-1.67%, and the docosatetraenoic acid, in proportions of 0.33% to 1.20% (Quezada and Cherian, 2012; Ciurescu et al., 2016; Dharavath et al., 2016). The total proportion of n-3 polyunsaturated fatty acids was of 33.34-58.32%, dominated by the linolenic acid, with 30.70-58.32%.

The cameliana meal contained 7.04-8.29% palmitic fatty acid and 2.27-2.60% stearic acid. The monounsaturated fatty acids, oleic and eicosenoic were

in proportions of 13.80-20.5% and 9.80-13.30%, respectively. The erucic acid was determined in rather high amounts in the studies conducted by Thacker and Widyaratne, (2012) and in moderate amounts (1.75%) by Cherian, (2012). The total amounts of n-6 PUFA were within 23.46-27.28% (Thacker and Widyaratne, 2012; Quezada and Cherian, 2012). From the n-6 PUFA, the linoleic acid was predominant, with 19.90-24.63%, while the eicosadienoic acid (1.4-2.30%) and docosatetraenoic acid (0.48-0.91%) were in lower proportions. The total proportion of n-3 PUFA was 29.37-32.3%, of which the linolenic acid was in a proportion of 29.37-35.40% (Thacker and Widyaratne, 2012; Quezada and Cherian 2012).

The review of the studies of the fatty acids profile of the camelina cakes shows that the saturated fatty acids were reported in proportions of 6.00-7.74% for the palmitic acid and 2.01-2.30% for the stearic acid. From the MUFAs, the oleic acid was reported in amounts of 15.57-18.76% (Ropota et al., 2010; Gheorghe et al., 2014), the eicosenoic acid in proportions of 9.91-11.42% (Gheorghe et al., 2014; Dharavath et al., 2016) and the erucic FA was reported in proportions lower than 3% (Ropota et al., 2010; Gheorghe et al., 2014; Dharavath et al., 2016). The n-6 PUFA were reported in amounts of 26.36% (Juodka et al., 2018), with the linoleic acid predominant 21.09-28.80% (Ropota et al., 2010; Gheorghe et al., 2014; Dharavath et al., 2016). The n-3 PUFA were reported in a proportion of 26.72%, represented mainly by the linolenic acid, with 24.20-38.49% (Ropota et al., 2010; Gheorghe et al., 2014; Dharavath et al., 2016; Juodka et al., 2018).

The balanced profile of the PUFA and the valuable nutrients (proteins, antioxidants, etc.) make consider that these raw materials can support the production of functional poultry foods.

 # Rapeseed and rapeseed by-products

The rape (*Brassica* spp.) and its by-products represent the second worldwide protein source for monogastric animals. Its use was boosted after 1970, when new varieties were developed and grown in Canada, with low levels of glucosinolates (<30 μmols/g de dry matter) and erucic acid (<2% of the total fatty acids in the oil), known as Canola (OECD, 2001) or „00" rape in Europe (low erucic acid, low glucosinolate; Newkirk, 2009).

Canola and its by-products (meals, cakes) have high protein levels and a better profile of amino acids than other plant proteins, being a good source of sulphur amino acids (methionine and cystine), but it is limited in lysine (Lomascolo et al., 2012). Besides the high-quality proteins, these by-products also have good quality fat, which meet the energy requirements and enrich the feeds in PUFA. Table 6 shows that the gross chemical composition of the rapeseeds has 17.42-21.01% crude protein, 40.58-54.20% ether extractives, 7.16-23.20% fibres and 3.60-9.02% ash (Nguyen et al., 2003; Yoshie-Stark and Wäsche, 2004; Ciurescu, 2009).

Table 4. Chemical composition of camelina seed and by-products investigated

Item	Dry matter, %	Crude protein, %	Ether extract, %	Crude fiber, %	Crude ash, %	References
Camelina Seed	88.70	27.00	37.80	nd	nd	Peiretti & Meineri, 2007
	93.20	24.50	30.20	33.30	3.20	Peiretti et al., 2007
	91.03	24.97	22.11	15.21	nd	Hăbeanu et al., 2011
	nd	25.80	38.90	nd	nd	Cherian & Quezada 2016
	93.66	24.78	36.84	11.40	4.27	Ciurescu et al., 2016
Camelina Meal	91.30	41.10	13.20	nd	nd	Peiretti & Meineri, 2007
	92.02	34.99	13.55	9.90	5.67	Pekel et al., 2009
	nd	37.2	11.9	nd	nd	Cherian et al., 2009
	nd	35.2	4.9	nd	6.5	Aziza et al., 2010 a, b
	90.00	36.20	12.00	8.40	6.50	Cherian, 2012
	91.38	33.03	11.14	nd	5.26	Thacker & Widyaratne, 2012
	91.00	36.47	7.48	10.84	5.58	Vasilachi et al., 2012
	nd	36.00	10.00	11.00	nd	Kakani et al., 2012
	89.2	33.70	13.50	15.20	5.40	Pekel et al., 2015
	93.20	35.60	13.10	12.60	5.10	Pekel et al., 2015
	93.45	46.90	4.82	11.90	6.50	Dharavath et al., 2016
Camelina Cake	nd	30.39	22.49	nd	nd	Gheorghe et al., 2014
	93.45	35.20	4.68	4.90	5.25	Dharavath et al., 2016

nd= not determined.

Table 5. Fatty acids profile of camelina seed and by-products investigated

Item	Fatty acids (% of total FAME)											References
	C16:0	C18:0	C18:1 n-9	C18:2 n-6	C18:3 n-3	C20:1 n-9	C20:2 n-6	C22:1 n-9	C22:4 n-6	Σn-6 PUFA	Σn-3 PUFA	
Camelina Seed	6.40	2.80	15.90	20.90	30.70	2.02	nd	nd	nd	nd	nd	Woods and Fearon, 2009
	6.43	2.02	14.92	18.01	51.11	nd	nd	1.72	nd	nd	nd	Ropota et al., 2010
	6.46	2.49	17.54	19.04	33.21	15.57	1.67	nd	0.47	22.24	33.34	Quezada and Cherian 2012
	6.07	1.91	16.46	18.84	33.43	12.99	1.47	5.02	0.33	21.66	34.29	Ciurescu et al., 2016
	9.00	2.50	nd	19.04	41.30	15.57	1.67	1.80	1.20	nd	nd	Dharavath et al., 2016
	6.46	2.49	17.54	19.04	33.21	15.57	nd	nd	nd	22.24	33.34	Cherian and Quezada, 2016
	2.16	1.04	15.23	23.15	58.32	nd	nd	nd	nd	23.15	58.32	Konieczka et al., 2017
Camelina Meal	9.0	2.5	20.2	23.4	29.6	10.1	1.4	nd	nd	nd	nd	Cherian et al., 2009
	7.6	2.3	20.5	24.3	29.5	11.20	1.6	nd	nd	nd	nd	Aziza et al., 2010 a, b
	7.19	2.48	20.25	24.63	30.17	13.30	nd	nd	0.96	26.14	30.32	Quezada and Cherian 2012
	7.59	2.27	20.46	24.35	29.37	11.23	1.64	nd	0.91	27.28	29.37	
	8.29	2.38	20.33	23.87	29.48	10.67	1.52	1.75	nd	nd	nd	Cherian, 2012
	7.11	2.39	20.88	24.49	23.65	11.38	1.39	3.21	nd	nd	nd	Vasilachi et al., 2012
	7.04	2.45	14.96	20.91	30.80	12.98	1.93	3.44	0.48	23.46	32.3	Thacker and Widyaratne, 2012
Camelina Cake	7.74	2.16	18.76	24.51	38.49	nd	nd	1.22	nd	nd	nd	Ropota et al., 2010
	7.43	2.01	17.69	21.09	29.47	11.42	1.33	2.99	0.25	nd	nd	Gheorghe et al., 2014
	6.00	2.30	nd	28.80	24.20	10.10	nd	1.70	0.90	nd	nd	Dharavath et al., 2016
	7.05	2.37	17.11	24.16	25.99	12.28	1.65	3.20	0.03	26.36	26.72	Juodka et al., 2018

C16:0, Palmitic; C18:0, Stearic; C18:1n-9, Oleic; C18:2n-6, Linoleic; C18:3n-3, α-Linolenic; C20:1n-9, Eicosenoic; C20:2n-6, Eicosadienoic; C22:1n-9, Erucic; C22:4n-6 Docosatetraenoic; nd=not determined.

The canola meals has 31.15-38.00% crude protein, 0.85-3.80% ether extractives, 9.13-15.49% crude fibre, and 4.70-8.02% ash (Ciurescu, 2009; RIRDC, 2009; Riyazi et al., 2009; Rostagno et al., 2011; Mikulski et al., 2012; Khajali and Slominski, 2012; Thacker and Widyaratne, 2012; Feedstuffs, 2012; Gheorghe et al., 2014; Panaite et al., 2016; Vlaicu et al., 2017a). The canola cakes have 28.00-36.10% crude protein, 12.20-17.80% ether extractives, 11.20-13.10% crude fibre and 5.60-7.10 ash (Leming and Lember, 2005; Lomascolo et al., 2012; Halle and Schone, 2013).

From analysis of studies that reported the rapeseed fatty acid profile (Table 7), the content in saturated fatty acids range from 2.27-5.10% for palmitic acid and between 0.46-2.20% for stearic acid results. From the monounsaturated fatty acids, the oleic acid range between 56.80-66.60% and the eicosenoic acid between 1.10-1.50%. Erucic acid was identified in low amount (0.10-0.20%). From the total PUFAs, the n-6 family ranges between 24.70-33.90%, predominantly linoleic acid 16.10-28.00% and from the total n-3 PUFA (9.64%), the linolenic acid was between 7.90-10.00%.

The rapeseed meal contains 5.60-12.04% palmitic acid, 1.60-2.73% stearic acid, monounsaturated oleic fatty acid 41.06-58.56% and eicosenoic acid 0.41-0.48%. Thacker and Widyaratne (2012) and Panaite et al. (2016) reported 26.40-35.85% total n-6 PUFA, with 21.50-35.03% linoleic acid. The total n-3 PUFA amounted to 2.96-4.42%, with 2.96-5.40% linolenic acid (Thacker and Widyaratne, 2012; Gheorghe et al., 2014; Panaite et al., 2016).

The fatty acids profile of the rapeseed cakes shows large variations in the palmitic acid 4.40% to 12.41% and the stearic acid from 0.60% to 2.21% (Halle and Schone, 2013; Juodka et al., 2018). From the monounsaturated fatty acids, the oleic acid dominated (40.99-59.60%) while the eicosenoic and erucic fatty acids were reported in very low amounts (0.60% and 0.09%). Among the PUFA, the linoleic acid represented 21.67-23.50%, and the linolenic acid, 10.60-13.11%.

These studies show that the rapeseeds and their by-products (meals, cakes) are rich in monounsaturated fatty acids, have low levels of erucic acid and have good supplies of polyunsaturated fatty acids for poultry diets.

Effects of using vegetable sources rich in PUFA in layers feeding

Fatty acids composition modification is one of the most efficient ways of enriching the poultry products (eggs and meat) in PUFA (Rymer and Givens, 2005; Wood et al., 2008; Ribeiro et al., 2013; Bhalerao et al., 2014). The enrichment of the most consumed foods (eggs and meat) by innovative feeding strategies, besides consumer health benefits (consumption of eggs and meat enriched in PUFA), also contributes to enhancing bird health.

Within this context, Tables 8 and 9 shows the main results of the studies on the use of flax, camelina and canola as rich PUFA vegetable sources in layers feeding, and their effects on the quantitative and qualitative performance, i.e. egg enrichment in n-3 fatty acids.

Table 6. Chemical composition of rapeseed and by-products investigated

Item	Dry matter, %	Crude protein, %	Ether extract, %	Crude fiber, %	Crude ash, %	References
Rape Seed	93.98	21.01	43.38	7.16	4.16	Nguyen et al., 2003
	92.99	19.00	54.20	23.20	3.60	Yoshie-Stark and Wäsche, 2004
	93.18	17.42	40.58	9.17	9.02	Ciurescu, 2009
Rape Meal	90.80	35.00	1.40	nd	4.70	Riyazi et al., 2009
	88.90	37.00	3.40	9.90	7.30	RIRDC, 2009
	88.00	36.00	3.50	12.00	6.10	Newkirk, 2009
	nd	37.97	1.21	11.20	nd	Rostagno et al., 2011
	nd	36.5	3.6	nd	6.8	Khajali and Slominski, 2012
	90.00	35.58	1.82	9.13	6.44	Mikulski et al., 2012
	92.00	35.36	3.10	nd	7.01	Thacker and Widyaratne, 2012
	91.00	38.00	3.80	11.10	7.20	Feedstuffs, 2012
	nd	35.32	0.85	nd	nd	Gheorghe et al., 2014
	89.60	33.15	1.04	12.40	8.02	Panaite et al., 2016
	90.03	31.15	1.02	12.40	5.71	Vlaicu et al., 2017a
Rape Cake	95.30	36.10	12.20	13.10	7.10	Leming and Lember, 2005
	91.70	28.00	17.80	11.20	6.50	
	91.30	35.00	nd	11.60	6.30	Lomascolo et al., 2012
	89.50	29.50	15.80	nd	5.60	Halle and Schone, 2013

nd = not determined.

Table 7. Fatty acids profile of rapeseed and by-products studied

Item	Fatty acids (% of total FAME)									References
	C16:0	C18:0	C18:1 n-9	C18:2 n-6	C18:3 n-3	C20:1 n-9	C22:1 n-9	Σn-6 PUFA	Σn-3 PUFA	
Rape Seed	4.40	1.80	61.90	19.00	9.90	1.50	0.20	28.90	nd	Szydłowska-Czerniak et al., 2010
	4.60	1.60	66.00	17.30	7.80	1.30	0.10	25.10	nd	
	4.60	1.50	56.80	23.90	10.00	1.40	0.20	33.90	nd	
	4.50	2.00	63.50	17.10	10.00	1.40	0.10	27.10	nd	
	5.10	1.90	62.20	19.60	8.40	1.20	0.20	28.00	nd	
	4.30	1.90	66.60	16.10	8.60	1.20	nd	24.70	nd	
	5.10	2.20	63.40	18.40	7.90	1.10	0.20	26.30	nd	
	2.27	0.46	58.64	28.00	9.64	nd	nd	28.03	9.64	Konieczka et al., 2017
Rape Meal	8.06	1.68	58.56	26.40	2.96	0.48	nd	26.40	2.96	Thacker and Widyaratne, 2012
	12.04	1.66	44.80	31.60	5.40	0.41	nd	nd	nd	Gheorghe et al., 2014
	11.92	2.73	41.06	35.03	4.42	nd	nd	35.85	4.42	Panaite et al., 2016
Rape Cake	4.40	0.60	59.60	23.50	10.60	nd	nd	nd	nd	Halle and Schone, 2013
	12.41	2.21	40.99	21.67	13.11	0.60	0.09	21.96	13.05	Juodka et al., 2018

C16:0, Palmitic; C18:0, Stearic; C18:1n-9, Oleic; C18:2n-6, Linoleic; C18:3n-3, α-Linolenic; C20:1n-9, Eicosenoic; C20:2n-6, Eicosadienoic; C22:1n-9, Erucic; C22:4n-6 Docosatetraenoic. Σn-6 PUFA sum n-6 PUFA; Σn-3 PUFA sum n-3 PUFA;
nd = not determined

Table 8. Summary of studies investigated the effects of flaxseed and its by-products on layer hens

Feeding details			Main results	References
Source	**Level**	**Period**		
Flaxseed	15%	56 d	↑ n-3 fatty acid content in eggs 562 mg/60g of egg vs. 207 mg/60 g of egg from hens fed canola seed diet ↑ egg n-3 content from 546 to 578 mg/60 g of egg (P=0. 01) as results of enzyme supplementation -flaxseed long-term feeding to laying hens ↓ egg production and eggshell quality *vs.* canola seed	Jia et al., 2008
Flaxseed	5%	32-45 wk	↑ ALA and DHA concentrations in eggs - no significant effect of layer performance	Criste et al., 2009
Flaxseed	10% +/- antioxidant (Toc or BHT)	56 d	- no effect on egg production, egg weight, egg mass, or feed conversion ↓ feed intake - no effect egg quality or egg cholesterol content ↑ ALA (18:3n-3), EPA (20:5n-3), and DHA (22:6n-3) acid in eggs content ↓ arachidonic acid (20:4n-6) content and n-6: n-3 ratio in experimental eggs *vs.* control eggs - antioxidants addition (Toc) ⇒ ↑ long-chain n-3 FA content of eggs	Hayat et al., 2009
Flaxseed	6%	28 wk	↑ n-3 LC-PUFA in the egg yolk, ↑ DHA and ALA	Lemahieu et al., 2015
Flaxseed	30%	5 wk	↑ n-3 fatty acids content of egg yolk, but ↓ the sensory quality of the eggs ⇒ 30% flaxseed not recommended	Coorey et al., 2015
Flaxseed	10%	16 wk	↑ feed intake (g/d) and egg production ↓ shell weight relative to egg weight (shell weight %), and shell thickness - no effect on Haugh unit, yolk: albumen ratio, and yolk weight ↑ ALA, DPA and DHA acids in egg yolk, ↑ total n-3 PUFA in flax eggs 3.09% *vs.* control eggs 1.19%	Cherian and Quezada, 2016
Flaxseed	5% + 5% tomato waste	6 wk	↑ n–3 PUFA in eggs from E group *vs.* control (5.13 *vs.* 1.49 g% total fatty acids) ↓ peroxide value (0.11 mEq/kg fat) and malonaldehyde (1.89mg/kg MDA) in eggs from E group ↑ antioxidant capacity in E eggs *vs.* control (15.24mM ascorbic acid equivalent vs. 10.24mM ascorbic acid equivalent)	Panaite et al., 2019
Flax meal	10%	12 wk	↑ egg production *vs.* control ↑ egg weights and Haugh units, and ↓ eggshell thickness ↑ egg yolk content of ALA and total n-3 PUFA than control	Aziza et al., 2013
Flax meal	0, 5 and 10%	12 wk	↑ total PUFA and omega-3 FA: ALA (C18:3n-3), DPA (C22:5n-3) and DHA (C22:6n-3) in liver and egg yolk ↓ total MUFA and omega-3:omega-6 ratio in the liver and egg yolk ↑ immune response of birds by ↑ serum antibody titres to sheep red blood cells (anti-SRBC) and ↓ blood heterophils: lymphocytes (H:L) ratio in hens fed the FSM diets 10 % FSM ↑ hepatic lipid peroxidation	Shafey et al., 2015

Feeding details			Main results	References
Source	**Level**	**Period**		
Flax meal	10%	12 wk	- no effect on yolk weight vs. control - no significant difference in ALA or other n-3 fatty acids content in eggs	Aziza et al., 2016
Flax meal	3% + 2% camelina meal and 2% grape seeds oil	4 wk	↑ ALA (C 18:3n3) and DHA (C 22:6n3) in the egg yolk from experimental group *vs.* control ↑eggs Haugh unit in E group vs. control, due to the fact that grape seeds oil acted as natural antioxidant	Criste et al., 2016 a
Flax meal	5% + 2% camelina meal + Cu (150 mg/kg)	6 wk	↓ flax meal and camelina meal supplemented with 150mg/kg Cu, has lowered the cholesterol concentration from egg yolks with 18,135% compared *vs.* C group	Criste et al., 2016 b
Flax meal	7% + 4% grape meal	4 wk	↓ n-6:n-3 PUFA ratio of experimental feeds by 93.34% (E1) and by 93.57% (E2), vs. control ↑ polyphenols content (3.86 mg gallic acid equivalent/g) and antioxidant capacity (34.99 mM Trolox equivalent/g) of grape meal, ↑ antioxidant capacity in the methanolic extracts from the experimental groups eggs: 96.72 mM Trolox equivalent /g yolk (E1), 100.10 mM Trolox equivalent /g yolk (E2), compared to control 91.78 mM Trolox equivalent /g yolk.	Olteanu et al., 2016 a
Flax meal	5% + 2% grape meal or 100 mg/kg feed vitamin E	4 wk	↑ ALA concentration (10-fold) in eggs fat of experimentals group (E1 and E2) vs. control ↓ n-6:n-3 PUFAs ratio (3-fold) in eggs fat of experimental groups vs. control ↑ total polyphenols concentration in the egg yolk, especially in vitamin E group, but also in grape meal group than control	Olteanu et al., 2016b
Flax meal	5% + 2% camelina meal + Cu (75, 100 and 150 ppm)	6 wk	- ALA eggs yolk concentration of the three experimental groups was 75.56% higher vs. control group - n-6: n-3 PUFA ratio of eggs yolk ↓ 158.93% in the three experimental vs. control groups - cholesterol concentration of eggs yolk ↓ in experimental groups, but the rate of reduction ↑ with the dietary Cu supplement level - fed enriched n-3 PUFA and supplemented with Cu (75, 100 and 150 ppm) diets resulted in eggs with functional food property	Panaite et al., 2016a
Flax meal	5% or 2% camelina meal + Cr (150 ppb)	4 wk	- no difference on organoleptic parameters of eggs between groups, except the "A" freshness parameter (37.50% in C vs. 58.33% in E group) - after 14 days storage of eggs on refrigerator, 50% of E eggs had "A" freshness *vs.* 33.3% from C eggs	Panaite et al., 2016b
Flax meal	7% + 2 or 3% grape meal	4 wk	- 7% flax meal enriched the diet in n-3 PUFA (by 14.17%) and ↓ n-6:n-3 ratio at 3.07 ↑ n-3 PUFA eggs yolk (~4.91%), and improve n-6: n-3 ratio (~4.25). ↓ egg yolk cholesterol level in experimental groups decresed by 13.57% in group E1, and by 16.27% in group E2 vs. control	Olteanu et al., 2017

Feeding details			Main results	References
Source	**Level**	**Period**		
Flax meal	7% + 1.5%; 3% grape seeds powder or 1% vitamin E	6 wk	↑ n-3 PUFA concentration in egg yolk from experimental groups (E1 and E2) ↓ egg yolk peroxide value in experimental groups (E1 and E2) samples compared to group C and E3	Saracila et al., 2017 a
			↑-7% flaxmeal with 1.5% grapeseed powder has increased the antioxidant capacity from group E1 ↓-7% flaxmeal with 1% vitamin E had the lowest value regarding the antioxidant capacity from egg yolks	Saracila et al., 2017 b
Flax meal	8.7% flaxmeal+ 3 % buckthorn meal	5 wk	↑- flax meal and buckthorn meal used in laying hens diet had a positive effect on the egg quality parameters and significantly improuved (P≤0.05) the egg yolk colour.	Panaite et al., 2017 c
Flax meal	7%	4 wk	↓ average daily feed intake in group fed flax meal and rosehip as antioxidant vs. control ↑ average egg weight in E1 (60.18 ±0.203 g) and E2 (60.54±0.184 g) group vs. control (60.04±0.228 g) (P≤0.05)	Vlaicu et al., 2017 b
Flax meal	8.73% + 3% sea buckthorn meal	5 wk	- no significant effect regarding the layer performances - the cholesterol concentration in experimental group decreased by 10.35% compared to control diet	Vlaicu et al., 2019
Flax cake	5, 10, 15% *vs*. 5, 10, 15% rapeseed cake	24 wk	- 15 % dietary linseed cake ↓ performance (feed intake, egg production and feed conversion ratio) *vs.* 5 and 10 % linseed cake groups ↑ dietary linseed cake level ↓ yolk percentage and ↑ egg white percentage ↑ dietary linseed cake level ↓ the percentages of most SFA and MUFA - up to 10% of linseed or rapeseed cakes enrich the yolk fat with n-3 PUFA with no negative effect on laying hens performance	Halle and Schone, 2013
Flax cake	2% flaxseed + 5% flax cake with or without Vitamin B6 (40mg/Kg)	4 wk	↓ egg yolk cholesterol in experimental groups (flax with or without vit. B6) vs. control ↑ egg yolk n-3 fatty acid content in experimental groups (with or without vit. B6) vs. control ↓ n-6 fatty acid content in egg yolk in group fed flax supplemented with vit. B6, vs. other groups ↓ n-6: n-3 ratio experimental groups (flax with or without vit. B6) vs. control	Khan, 2019

↑ - increase; ↓ - decrease.

Table 9. Summary of studies investigated the effects of camelina and canola seed and meal on layer hens

Feeding details			Main results	References
Source	**Level**	**Period**		
Camelina				
Camelina seed	10%	16 wk	↑ feed consumption in hens (g/d) ↓ egg weight and albumen weight ↑ ALA, DPA and DHA content in egg yolk	Cherian and Quezada, 2016
Camelina meal	5, 10, 15%	80 d	- 10% camelina meal ↑ over 8-fold the n-3 egg fatty acids, and ↓ SFA and MUFA content - 5 and 10% camelina meal did not affect egg production or egg quality - 15% camelina meal ↓ egg production, yolk fat and yolk size, with no effect on egg weight	Cherian et al., 2009
Camelina meal	3 and 6%	60 d	↓ feed conversion ratio (g feed/g egg) of E1 (1.883±0.10) and E2 (1.817±0.15) groups *vs.* control (1.908±0.10) ↓ egg production of E2 group (93.68±2.26%) *vs.* other groups (97.22±1.76% for C; 97.99±1.99 for E1) - no difference in eggs weight for E2 group (64.00±2.31 g/egg) *vs.* eggs weight of C (64.61±2.48)	Vasilachi et al., 2012
Camelina meal	5% and 10%	12 wk	- no significant effect on egg production and feed consumed per dozen eggs by feeding 5 or 10% camelina meal ↑ egg shell strength in camelina groups *vs.* control ↑ egg total n-3 fatty acid content 1.9- and 2.7-fold in 5 and 10% camelina groups; ↑ DHA content in eggs - did not alter glucosinolate levels, no detectable glucosinolates or metabolic product isothiocyanates were found in the eggs from 5 or 10% camelina groups	Kakani et al., 2012
Camelina meal	10%	12 wk	↑ egg production ↑ egg yolk content of ALA and total n-3 PUFA vs. control ↓ digestibility of LA, crude protein and metabolisable energy AMEn	Aziza et al., 2013
Canola				
Canola seed	15, 20%	7 wk	up to 20% canola seed can be used in layers feed, as partialy substitution of soybean meal (25-30%) no significant effect on laying performance and egg quality	Ciurescu, 2009
Canola meal	15, 20%	7 wk	up to 15% canola meal can be used in layers feed, replacing up to 50% of the soybean meal	Ciurescu, 2009
Canola meal	5, 10 and 15%	36 wk	↑ eggshell weight as results of 10% canola meal in diets ↑ rapeseed meal level in diets ↓ yolk index recommended level in layers diet = 10% canola meal	Riyazi et al., 2009
Canola meal	8%	17 wk	- no significant effect on egg weight after 4 weeks of egg production - after 7 weeks of experimental period egg weight ↓	Rutkowski et al., 2015

↑ - increase; ↓ - decrease.

CONCLUSIONS

The most promising and dynamically developing segments of food industry are functional foods. The trend for the consumption of the functional foods as part of the normal diet revelled the necessity to search for alternative fat sources. Recent research shows that the poultry meat and eggs, produced by birds fed vegetable sources such as flaxseed, camelina and rapeseed, have high PUFA levels, particularly those of the omega-3 family. This fact enhanced the interest for their use, and for the use of their by-products in poultry diets due to the favourable functional properties. Increasing consumer awareness represents one of many several factors supporting the inflow of functional products in combination with new advances in various scientific domains. Therefore, the present study shows the potential of flax, camelina and rapeseed for incorporation into new value-added products that could provide health benefits beyond basic nutrients. This review gives information on the feeding value of the flaxseeds, camelina and rapeseeds, together with their by-products, as well as a survey of the literature on their use in poultry feeding to produce foods beneficial to consumer health.

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