



Mathematically Modeling Based on Different Feed Ingredients

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ABSTRACT: Various feed ingredients including omega oils and oil seeds, have been used worldwide to improve intake among the birds. In this research paper, feed ingredients were analyzed for fat, fiber, protein, tannins and cyanogenic glycosides (HCN) contents along the fatty acid characterization. Different supplemented enriched experimental diets were also developed to estimate the Crude fat, protein, fatty acids content and gross energy estimation. These experimental isocaloric and isonitrogenous diets were evaluated through mathematical model for characterization. TOPSIS technique is applied in feed ingredients, protein, tannins and cyanogenic glycosides. PIS and NIS solution proposed in different protein. To define the collective index of the ranking

Keywords: Cyanogenic glycosides, feed ingredients, TOPSIS technique, numerical example, entropy measure.

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1. Introduction

Laying hens were fed on different dietary sources based on oils, oil seeds etc, which further enhance the feed intake with improved palatability. Immunity levels were also boosted up with lesser ratio of morbidity [1–3]. Compared to the broilers, layers have a unique physiological state. The lipid metabolism disorders occurrence ratio was more than in the broilers, as a result. For this reason, an ample proportion of suitable oil type particularly important for the production performance, lipid metabolism, and egg quality of layers. A combination of animal and vegetable oils has been used in birds feed, which were rich in unsaturated fatty acids; playing a vital role in body functions. It has been noticed that linolenic acid required in adequate proportion for the proper growth of hens and improves their production performance. The other EFA, which has been important role linoleic acid that present in egg yolk, and its deposition was directly proportional to the egg weight [4]. Triglycerides (TGs) was majorly extracted from animal fat

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tissue, which enhances the UFA of eggs when fed to hens via diet [5, 6]. The complementary value-added sources to diets enhancing hen's health and growth [7, 8]. To meet the diversified human needs, poultry industry was more focused to improve egg quality via hen performance. The use of different feed ingredients determines the ultimate performance of eggs quality parameters. The Flaxseed (FS) (*Linum usitatissimum* L) or linseed with oval or sometime flat in shape [9]. Its color varied from brown to yellow. It has been believed that the flaxseed is considered as oldest crop of the world that cultivated for oil as well as for fiber [10]. The FS gained popularity due to its diverse nature and wide usage in the industrial sector. Flaxseed has unsaturated FAs in balanced proportions associated with lignans and mucilage [10-12]. Mucilage was the soluble fiber of FS, and its production directly proportional to the extraction method. The geographical distinction the main factor that greatly influenced on mucilage in the range 3.6-8 based on data collected from different regions [13]. The other factor that easily affected by natural factors, such as environmental influence, was protein content. Different conversion factors reported by different authors for protein determination from nitrogen concentration formula, such as 6.5 whereas another one 5.41 used for FS [14]. There was several factors regarding environmental distinctions that determine FS quality, such as heat stress, famine, and sun exposure [15]. The color change from light to darken immature frost dented seeds caused decreased values of FS oil [16]. Chia belongs to Genera *Salvia* Specie [17]. Chia plant reaches almost to the height of about one meter having arranged alternately or opposite in the rachis in petiolate and serrated leaves that are 4-8cm long and 3-5cm wide. It was an annual herb that has flower in summer which consist of both staminate and carpellate parts; male, pollen-producing and female, ovule-producing, respectively called hermaphrodite. The chia plant growing cycle depends on location and mostly controlled by elevation [18]. According to the research data, the dietary fiber present in chia seed comprises of lignin acting as antioxidant and effective for people having hypocholesterolemic symptoms [19]. Chia seed was famous for its significant FAs composition among the plant seeds. Among the lipid profile of PUFAs, Ω -3 ALA was the highest known content reported in chia as compare to other sources including camelina (*Camelina sativa* L) and perilla (*Perilla frutescens* L) [20]. The increased demand of chia seed was due to the presence of good proportions of Ω -3 PUFAs that beneficial to human health. Cultivation of chia seed increasing day by day to its FAs and nutritional profile. The Ω -3 PUFAs further divided into ALA, EPA and DHA. The Ω -6 class includes LA and arachidonic acid [21]. According to the data published, chia contains highest levels regarding to Ω -3 and Ω -6 classes relatively to other FAs food sources. The significant amount of PUFAs was reported in chia seed. It has been stated that chia seed [22, 23, 24, 25, 26, 27]. Fuzzy set was introduced by LA Zadeh in 1965. The model routed was unequivocal with no ambiguities. Certainty eventually indicates that we assume the structures and parameters of the model to be definitely known and that there was no doubts about their values or their occurrence [28, 29, 30]. A hypothetical case demonstrates how the comparison method distinguishes minor changes and fluctuations within patterns from major changes [31]. My findings show how the theoretical perspective developed here allows for a detailed analysis of causal core, periphery, and asymmetry, shifting the focus to midrange theories of causal processes [32]. The proposed fuzzy set approach incorporates students' opinions into the assessment, allowing them to gain a better understanding of the assessment criteria [33]. The simplicity and flexibility of this technique provide needed support for more explicit, objective decisions [34]. On the basis of individual nutrition assessment, fuzzy logic in connection with fuzzy decision making, allows optimization of meals considering individual food preferences [35]. By taking wholemeal bread brands in supermarkets as an example, the empirical application of the proposed method [36]. To prove that the approach to decision-making problems with imprecise data, more accurate than other types of approaches [37, 38, 39, 40, 41, 42]

2. Fuzzy TOPSIS way and entropy

The entropy neutral weighting strategy comprises mounting a baton's weight based on the score of the reign of its esteem among all the conceivable choices. To do this, the following ladders ought to be done: These criteria must to be pertinent to the specific setting or space you are assessing. Build an excellent lattice: Make an excellent lattice where each push expresses to an element and each pilaster speaks to a model. Populate the framework with the normalized ideals for each voting portion. Determine the configurations that are both flawless and imperfect. For every measure, determine the positive and

negative perfect arrangements. While the negative ideal arrangement refers to the most terrible poor esteem, the perfect arrangement speaks to the most fantastic esteem for each basis. The negative ideal arrangement is the opposite of the perfect arrangement, which is often the most extreme esteem for fetched criteria and the least extreme esteem for advantage criteria.

Step 1: Compute the fuzzy TOPSIS approach decision-making problem with m scholars and n decision characteristics below the manifold attributes. It is possible to display the outline fuzzy decision matrix in surveys:

$$R = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix}$$

Step 2: Calculate the FWA operator.

Step 3: Believed a fuzzy TOPSIS decision matrix

$$E = u_{ij}.$$

The thoughtful of the normalized frequency is

$$u_{ij} = \frac{\gamma_{ij}}{\sqrt{\sum_{j=1}^n (\gamma_{ij})^2}}.$$

Step 4: Calculate the weighted normalized fuzzy TOPSIS decision matrix. The weighted normalized value is thoughtful by

$$u_{ij} = \gamma_{ij} w_j.$$

Step 5: Reflect the probabilities

$$T = \frac{P(x)}{\sum_x P(x)}.$$

Step 6: Find the clustering

$$C_{ij} = \frac{\sum_{j=1}^n (K_j)^\zeta \xi_j}{\sum_{j=1}^n (K_j)^\zeta}.$$

Step 7: The fuzzy TOPSIS system positive-ideal key and the fuzzy TOPSIS negative-ideal answer are distinct as

$$f_j^* = (f_1^*, f_2^*, \dots, f_m^*),$$

$$f_j^- = (f_1^-, f_2^-, \dots, f_m^-).$$

Step 8: Henceforth all candidates of separation from the FPIS are supposed as

$$\rho^* = \sqrt{\sum_{j=1}^m (w_j t_{ij} - L_j^*)^2},$$

and the farewell of each candidate from the FNIS is given as

$$\rho^- = \sqrt{\sum_{j=1}^m (w_j t_{ij} - L_j^-)^2}.$$

Step 9: Compute comparisons to the ideal result. This movement knows the semblances to an ideal solution by

$$Q = \frac{\rho^-}{\rho^- + \rho^*}.$$

2.1. Example

ABC Food Business, a well-known builder of fitness foods, is rational of creating a new range of properties with an augmented omega-3 content. To ensure the quality and nutritional value of their products, they decide to conduct a comprehensive analysis of their primary ingredients, chia and flax seeds.

The primary objective is to analyze the content of fat, fiber, protein, tannins, cyanogenic glycosides, and fatty acids in the raw materials.

- **Fat Content:** Determined using the Soxhlet apparatus and petroleum ether extraction.
- **Fiber Content:** Labconco Fibertech was used to analyze the fiber content following sulfuric acid and NaOH digestion.
- **Protein Concentration:** Determined by utilizing Kjeldahl's apparatus to measure the amount of nitrogen.
- **Tailoring:** Accomplished by the use of spectrophotometric methods.
- **Cyanogenic Glycoside Estimation:** Titration, distillation, and hydrolysis techniques are applied.
- **Characterization of Fatty Acids:** Fatty acid methyl esters (FAMES) are analyzed using gas chromatography.

Step 1: Fuzzy TOPSIS Decision Matrix (Table 2)

	Ethics 1	Ethics 2	Ethics 3	Ethics 4
Alternative 1	0.2634	0.3098	0.4098	0.5045
Alternative 2	0.3476	0.6767	0.1234	0.4523
Alternative 3	0.1045	0.2578	0.7412	0.8974
Alternative 4	0.4876	0.4456	0.2569	0.4512

Step 2: Fuzzy Weight Average Operator (Table 3)

	Ethics 1	Ethics 2	Ethics 3	Ethics 4
Alternative 1	0.1856	0.4525	0.4096	0.5689
Alternative 2	0.7412	0.8523	0.1085	0.3425
Alternative 3	0.0174	0.3698	0.1954	0.3159
Alternative 4	0.0978	0.1598	0.2983	0.1156

Step 3: Normalized Fuzzy TOPSIS Decision Matrix (Table 4)

	Ethics 1	Ethics 2	Ethics 3	Ethics 4
Alternative 1	0.7896	0.4891	0.4412	0.3963
Alternative 2	0.7423	0.1258	0.1451	0.7321
Alternative 3	0.8541	0.2741	0.1125	0.0789
Alternative 4	0.1189	0.1987	0.2741	0.3412

Step 4: Weighted Normalized Fuzzy TOPSIS Decision Matrix (Table 5)

	Ethics 1	Ethics 2	Ethics 3	Ethics 4
Alternative 1	0.1032	0.3012	0.4027	0.3598
Alternative 2	0.2078	0.2096	0.1356	0.1874
Alternative 3	0.2963	0.2569	0.1202	0.2089
Alternative 4	0.1123	0.1298	0.2034	0.3987

Step 5: Probabilities

$$T_1 = 0.2345, \quad T_2 = 0.2095, \quad T_3 = 0.1266, \quad T_4 = 0.8012$$

Step 6: Clustering

(Defined as per method, not explicitly given in this case.)

Step 7: Ideal Solutions

Positive-ideal solution:

$$f^* = [0.4045, 0.3012, 0.4027, 0.3598]$$

Negative-ideal solution:

$$f^- = [0.1032, 0.1298, 0.1202, 0.1369]$$

Step 8: Separation Measures

From FPIS:

$$f_1^+ = 0.9234, \quad f_2^+ = 0.4335, \quad f_3^+ = 0.0119, \quad f_4^+ = 0.2312$$

From FNIS:

$$f_1^- = 0.1945, \quad f_2^- = 0.2987, \quad f_3^- = 0.4453, \quad f_4^- = 0.3966$$

Step 9: Closeness Coefficients

$$Q_1 = 0.3223, \quad Q_2 = 0.3654, \quad Q_3 = 0.1087, \quad Q_4 = 0.0987$$

3. Materials and Methods

3.1. Raw ingredients

The raw ingredients including chia seed and flax seed was purchased in bulk densities from the local grain market, Ghala Mandi, Punjab, Faisalabad, Pakistan. All the raw ingredient material was gathered and made it free from dust. The fish oil was purchased from local fish oil supplier. The raw material was stored in airtight containers and stored at 4°C until further processing.

3.2. Analysis of raw material

The raw materials were chemically analyzed for fat, fiber, protein, tannins and cyanogenic glycosides (HCN) contents. The fatty acid characterization of raw materials was determined.

3.2.1. Fat content. Chia and FS were estimated for fat content using the Soxhlet apparatus (Model: H-2 1045 Extraction Unit, Hoganas, Sweden) by following Method No. 30-25 (American Association of Cereal Chemists [24]). The 3g of sample was used to extract the fat content by using petroleum ether as extractor with approx. 6 drops in a second (s). The dry sample obtained was cooled down and weighed. The experiment was repeated to gain the dry fat with constant weight.

3.2.2. Fiber content. The fiber content of samples was examined by using Labconco Fibertech (Labconco Corporation, Kansas, USA). The samples were assimilated with sulfuric acid of concentration 1.25

3.2.3. Protein concentration. The estimation of protein was investigated by the percentage nitrogen was determined by using Kjeldahl's apparatus.

3.2.4. Determination of tannins. The tannin content was determined according to the previously described method [25]. The 0.5g of each sample was taken in a flask (250mL) and 75mL water was added. The mixture was stirred gently under the heat and boiled for 30 minutes (min). The centrifugation was done at the rate of 2,000 rpm for 15 minutes. After the centrifugation process water (distilled) was used to make the 100mL volume. 75mL of distilled water added to 1 mL of extracted mixture in 100mL volumetric flask. The volume of 100mL was made up by the addition of Folin-Denis reagent (5mL) and 10mL of Na₂CO₃ solution followed by the shaking of whole mixture. The absorbance was measured at 700nm by spectrophotometer (IREMCO, Model 2020, Germany) after keeping the mixture for about half an hour (h).

3.2.5. Cyanogenic glycosides estimation. Cyanogenic glycosides (HCN) were estimated through the previously described method (Association of Official Analytical Chemists [AOAC], 1990). A sample of 20 g was taken in a Kjeldahl flask, and 200 mL of water was added to the sample in intervals and mixed well. The flask was covered with a lid and kept for 3 hours to accomplish the hydrolysis process. To collect the distillate, the flask was attached to a vapor distillation apparatus. The distillate was collected in a flask containing 20 mL of 2.5% NaOH solution. Six molar NH_4OH (8 mL) was mixed with 5% KI (2 mL) and used to titrate with 0.02 M silver nitrate. The volume of AgNO_3 used was measured for all samples individually.

3.2.6. Fatty acids characterization of raw materials. A Gas Chromatograph (GC) fitted with an autosampler, flame ionization detector (FID), and Supelco wax column (30 m \times 0.25 μm film coating) was used for the determination of fatty acid characterization (American Oil Chemists Society, 1998). The fatty acid esters were analyzed through GC for all samples. One gram of sample was transferred to a screw-capped tube of size 16 \times 150 mm. Then, 10 mL of hexane (containing 0.1% BHT) was added. The tube was tightly closed and agitated strenuously for one minute, followed by keeping it in a water bath (ultrasonic). The tubes were centrifuged for 5 minutes at 1500 \times g and transferred into a heating block at 60°C. The hexane was evaporated by blowing a nitrogen gas stream into the tubes. Next, 1 mL of toluene was added to 50 mg of the sample in a screw-top test tube, followed by 2 mL of boron trichloride–methanol solution. The mixture was flushed with nitrogen gas for 10 seconds and then heated in a water bath (60°C) for 10 minutes. After cooling, 2 mL of water and 2 mL of hexane were added and agitated steadily to extract fatty acid methyl esters (FAMES). To remove moisture, anhydrous Na_2SO_4 was added to the hexane extracts. The anhydrous hexane extracts were transferred to a 10 mL volumetric flask and the volume completed with hexane. This step was performed twice to ensure extraction of all FAMES from the oil. The FAMES were evaluated through GC. A 1 μL sample of FAMES was injected with Helium (He) at the rate of 1 mL/min as carrier gas. The programmed working conditions were as follows:

- Column oven temperature: 160°C at 0 min, increased at 3°C/min until 180°C.
- From 180°C to 220°C at 1°C/min, held for 7.5 minutes.
- Split ratio: 50%.
- Injector temperature: 240°C.
- Detector temperature: 250°C.

The Varian Chem Station software was used for calculation of peak area and total fatty acid composition of each sample based on retention time [27].

3.2.7. Gross energy estimation. Gross energy assessment of samples was determined [28]. An Oxygen Bomb Calorimeter (IKA[®]-WERKE C 2000 Basic Version) was used. It was equipped with a decomposition container and a cooling water system with KV 600 Thermostat.

Table 1: *
Table 6. The experimental diet plan for Leghorn layers

Experimental code	Experimental feed
T0	Control feed
T1	FS 10 g / 100 g of control feed
T2	FS 20 g / 100 g of control feed
T3	CS 15 g / 100 g of control feed
T4	CS 30 g / 100 g of control feed
T5	FO 1 mL / 100 g of control feed
T6	FO 2 mL / 100 g of control feed
T7	FS 5 g, chia seed 5 g, fish oil 1 mL per 100 g of control feed
T8	FS 5 g, chia seed 10 g, fish oil 1 mL per 100 g of control feed

Note: T = Treatment; FS = Flax seed; CS = Chia seed; FO = Fish oil.

4. Results and Discussions

4.1. Characterization of Raw Ingredients and Fatty Acid Profiling

The ingredients analysis was done in order to evaluate suitability for hens feed preparation and compatibility with other components. The results of fat, fiber, protein, tannins, and HCN of chia seed and flaxseed ingredients are given in Table 7. The flaxseed has a distinguishing characteristic of fat content, and chia seed nutritive highlights boost up their practices in poultry feeds preparation as well as in functional foods. The results presented (Table 7) showed that flaxseed has higher fat contents ($39.40 \pm 0.55\%$) as compared to chia seed ($32.15 \pm 0.46\%$). The fat contents recorded in the present study for chia seed are in range with values 29.98–33.5 g/100g [29]. The current results was also in line with other findings 30.74 g/100g [30]. According to the present study, fat content for flaxseed is 39.40 g/100g which was approximately similar to the fat content 41 g/100g [31]. The fiber contents for chia seed as 33.75 ± 0.42 g/100g was in the range of the daily recommended value for adult dietary fiber intake, as 20 to 35 g/day [32]. The current studied fiber contents equate to (100%) the daily recommendations under adult population consideration [33]. The fiber contents of chia seed reported were relevant with USDA provided values in 2011 (34.4 g/100g) [33]. Flaxseed samples possessed fiber content (27.82 ± 0.36 g/100g) which approximately in agreement with the fiber content (28 g/100g) reported [42].

According to the present study, the results showed that chia seeds have protein content (25.30 ± 0.27 g/100g). These results was in line with previous researchers who reported protein contents in the range of 15.95–26.03 g/100g [40]. According to another study, these results was inconsistent with previous reported protein contents, which were noted 16.54 g/100g [41]. The present study showed that flaxseed has 19.96 ± 0.16 g/100g protein contents, which was similar to the results reported earlier (20 g/100g) [42]. In the present study, no toxic compounds and anti-nutritional compounds have been found in chia seed. This property of chia seeds makes it a safe component to use in laying hen diets. This reporting was supported by the findings [43]. The tannin and HCN content in the present study for flaxseeds were 177.51 ± 2.34 mg/100g and 170.71 ± 2.18 mg/kg, documenting the tannin content in defatted flaxseed meal (125 – 137 mg/100g) [44]. Quite lower tannin content (130 – 136 mg/100g) in flaxseed meal as compared to the present findings was reported [45]. The variation in the outcomes might be credited to the dissimilar seed variety, nutritional composition, and environmental conditions [46].

The current HCN content values were consistent with the findings, who published 120.4–190.6 mg/kg during analysis of ten Canadian flaxseed cultivars [47]. Another research group reported 137.38 mg/kg HCN content present in flaxseed samples which was lower than the present results [48], reported concentration of 145.72 mg/kg for HCN contents on hydrolysis [49]. Several scientists reported different HCN content in different study years such as 157.68 mg/kg HCN in flaxseed meal declared by 377 mg/kg HCN, 252 mg/kg HCN by and 298.6 mg/kg HCN by [50], [51], [52], [53]. The difference in results may be

linked with cultivation in different study years, concentration of protein and glycosidase enzymes [54]. Environmental factors, plant growth stage, and nutritional composition of flaxseed affect the cyanogenic contents in flaxseed [55,56,57]. The plants having oil seeds are enriched with a wide range of essential and non-essential fatty acids including stearic acid (SA), oleic acid (OA), linoleic acid (LA), alpha-linolenic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA). The results regarding major fatty acids composition, including palmitic acid, SA, OA, LA, ALA, AA, EPA and DHA in raw ingredient samples have been outlined in Table 7. The low concentration of EPA and DHA might be due to the deposition of other fatty acids in raw form of raw material that further convert to other forms on processing. Percentage content of fatty acids in chia seed for PA 7.04, SA 2.84, OA 7.30, LA 18.89, ALA 63.79 were reported [58]. According to another study, chia seed fatty acid composition in g/100g oil for PA 6.95 ± 0.26 , SA 4.33 ± 0.34 , OA 9.17 ± 0.08 , LA 21.51 ± 0.35 and ALA 56.98 ± 0.77 , respectively [59]. The palmitic acid content in chia seed is $6.70 \pm 0.15\%$ which was quite in agreement and closer to the results reported [60], [61]. Nevertheless, this value was lower than the value reported [62].

The stearic acid content in present research supported by other researchers, while partially close to the results reported [63], [60]. The OA and LA contents were supported by the content determined [60]. The ALA in the present study was closely relevant to the results declared by several researchers. Another study reported the fatty acid AA content as $0.13 \pm 0.10\%$ of the percentage composition declared by [62]. The difference in fatty acid concentrations was attributed to many factors such as climatic changes, geographical distribution, and procedures followed for extraction purposes [64], [65], [66]. The PA content in the present study was in close agreement with results published [67], [68]. However, these findings controversial who stated a wider range of about 7.8–9.2% and who published lower content [69], [70]. Different varieties of flaxseed showed different palmitic acid content reported by various researchers. According to a previous study, brown flaxseed showed palmitic acid percentage composition of 6.14 and gold flaxseed 5.39, respectively [58]. The SA contents in flaxseed showed accordance to disagreement with, who found less SA content (2.7–3.3%) in their lab studies [71], [72], [73], [74]. This difference in results can be attributed to the growth of crop in different years influenced by climatic behavior [71], [75]. According to a previous study, brown flaxseed showed SA percentage composition of 4.23 and gold flaxseed 3.17, respectively [58].

The OA content of flaxseed is $16.7 \pm 0.14\%$ and the LA content in the present study is $14.49 \pm 0.12\%$. The results regarding OA was supported by the results reported earlier [76], [77]. In different varieties of flaxseed, OA content varied as brown flaxseed showed 22.43 and gold flaxseed 18.70 [58]. The content of ALA was found $55.60 \pm 0.45\%$ in flaxseed, as presented in Table 7. The essential oil present in chia oil shows high antioxidant properties and therapeutic responses [78].

Several findings have been reported by different researchers in alternative study years. Some findings are controversial while some fully or partially supported by the fallouts of the current work for Ω -3 fatty acids composition of flaxseed. The ALA content in range of 52.8–60.4% has been reported which supports the present study results [79], [80]. Another study reported 38.43% ALA in flaxseed which were lower than the present study [81]. It has been stated that ALA contents varied with passage of time and it might be associated with studies in different years; however, the present study results are supported by Canada Grain Commission [82].

The AA, EPA, and DHA content in the present study was $0.06 \pm 0.03\%$, $0.08 \pm 0.06\%$ and $0.05 \pm 0.08\%$, respectively. The AA (Ω -6) content quite in agreement and EPA (Ω -3) and DHA (Ω -3) in variable status with other studies [81]. Another study reported 0.52% EPA content in flaxseed [81]. The variability has been referred to the different growing conditions, climatic behavior, agronomic factors, management factors, insect attack, disease risk, harvesting practices, handling techniques, and environmental behaviors [57].

The PA, SA, OA, LA, ALA, AA, EPA, and DHA contents of fish oil presented in Table 7. The Cottonseed oil used as vegetable oil and crumble form of feed was used. The SFAs including palmitic and stearic acid are in range of 31.94 ± 0.33 and 8.04 ± 0.11 of fatty acid percentage composition. The fish oil used for supplementation in current case showed relevance with the fatty acid composition for the oil extracted from fish of different species [83].

Table 2: *

Table 7. Characterization of chia seed and flaxseed

Raw ingredients	Fat (g/100g)	Fiber (g/100g)	Protein (g/100g)	Tannins (mg/100g)	HCN (mg/kg)
Chia seed	32.15±0.46 ^b	33.75±0.42 ^a	25.30±0.27 ^a	NR	NR
Flaxseed	39.40±0.55 ^a	27.82±0.36 ^b	19.96±0.16 ^b	177.51±2.34	170.71±2.18

± SD of three replicate analyses ($n = 3$) represent mean values.

Means followed by different superscript letters in the same column are significantly different ($p < 0.05$).

¹Total dietary fiber.

*HCN = Cyanogenic Glycosides.

*NR = Not reported.

Table 3: *

Table 8. Fatty acids composition of raw ingredients

Raw materials	C16:0	C18:0	C18:1	C18:2n-6	C18:3n-3	C20:4n-6	C20:5n-3	C22:6n-3
Chia seed	6.70±0.15 ^b	2.99±0.06 ^c	7.21±0.12 ^c	20.54±0.15 ^a	65.23±0.52 ^a	0.08±0.05 ^b	0.07±0.05 ^b	0.04±0.09 ^b
Flaxseed	6.02±0.19 ^c	4.02±0.08 ^b	16.70±0.14 ^a	14.49±0.12 ^b	55.60±0.45 ^b	0.06±0.03 ^b	0.08±0.06 ^b	0.05±0.08 ^b
Fish oil	31.94±0.33 ^a	8.04±0.11 ^a	11.01±0.20 ^b	9.17±0.11 ^c	0.63±0.09 ^c	0.45±0.08 ^a	0.61±0.08 ^a	1.28±0.10 ^a

± SD of three replicate analyses ($n = 3$) represent mean values.

Means followed by different superscript letters in the same column are significantly different ($p < 0.05$).

*Values expressed as % of total fatty acids.

**C16:0 = Palmitic acid; C18:0 = Stearic acid; C18:1 = Oleic acid; C18:2n-6 = Linoleic acid;

C18:3n-3 = α -Linolenic acid; C20:4n-6 = Arachidonic acid; C20:5n-3 = Eicosapentaenoic acid;

C22:6n-3 = Docosahexaenoic acid.

Nutrient and fatty acid profiling of experimental diets

The nutrient alignment regarding the experimental diets outlined in Table 9, is directly linked to the performance and growth of layers. Different feed ingredients, including animal or vegetable fat blend, cereal grains, soybean meal, and vitamins-minerals premix were used to make poultry diets [84]. The protein quantity was responsible for the bioavailability and digestibility of poultry diets, and unspecified composition can have adverse effects on optimal growth, production, and quality parameters of eggs, as reported [85]. A computer software (Feed Formulation Ver. 3.0) was used to formulate the EDs and calculate the percentage of protein contents. The fat contents, protein contents, and metabolizable energy in EDs ranged between 10.20±0.29% to 10.38±0.40%, 17.00±0.10% to 17.10±0.15%, and 2850.12±2.21 kcal/kg to 2860.34±2.89 kcal/kg.

The results outlined for protein contents showed similarity with the verdicts [86,87], conducted a research trial on laying hens of age 21 to 57 weeks by feeding flaxseed-enriched diets containing 15.86% to 18.54% protein contents [88]. Different fat blends (animal source or plant source) was available at commercial level in different ratios associated with egg production and quality parameters [89]. The fat content results showed non-significant difference among EDs (Table 10). These results was in accordance to described 10% and 20% fat content in EDs [90]. The results for metabolizable energy, which plays a vital role in terms of feed intake, was consistent with previous researchers who reported values ranging from 2750 kcal/kg to 2875 kcal/kg via supplementation with 10% flaxseed [91], [92], [93].

The fatty acid composition of EDs directly affects the digestion of feed constituents, the rate, and the regularity of egg production. The presence or absence of double bonds determines the final fatty acid composition of EDs and consequently, egg yolk composition. In this way, the saturation and unsaturation index has vital importance. According to previously published data, it has been stated that the desired fatty acid profile can be achieved by altering or substituting one fat ingredient for another [94]. The fatty acid characterization of control and supplemented diets with different Ω -3 enriched ingredients was given in Table ???. There was considerable difference among the fatty acid composition of different EDs regarding saturation and unsaturation. It was clear that the control diet has a lower degree of unsaturated content compared to the supplemented treatments. The results showed that PA (12.76±0.45%) and SA (15.48±0.46%) were present in T₀, relevant results, supporting the findings of the present study [87].

The PA content in different supplemented EDs varied from $6.19\pm 0.27\%$ to $12.71\pm 0.43\%$. A previous study reported closely related results when different levels of fish oil and flaxseed were used in layer diets. Different dietary treatments were developed, such as: control diet with no fish oil and flaxseed, 1.5% fish oil, 4.32% flaxseed, 1.5% fish oil + 4.32% flaxseed, and 8.64% flaxseed [95], reported closely related results in reference to PA [96]. Similar consistency has been found in studies using chia seed and fish oil [97]. The control diet showed higher stearic acid (SA) content in comparison to the other treatments (Table 9). In the present study, the variation among treatments other than T_0 was in the range of $7.22\pm 0.28\%$ to $15.37\pm 0.43\%$. Different variations have been observed in other studies. Published data reported SA contents ranging from 2.29% to 3.48% when diets were modified with flaxseed [95]. Another variation in SA contents (0.78–0.99%) was reported when diets were supplemented with different Ω -enriched sources [97].

According to the present results, there was a wide difference between MUFA and PUFA contents of EDs. OA classified as a monounsaturated Ω -9 fatty acid, and LA of polyunsaturated Ω -6 fatty acid. The control diet contained $28.33\pm 0.57\%$ OA. The OA contents found in flaxseed-based diets ranged from $22.87\pm 0.51\%$ to $23.92\pm 0.52\%$, in chia-based diets from $18.78\pm 0.33\%$ to $23.45\pm 0.53\%$, in fish oil-based diets from $28.25\pm 0.56\%$ to $28.29\pm 0.59\%$, and in combination treatments from $23.12\pm 0.53\%$ to $23.65\pm 0.58\%$. These results was in agreement [98]. A disparity in OA contents ranging from 20.86% to 21.99% in different flaxseed-supplemented diets was also reported [95].

According to the present study, the control diet contained $37.57\pm 0.65\%$ LA. The LA contents in flaxseed-, chia seed-, and fish oil-based diets and their combinations varied between $37.43\pm 0.65\%$ to $41.44\pm 0.72\%$. Regarding LA, 34–41.38% variation was observed in flaxseed-supplemented diets, while other researchers reported variations when chia and flaxseed were fed [95]. The high contents of ALA was characteristic of flaxseed. The ALA content in the control diet was $2.41\pm 0.23\%$, found higher ALA content (7.7%) in flaxseed-supplemented diets [99]. The ALA content increased linearly with increasing flaxseed concentration. In the present study, diets supplemented with 20g flaxseed had higher ALA content than those with 10g. These results was similar to previous studies on higher ALA contents in flaxseed diets. Similarly, diets supplemented with 30% chia had more ALA than those with 15% chia [100], [86], [93]. The long chain PUFAs AA, EPA, and DHA in the control diet were $0.50\pm 0.09\%$, $0.34\pm 0.04\%$, and $0.06\pm 0.01\%$, respectively (Table 9). The long-chain PUFA contents differed significantly among EDs. The higher levels of these fatty acids are associated with different Ω sources. The present results are consistent reported lower PUFA levels in flaxseed-based diets [99], [86]. This difference may be attributed to the diversity in feed compositions, fatty acid profiles, or analytical techniques used in different studies [86].

Table 4: *

Table 9. Nutrient profile and calculated measurements of experimental diets of Leghorn layers

Diet code	Crude fat (%)	Crude protein (%)	Metabolizable energy (kcal/kg)
T ₀ ¹	10.24±0.32 ^a	17.00±0.10 ^b	2850.12±2.21 ^c
T ₁ ²	10.20±0.29 ^a	17.03±0.14 ^b	2853.46±2.34 ^c
T ₂ ³	10.31±0.31 ^a	17.05±0.13 ^b	2858.57±2.56 ^c
T ₃ ⁴	10.29±0.35 ^a	17.01±0.05 ^b	2851.89±2.71 ^c
T ₄ ⁵	10.27±0.30 ^a	17.04±0.07 ^b	2855.10±2.10 ^c
T ₅ ⁶	10.33±0.37 ^a	17.10±0.15 ^b	2853.66±2.60 ^c
T ₆ ⁷	10.21±0.34 ^a	17.07±0.06 ^b	2859.90±2.75 ^c
T ₇ ⁸	10.38±0.40 ^a	17.09±0.09 ^b	2857.12±2.14 ^c
T ₈ ⁹	10.22±0.32 ^a	17.08±0.06 ^b	2860.34±2.89 ^c

± SD of three replicate analyses ($n = 3$) represent mean values.

Means followed by similar superscript letters in the same column are not significantly different ($p > 0.05$).

¹ Control feed.

² Flaxseed 10g/100g of control feed.

³ Flaxseed 20g/100g of control feed.

⁴ Chia seed 15g/100g of control feed.

⁵ Chia seed 30g/100g of control feed.

⁶ Fish oil 1mL/100g of control feed.

⁷ Fish oil 2mL/100g of control feed.

⁸ Flaxseed 5g, chia seed 5g, fish oil 1mL/100g of control feed.

⁹ Flaxseed 5g, chia seed 10g, fish oil 1mL/100g of control feed.

Table 5: Experimental diets fatty acid characterization prepared for Leghorn layers (Table 10)

Diet code	C16:0	C18:0	C18:1	C18:2n-6	C18:3n-3	C20:4n-6	C20:5n-3	C22:6n-3
T ₀ ¹	12.76±0.45 ^a	15.48±0.46 ^a	28.33±0.57 ^a	37.57±0.65 ^e	2.41±0.23 ^e	0.50±0.09 ^a	0.34±0.04 ^b	0.06±0.01 ^b
T ₁ ²	9.10±0.35 ^b	13.18±0.44 ^b	23.92±0.52 ^b	38.65±0.66 ^d	7.66±0.30 ^d	0.29±0.07 ^a	0.50±0.07 ^b	0.11±0.05 ^b
T ₂ ³	7.74±0.29 ^d	8.76±0.32 ^d	22.87±0.51 ^c	40.53±0.70 ^b	13.98±0.42 ^b	0.18±0.05 ^a	0.55±0.04 ^b	0.13±0.06 ^b
T ₃ ⁴	8.42±0.31 ^c	10.98±0.37 ^c	23.45±0.53 ^b	39.59±0.69 ^c	10.83±0.35 ^c	0.23±0.07 ^a	0.51±0.06 ^b	0.17±0.08 ^b
T ₄ ⁵	6.19±0.27 ^e	7.22±0.28 ^e	18.78±0.33 ^d	41.44±0.72 ^a	21.67±0.50 ^a	0.27±0.06 ^a	0.59±0.08 ^b	0.18±0.05 ^b
T ₅ ⁶	12.71±0.43 ^a	15.34±0.44 ^a	28.25±0.56 ^a	37.43±0.65 ^e	2.45±0.23 ^e	0.28±0.09 ^a	1.36±0.21 ^a	0.65±0.07 ^a
T ₆ ⁷	12.68±0.41 ^a	15.37±0.43 ^a	28.29±0.59 ^a	37.50±0.63 ^e	2.52±0.27 ^e	0.26±0.07 ^a	1.58±0.13 ^a	0.83±0.08 ^a
T ₇ ⁸	9.20±0.37 ^b	13.27±0.41 ^b	23.65±0.58 ^b	38.05±0.62 ^d	7.34±0.29 ^d	0.23±0.09 ^a	1.41±0.12 ^a	0.68±0.05 ^a
T ₈ ⁹	8.33±0.30 ^c	10.89±0.35 ^c	23.12±0.53 ^c	39.45±0.67 ^c	10.64±0.36 ^c	0.25±0.06 ^a	1.44±0.10 ^a	0.72±0.06 ^a

Values reported as means ± SD of three replicate analyses ($n = 3$).

Means followed by different superscript letters in the same column are significantly different ($p < 0.05$).

*Values expressed as % of total fatty acids.

**C16:0 = Palmitic acid; C18:0 = Stearic acid; C18:1 = Oleic acid; C18:2n-6 = Linoleic acid;

C18:3n-3 = α -Linolenic acid; C20:4n-6 = Arachidonic acid; C20:5n-3 = Eicosapentaenoic acid; C22:6n-3 = Docosahexaenoic acid.

¹ Control feed.

² Flaxseed 10g/100g of control feed.

³ Flaxseed 20g/100g of control feed.

⁴ Chia seed 15g/100g of control feed.

⁵ Chia seed 30g/100g of control feed.

⁶ Fish oil 1mL/100g of control feed.

⁷ Fish oil 2mL/100g of control feed.

⁸ Flaxseed 5g, chia seed 5g, fish oil 1mL/100g of control feed.

⁹ Flaxseed 5g, chia seed 10g, fish oil 1mL/100g of control feed.

5. Conclusion

The experimental diets made as control with no added fortified components were analyzed with modified diets incorporated with flaxseed, chia seed and fish oil supplementation. The flaxseed contained considerable amounts of cyanogenic compounds, linoleic and linolenic fatty acids while chia seed and fish oil possessed significant amount of PUFAs to fortify the diet of laying hens. The composition of saturated and unsaturated fatty acids in experimental diets was found to be significantly different from modified diets.

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All authors equally contributed to this manuscript.

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References

1. M. Gopi, "Essential oils as a feed additive in poultry nutrition," *Adv. Anim. Vet. Sci.*, vol. 2, pp. 1–7, 2013.
2. Z.D. Stevanović, J. Bošnjak-Neumüller, I. Pajić-Lijaković, J. Raj and M. Vasiljević, "Essential oils as feed additives—future perspectives," *Molecules*, vol. 23, p. 1717, 2018.
3. D.L. Palmquist, "Omega-3 fatty acids in metabolism, health, and nutrition and for modified animal product foods," *Prof. Anim. Sci.*, vol. 25, pp. 207–249, 2009.
4. V. Kostik, B. Gjorgjeska, B. Bauer and K. Filev, "Production of shell eggs enriched with n-3 fatty acids," *IOSR J. Pharm.*, vol. 5, pp. 48–51, 2015.
5. R.D. O'Brien, "Fats and Oils: Formulating and Processing for Applications," 3rd ed., CRC Press, New York, NY, USA, 2008.
6. G. Kralik, Z. Kralik, M. Grčević, O. Galović, D. Hanzek and E. Biazik, "Fatty acid profile of eggs produced by laying hens fed diets containing different shares of fish oil," *Poult. Sci.*, vol. 100, p. 101379, 2021.
7. S. Grobas, J. Méndez, R. Lázaro, C. de Blas and G.G. Mateo, "Influence of source and percentage of fat added to diet on performance and fatty acid composition of egg yolks of two strains of laying hens," *Poult. Sci.*, vol. 80, pp. 1171–1179, 2001.
8. N. Ceylan, I. Ciftçi, C. Mızrak, Z. Kahraman and H. Efil, "Influence of different dietary oil sources on performance and fatty acid profile of egg yolk in laying hens," *J. Anim. Feed Sci.*, vol. 20, pp. 71–83, 2011.
9. A. Diederichsen and K.W. Richards, "Cultivated flax and the genus *Linum* L.: Taxonomy and germplasm conservation," in *Flax: The Genus Linum*, A. Muir and N. Westscott, Eds., pp. 22–54, Taylor & Francis, London, UK, 2003.
10. H.S. El-Beltagi, Z.A. Salama and D.M. El-Hariri, "Evaluation of fatty acids profile and the content of some secondary metabolites in seeds of different flax cultivars (*Linum usitatissimum* L.)," *Gen. Appl. Plant Physiol.*, vol. 33, no. 3–4, pp. 187–202, 2007.
11. T.J. Schmidt, M. Klaes and J. Sendker, "Lignans in seeds of *Linum* species," *Phytochemistry*, vol. 82, pp. 89–99, 2012.
12. M. Bjelkova, J. Nozkova, K. Fatrcova-Sramkova and E. Tejklova, "Comparison of linseed (*Linum usitatissimum* L.) genotypes with respect to the content of polyunsaturated fatty acids," *Chem. Pap.*, vol. 66, no. 10, pp. 972–976, 2012.
13. T. Chornick, L. Malcolmson, M. Izydorczyk, S. Duguid and C. Taylor, "Effect of cultivar on the physiochemical properties of FS mucilage," *Proc. 59th Flax Institute of the United States*, pp. 7–13, Fargo, North Dakota, 2002.
14. B.D. Oomah and G. Mazza, "Effect of dehulling on chemical composition and physical properties of FS," *LWT-Food Sci. Technol.*, vol. 30, no. 2, pp. 135–140, 1997.
15. J.K. Daun, V.J. Barthet, T.L. Chornick and S. Duguid, "Structure, composition, and variety development of FS," in *FS in Human Nutrition*, pp. 1–45, AOCS Publishing, Champaign, IL, 2003.
16. G.H. Gubbels, D.M. Bonner and E.O. Kenaschuk, "Effect of frost injury on quality of flax seed," *Can. J. Plant Sci.*, vol. 74, no. 2, pp. 331–333, 1994.

17. H.S. Hentry, M. Mittleman and P.R. McCrohan, "Introducción de la chia y la goma de tragacanto en los Estados Unidos," in *Avances en Cosechas Nuevas*, pp. 252–256, Prensa de la Madera, Portland, Ohio, 1990.
18. R. Ayerza and W. Coates, "Influence of environment on growing period and yield, protein, oil and α -linolenic content of three chia (*Salvia hispanica* L.) selections," *Ind. Crops Prod.*, vol. 30, no. 2, pp. 321–324, 2009.
19. E. Reyes-Caudillo, A. Tecante and M.A. Valdivia-Lopez, "Dietary fibre content and antioxidant activity of phenolic compounds present in Mexican chia (*Salvia hispanica* L.) seeds," *Food Chem.*, vol. 107, no. 2, pp. 656–663, 2008.
20. J.A.R. Uribe, J.I.N. Perez, H.C. Kauil, G.R. Rubio and C.G. Alcocer, "Extraction of oil from chia seeds with supercritical CO₂," *J. Supercrit. Fluids*, vol. 56, no. 2, pp. 174–178, 2011.
21. R. Pawlosky, J. Hibbeln, Y. Lin and N. Salem, "N-3 fatty acid metabolism in women," *Br. J. Nutr.*, vol. 90, no. 5, pp. 993–994, 2003.
22. D. Manzella and G. Paolisso, "Cardiac autonomic activity and Type II diabetes mellitus," *Clin. Sci.*, vol. 108, no. 2, pp. 93–99, 2005.
23. R. Ullah, M. Nadeem, S. Ahmad, M.W. Azeem and M. Tayyab, "Fractionation of chia oil to enhance omega 3 & 6 fatty acids: Oxidative stability of fractions," *Food Sci. Biotechnol.*, Accepted, 2015.
24. AACC, "Approved Methods of American Association of Cereal Chemists," 10th ed., The American Association of Cereal Chemists, Inc., St. Paul, Minnesota, USA, 2000.
25. S.H. Schanderi, "Methods in Food Analysis," Academic Press, New York, USA, pp. 709, 1970.
26. NRC, "Nutrient Requirements of Poultry," 8th ed., National Academy Press, Washington, DC, USA, 1984.
27. A. Javed, M. Imran, N. Ahmad and A.I. Hussain, "Fatty acids characterization and oxidative stability of spray dried designer egg powder," *Lipids Health Dis.*, vol. 17, p. 282, 2018.
28. L.A. Zadeh, "Fuzzy sets," *Inf. Control*, vol. 8, no. 3, pp. 338–353, 1965.
29. G. Klir and B. Yuan, "Fuzzy sets and fuzzy logic," Prentice Hall, New Jersey, vol. 4, pp. 1–12, 1995.
30. H.J. Zimmermann, "Fuzzy set theory," *Wiley Interdiscip. Rev. Comput. Stat.*, vol. 2, no. 3, pp. 317–332, 2010.
31. A. Hagen, "Fuzzy set approach to assessing similarity of categorical maps," *Int. J. Geogr. Inf. Sci.*, vol. 17, no. 3, pp. 235–249, 2003.
32. P.C. Fiss, "Building better causal theories: A fuzzy set approach to typologies in organization research," *Acad. Manag. J.*, vol. 54, no. 2, pp. 393–420, 2011.
33. J. Ma and D. Zhou, "Fuzzy set approach to the assessment of student-centered learning," *IEEE Trans. Educ.*, vol. 43, no. 2, pp. 237–241, 2000.
34. M.J. Ducey and B.C. Larson, "A fuzzy set approach to the problem of sustainability," *For. Ecol. Manag.*, vol. 115, no. 1, pp. 29–40, 1999.
35. B. Wirsam, A. Hahn, E.O. Uthus and C. Leitzmann, "Fuzzy sets and fuzzy decision making in nutrition," *Eur. J. Clin. Nutr.*, vol. 51, no. 5, pp. 286–296, 1997.
36. D. Nakandala and H.C. Lau, "An application of a fuzzy-based optimisation model for selecting food products based on cost and nutrition," *J. Res. Consum.*, vol. 24, no. 1, pp. 15–21, 2013.
37. R.A. Priyono and K. Surendro, "Nutritional needs recommendation based on fuzzy logic," *Procedia Technol.*, vol. 11, pp. 1244–1251, 2013.
38. J.C. Buisson, "Nutri-Educ, a nutrition software application for balancing meals, using fuzzy arithmetic and heuristic search algorithms," *Artif. Intell. Med.*, vol. 42, no. 3, pp. 213–227, 2008.
39. A.A. El-Atik, R. Abu-Gdairi, A.A. Nasef, S. Jafari and M. Badr, "Fuzzy soft sets and decision making in ideal nutrition," *Symmetry*, vol. 15, no. 8, p. 1523, 2023.
40. R.H. Ayerza and W. Coates, "Some quality components of four chia (*Salvia hispanica* L.) genotypes grown under tropical coastal desert ecosystem conditions," *Asian J. Plant Sci.*, vol. 8, no. 4, pp. 301–307, 2009.
41. USDA, "United States Department of Agriculture. National Nutrient Database for Standard Reference, Release 24," Nutrient Data Laboratory, U.S. Department of Agriculture, Agricultural Research Service, 2011.
42. D.H. Morris, "Description and composition of flax," in *Flax: A Health and Nutrition Primer*, Flax Council of Canada, 2007.
43. V. Menga, M. Amato, T.D. Phillips, D. Angelino, F. Morreale and C. Fares, "Gluten-free pasta incorporating chia (*Salvia hispanica* L.) as thickening agent: An approach to naturally improve the nutritional profile and the in vitro carbohydrate digestibility," *Food Chem.*, vol. 221, pp. 1954–1961, 2017.
44. R. Amarowicz, P.K.J.P.D. Wanasundara and F. Shahidi, "Chromatographic separation of flaxseed phenolics," *Nahrung/Food*, vol. 38, no. 5, pp. 520–526, 1994.
45. J.P. Wanasundara and F. Shahidi, "Alkanol-ammonia-water/hexane extraction of flaxseed," *Food Chem.*, vol. 49, no. 1, pp. 39–45, 1994.

46. B.D. Oomah, E.O. Kenaschuk and G. Mazza, "Phenolic acids in flaxseed," *J. Agric. Food Chem.*, vol. 43, no. 8, pp. 2016–2019, 1995.
47. R.K. Chadha, J.F. Lawrence and W.M.N. Ratnayake, "Ion chromatographic determination of cyanide released from flaxseed under autohydrolysis conditions," *Food Addit. Contam.*, vol. 12, no. 4, pp. 527–533, 1995.
48. E.R. Park, J.H. Hong, D.H. Lee, S.B. Han, K.B. Lee, J.S. Park, H.W. Chung, K.H. Hong and M.C. Kim, "Analysis and decrease of cyanogenic glucosides in flaxseed," *J. Korean Soc. Food Sci. Nutr.*, vol. 34, no. 6, pp. 875–879, 2005.
49. S. Hussain, "Utilization of flaxseed as a functional food," Doctoral dissertation, Dept. Food Technology, Univ. of Agriculture, Faisalabad, Pakistan, 2009.
50. H. Yang, Z. Mao and H. Tan, "Determination and removal methods for cyanogenic glucoside in flaxseed," in *2004 ASAE Annual Meeting*, p. 1, American Society of Agricultural and Biological Engineers, 2004.
51. D. Feng, Y. Shen and E.R. Chavez, "Effectiveness of different processing methods in reducing hydrogen cyanide content of flaxseed," *J. Sci. Food Agric.*, vol. 83, no. 8, pp. 836–841, 2003.
52. T. Yamashita, T. Sano, T. Hashimoto and K. Kanazawa, "Development of a method to remove cyanogen glycosides from flaxseed meal," *Int. J. Food Sci. Technol.*, vol. 42, no. 1, pp. 70–75, 2007.
53. M. Wu, D. Li, L.J. Wang, Y.G. Zhou, M.S.L. Brooks, X.D. Chen and Z.H. Mao, "Extrusion detoxification technique on flaxseed by uniform design optimization," *Sep. Purif. Technol.*, vol. 61, no. 1, pp. 51–59, 2008.
54. J.E. Poulton, "Toxic compounds in plant foodstuffs: Cyanogens," in *Food Proteins*, J.E. Kinsella and W.G. Soucie, Eds., AOCS, Champaign, IL, pp. 381–401, 1989.
55. B.D. Oomah, G. Mazza and E.O. Kenaschuk, "Cyanogenic compounds in flaxseed," *J. Agric. Food Chem.*, vol. 40, no. 8, pp. 1346–1355, 1992.
56. Niedzwiedz-Siegien, I. (1998). Cyanogenic glucosides in *Linum usitatissimum*. *Phytochemistry*, 49(1), 59–63.
57. Daun, J. K., Barthet, V. J., Chornick, T. L., & Duguid, S. (2003). Structure, composition, and variety development of flaxseed. In: *Flaxseed in Human Nutrition* (pp. 1–45). AOCS Publishing, Champaign, IL.
58. Nitrayova, S., Brestensky, M., Heger, J., Patras, P., Rafay, J., & Sirotkin, A. (2014). Amino acids and fatty acids profile of chia (*Salvia hispanica* L.) and flax (*Linum usitatissimum* L.) seed. *Potravinarstvo Slovak Journal of Food Sciences*, 8(1), 72–76.
59. Ding, Y., Lin, H. W., Lin, Y. L., Yang, D. J., Yu, Y. S., Chen, J. W., Wang, S. Y., & Chen, Y. C. (2018). Nutritional composition in the chia seed and its processing properties on restructured ham-like products. *Journal of Food and Drug Analysis*, 26(1), 124–.
60. Craig, R., & Sons, M. (2004). Application for approval of whole chia (*Salvia hispanica* L.) seed and ground whole chia as novel food ingredients. *Advisory committee for novel foods and processes*. Ireland: Company David Armstrong, 1, 1–29.
61. Ayerza, R., & Coates, W. (1999). An ω -3 fatty acid enriched chia diet: influence on egg fatty acid composition, cholesterol and oil content. *Canadian Journal of Animal Science*, 79(1), 53–58.
62. Segura-Campos, M. R., Ciau-Solis, N., Rosado-Rubio, G., Chel-Guerrero, L., & Betancur-Ancona, D. (2014). Physico-chemical characterization of chia (*Salvia hispanica*) seed oil from Yucatan, Mexico. *Agricultural Sciences*, 5(3), 220.
63. Coelho, M. S., & Salas-Mellado, M. M. (2014). Chemical characterization of chia (*Salvia hispanica* L.) for use in food products. *Journal of Food and Nutrition Research*, 2(5), 263–269.
64. Ayerza, R., & Coates, W. (2011). Protein content, oil content and fatty acid profiles as potential criteria to determine the origin of commercially grown chia (*Salvia hispanica* L.). *Industrial Crops and Products*, 34, 1366–1371.
65. Ixtaina, V. Y., Martinez, M. L., Spotorno, V., Mateo, C. M., Maestri, D. M., Diehl, B. W. K., Nolasco, S. M., & Tomas, M. C. (2011). Characterization of chia seed oils obtained by pressing and solvent extraction. *Journal of Food Composition and Analysis*, 24(2), 166–174.
66. Capitani, M. I., Spotorno, V., Nolasco, S. M., & Tomas, M. C. (2012). Physicochemical and functional characterization of by-products from chia (*Salvia hispanica* L.) seeds of Argentina. *LWT-Food Science and Technology*, 45(1), 94–102.
67. Gambus, H., Borowiec, F., & Zajac, T. (2003). Chemical composition of linseed with different colour of bran layer. *Polish Journal of Food and Nutrition Sciences*, 12(3), 67–70.
68. Hosseinian, F. S., Rowland, G. G., Bhirud, P. R., Dyck, J. H., & Tyler, R. T. (2004). Chemical composition and physicochemical and hydrogenation characteristics of high-palmitic acid solin (low-linolenic acid flaxseed) oil. *Journal of the American Oil Chemists' Society*, 81(2), 185–188.
69. Bonnarme, P., Djian, A., Latrasse, A., Feron, G., Ginies, C., Durand, A., & Le Quere, J. L. (1997). Production of 6-pentyl- α -pyrone by *Trichoderma* sp. from vegetable oils. *Journal of Biotechnology*, 56(2), 143–150.
70. Diederichsen, A. (2001). Comparison of genetic diversity of flax (*Linum usitatissimum* L.) between Canadian cultivars and a world collection. *Plant Breeding*, 120(4), 360–362.
71. Bozan, B., & Temelli, F. (2002). Supercritical CO₂ extraction of flaxseed. *Journal of the American Oil Chemists' Society*, 79(3), 231–235.

72. Tulbek, M. C., Schorno, A., Meyers, S., Hall, C., & Manthey, F. (2004). Chemical and sensory analysis and shelf life stability of roasted flaxseed. *Proceedings of the 60th Flax Institute of the United States*, Fargo, ND, (pp. 31–36). Flax Institute of the United States, Fargo, ND.
73. Gryglewicz, S., Grabas, K., & Gryglewicz, G. (2000). Use of vegetable oils and fatty acid methyl esters in the production of spherical activated carbons. *Bioresource Technology*, *75*(3), 213–218.
74. Van Ruth, S. M., Shaker, E. S., & Morrissey, P. A. (2001). Influence of methanolic extracts of soybean seeds and soybean oil on lipid oxidation in linseed oil. *Food Chemistry*, *75*(2), 177–184.
75. Barthet, V. J., Chornick, T., & Daun, J. K. (2002). Comparison of methods to measure the oil contents in oilseeds. *Journal of Oleo Science*, *51*(9), 589–597.
76. Wakjira, A., Labuschagne, M. T., & Hugo, A. (2004). Variability in oil content and fatty acid composition of Ethiopian and introduced cultivars of linseed. *Journal of the Science of Food and Agriculture*, *84*(6), 601–607.
77. Choo, W. S., Birch, J., & Dufour, J. P. (2007). Physicochemical and quality characteristics of cold-pressed flaxseed oils. *Journal of Food Composition and Analysis*, *20*(3–4), 202–211.
78. Kris-Etherton, P. M., Taylor, D. S., Yu-Poth, S., Huth, P., Moriarty, K., Fishell, V., Hargrove, R. L., Zhao, G., & Etherton, T. D. (2000). Polyunsaturated fatty acids in the food chain in the United States. *The American Journal of Clinical Nutrition*, *71*(1), 179S–188S.
79. Stenberg, C., Svensson, M., & Johansson, M. (2005). A study of the drying of linseed oils with different fatty acid patterns using RTIR-spectroscopy and chemiluminescence (CL). *Industrial Crops and Products*, *21*(2), 263–272.
80. Nykter, M., Kymalainen, H. R., Gates, F., & Sjoberg, A. M. (2006). Quality characteristics of edible linseed oil. *Agricultural and Food Science*, *15*(4), 402–413.
81. Najib, H., & Al-Yousef, Y. M. (2010). Essential fatty acid content of eggs and performance of Layer Hens fed with different levels of full-fat flaxseed. *Journal of Cell and Animal Biology*, *4*(3), 58–63.
82. Canadian Grain Commission. (1996). Quality of western Canadian flaxseed 1996. Grain Research Laboratory, Crop Bulletin no. 231. Winnipeg, Canada.
83. Hameed, A., Hussain, S. A., Shabbir, M. A., Pasha, I., & Song, Y. (2017). Nutritional and Fatty Acids Profile Analyses of Commonly Consumed Fresh Water Fish Species in Pakistan. *American Journal of Biochemistry and Biotechnology*, *13*(1), 15–26.
84. Sauvant, D., Perez, J. M., & Tran, G. (2004). *Tables of composition and nutritional value of feed materials: pigs, poultry, cattle, sheep, goats, rabbits, horses and fish*. Wageningen Academic Publishers.
85. Forbes, J. M., & Shariatmadari, F. (1994). Diet selection for protein by poultry. *World's Poultry Science Journal*, *50*(1), 7–24.
86. Hayat, Z., Cherian, G., Pasha, T. N., Khattak, F. M., & Jabbar, M. A. (2009). Effect of feeding flax and two types of antioxidants on egg production, egg quality, and lipid composition of eggs. *Journal of Applied Poultry Research*, *18*(3), 541–551.
87. Leeson, S., Summers, J. D., & Caston, L. J. (2000). Response of layers to dietary flaxseed according to body weight classification at maturity. *Journal of Applied Poultry Research*, *9*(3), 297–302.
88. Novak, C., & Scheideler, S. E. (2001). Long-term effects of feeding flaxseed-based diets. 1. Egg production parameters, components, and eggshell quality in two strains of laying hens. *Poultry Science*, *80*(10), 1480–1489.
89. Grobas, S., Mendez, J., Lazaro, R., De Blas, C., & Mateo, G. G. (2001). Influence of source and percentage of fat added to diet on performance and fatty acid composition of egg yolks of two strains of laying hens. *Poultry Science*, *80*(8), 1171–1179.
90. Caston, L., & Leeson, S. (1990). Research note: dietary flax and egg composition. *Poultry Science*, *69*(9), 1617–1620.
91. Wu, G., Bryant, M. M., Voitle, R. A., & Roland Sr, D. A. (2005). Effect of dietary energy on performance and egg composition of Bovans White and Dekalb White hens during phase I. *Poultry Science*, *84*(10), 1610–1615.
92. Caston, L. J., Squires, E. J., & Leeson, S. (1994). Hen performance, egg quality, and the sensory evaluation of eggs from SCWL hens fed dietary flax. *Canadian Journal of Animal Science*, *74*(2), 347–353.
93. Hayat, Z., Cherian, G., Pasha, T. N., Khattak, F. M., & Jabbar, M. A. (2010). Oxidative stability and lipid components of eggs from flax-fed hens: Effect of dietary antioxidants and storage. *Poultry Science*, *89*(6), 1285–1293.
94. Salmon, R. E. (1976). The effect of age and sex on the rate of change of fatty acid composition of turkeys following a change of dietary fat source. *Poultry Science*, *55*(1), 201–208.
95. Basmacioglu, H., Cabuk, M., Unal, K., Ozkan, K., Akkan, S., & Yalcin, H. (2003). Effects of dietary fish oil and flax seed on cholesterol and fatty acid composition of egg yolk and blood parameters of laying hens. *South African Journal of Animal Science*, *33*(4), 266–273.
96. Sujatha, T., & Narahari, D. (2011). Effect of designer diets on egg yolk composition of ‘White Leghorn’ hens. *Journal of Food Science and Technology*, *48*(4), 494–497.

97. Antruejo, A., Azcona, J. O., Garcia, P. T., Gallinger, C., Rosmini, M., Ayerza, R., Coates, W., & Perez, C. D. (2011). Omega-3 enriched egg production: the effect of α -linolenic ω -3 fatty acid sources on laying hen performance and yolk lipid content and fatty acid composition. *British Poultry Science*, 52(6), 750–760.
98. Ayerza, R., & Coates, W. (2001). Chia seeds: new source of omega-3 fatty acids, natural antioxidants, and dietetic fiber. Southwest Center for Natural Products Research and Commercialization, Office of Arid Lands Studies, Tucson, Arizona, USA.
99. Sosin, E., Borowiec, F., Strzetelski, J., & Smulikowska, S. (2006). The effect of feeding regular or low alpha-linolenic acid linseed on the fatty acid composition of egg yolks. *Journal of Animal and Feed Sciences*, 15(4), 641.
100. Bean, L. D., & Leeson, S. (2003). Long-term effects of feeding flaxseed on performance and egg fatty acid composition of brown and white hens. *Poultry Science*, 82(3), 388–394.

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