

Poultry Science Journal

ISSN: 2345-6604 (Print), 2345-6566 (Online) http://psj.gau.ac.ir DOI: 10.22069/psj.2017.13717.1271



Effects of Irradiated Flaxseed on Performance, Carcass Characteristics, Blood Parameters, and Nutrient Digestibility in Broiler Chickens

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Poultry Science Journal 2017, 5 (2): 153-163

Keywords Broiler Flaxseed Performance Electron irradiation Nutrient digestibility

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Article history

Received: July 26, 2017 Revised: September 16, 2017 Accepted: September 28, 2017

Abstract

The objective of this study was to investigate the effects of feeding electron irradiated flaxseed (FS) on performance, carcass characteristics, blood parameters, digesta viscosity, and nutrient digestibility in broiler chickens. In a 2 × 2 factorial arrangement, 320 day-old broiler chicks were randomly assigned to one of five experimental diets, each with four replicates containing 16 chicks each. Dietary treatments included a corn-soybean meal-based diet (control), and diets containing 10% or 20% raw flaxseed (FS10, FS20), or 10% or 20% flaxseed irradiated at 20 kGy (RFS10, RFS20). Feeding irradiated flaxseed improved body weight gain in grower and finisher periods of the experiment (P < 0.05). Birds fed FS20 had a lower (P < 0.05) body weight gain in finisher period as well as lower breast muscle percentage in comparison to chicks fed FS10. Thigh percentage was greater in chicks fed FS20 compared to chicks fed FS10 (P < 0.05). Liver percentage decreased (P < 0.05) in birds fed RFS20 compared other treatments. Birds fed FS20 and RFS20 had significantly lower aspartate aminotransferase activity compared to birds fed FS10 and RFS10 (P < 0.05). Dry matter, organic matter, and ether extract digestibility decreased (P < 0.05) as the levels of FS increased. Apparent digestibility of dry matter, organic matter, and ether extract in irradiated FS increased in birds fed raw flaxseed. Irradiation of flaxseed significantly decreased digesta viscosity compared to diets containing raw irradiated flaxseed (P < 0.05). Results of this study demonstrated that irradiation increases the inclusion level of flaxseed in broiler diets without any negative impacts on broiler performance.

Introduction

Flaxseed contains high amounts of α -linolenic acid (52% of the total fatty acids), an essential fatty acid, making flaxseed a unique oilseed crop for oil production as well as for incorporation in foods (Chung *et al.*, 2005). Flaxseed is a good source of protein, oil, and α -linolenic acid, so it can be used for enrichments of poultry meat and eggs (Leeson and Summers, 2005). Due to anti-

nutritional factors (ANF) present in flaxseed [non-starch poly saccharides (NSPs), cyanogenic glycosides, trypsin inhibitors, mucilages, linatine dipeptide (a vitamin B6 antagonist), and phytic acid], flaxseed has been shown to adversely affect broiler performance (Ajuyah *et al.*, 1993; Bhatty, 1995; Ortiz *et al.*, 2001; Alzueta *et al.*, 2003; Hernandez, 2013). These ANF and NSPs

Please cite this article as: Beheshti Moghadam MH, Rezaei M, Behgar M & Kermanshahi H. 2017. Effects of Irradiated Flaxseed on Performance, Carcass Characteristics, Blood Parameters, and Nutrient Digestibility in Broiler Chickens. Poult. Sci. J. 5 (2): 153-163.

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are associated with increasing intestinal viscosity, reducing litter quality, and poor growth performance in broiler birds (Hall *et al.*, 2006).

Gamma and electron radiation can denature proteins and decrease starch crystallinity (Chamani *et al.*, 2009; Shawrang *et al.*, 2013). Nayefi *et al.* (2015) showed an increase in feed intake and body weight gain in broiler chicks fed diets containing 12% irradiated (30 kGy) cotton seed meal compared to those fed control diet. Previous studies using gamma or electron irradiation show a reduction in anti-nutrient content of canola meal, barley, and cottonseed meal and an improvement in their utilization in broilers (Gharaghani *et al.*, 2008; Chamani *et al.*, 2009; Shawrang *et al.*, 2013; Nayefi *et al.*, 2015., Bahraini *et al.*, 2017).

There is limited information on the use of irradiated flaxseed broiler nutrition. in Therefore, the present study was conducted to investigate the effects of FS diets irradiated by electron beam on performance, carcass characteristics, blood parameters, nutrient digestibility and digesta viscosity of broiler chickens.

Materials and methods

All experimental methods were in accordance with Sari Agricultural Sciences and Natural Resources University Research Policy on Animal Ethics and Welfare (Sari, Iran).

Preparing of irradiated flaxseed

One hundred ten kg of raw Canadian flaxseed (Linum usitatissimum) was purchased from Zarbal Company (Amol, Mazandaran, Iran). The flaxseed sample was packed in 35 × 25 cm² polyethylene bags and exposed to electron beam irradiation (Yazd radiation processing center, AEOI, Yazd center, Iran) at a dose of 20 kGy (fixed beam energy of 10 MeV) at room temperature by a Rhodotron accelerator model TT200 (Ion Beam Applications Company, Ottignies-Louvain-la-Neuve, Belgium). A dose rate of 180 kGy min-1 was used for irradiation as determined by cellulose triacetate film (ISO/ASTM 51650, 2015). Uncertainty for electron radiation was 5% and measured dose uniformity ratio (Dmax/Dmin) was 1.10.

Chemical analysis of flaxseed

We assessed the chemical composition of three samples of raw (RFS) and irradiated flaxseed

(IFS) to determine content of organic matter (OM), crude protein (CP), ether extract (EE), crude fiber (CF), calcium, and phosphorus according to AOAC (2005) analytical methods in Sari Agricultural and Natural Resources University, Sari, Mazandaran, Iran.

Total cyanogenic glycosides (TCG, or cyanide) were measured using the Picrate method (Egan et al., 1998; Bradbury et al., 1999) using a Cyanide kit (courtesy of Howard Bradbury, The Australian National University, Canberra, Australia). About 25-100 mg ground flaxseed was mixed with phosphate buffer (0.5 mL, 0.1 M at pH=4-10) and cyanoglucoside enzyme. A picrate paper attached to a plastic backing strip (Bradbury et al., 1999) was inserted into the sample and after about 16 hrs at 30°C, the picrate paper was removed and immersed in 5.0 mL water for ~30 min. The absorbance of picrate solution was measured at 510 nm. The total cyanide content (ppm) determined as follows:

Total cyanide content (ppm) = $396 \times absorbance \times 100/z$,

where z = sample weight (mg)

All the fatty acid (FA) analysis were done at the lipid laboratory (Oregon State University, Corvallis, USA). Total lipid was extracted from ~2 g of flaxseed using chloroform: methanol (2:1) following methods described by Folch et al. (1957). Fatty acid methyl esters were prepared from total lipid extract using boron trifluoride methanol (Beheshti Moghadam et al., 2017). Fatty acid analysis was performed with an HP 6890 gas chromatograph (Hewlett-Packard Co., Wilmington, DE) equipped with an autosampler, flame ionization detector, and SP-2360 fused silica capillary column. Samples in hexane (1 µL) were injected with helium as a carrier gas into the column programmed for ramped oven temperatures. Initial oven temperature was set at 150°C and held for 1.5 min, then ramped at 15°C /min to 190°C and held for 20 min, then ramped again at 30°C /min to 230°C and held for 3 min. Inlet and detector temperatures were both 250°C. Fatty acid methyl esters were identified by comparison with retention times of authentic internal or external standards (Nuchek Prep, Elysian, MN). Peak areas and percentages were calculated using Hewlett-Packard ChemStation software (Agilent Technologies Inc., Wilmington, DE). Fatty acid values are reported as percentage of methyl esters.

Birds and dietary treatments

A total of 320 day-old male broiler chicks (Ross 308 strain) were individually weighed and randomly distributed to five treatments, with four replicates of 16 chicks each (placed in 20 floor pens bedded with wood shavings). Light was continuous for the first three days post-hatch, after which a 23L:1D was applied. At one day of age, the room temperature was set at 33°C and subsequently reduced by 2 °C/week. Birds had free access to water and feed throughout the experiment.

Dietary treatments consisted of a cornsoybean meal based diet (control), and diets containing 10% raw FS (RFS10), 10% irradiated FS (IFS10), 20% raw FS (20RFS), or 20% irradiated FS (20IFS). Experimental diets were fed during the 3-phase feeding schedule: starter (0 to 10 d), grower (11-22 d), and finisher (23-42 d). All diets were mash and formulated to meet or exceed the minimum requirements for broiler chickens according to Ross 308 catalogue (2014). The composition of experimental diets is given in Table 1.

Table 1. Composition and nutrient content of starter, grower and finisher experimental diets (g/kg)

· · · · ·	Sta	arter (0-10	d)	Gro	wer (11-24	4 d)	Fini	sher (25-42	<u>(0, 0,</u> d)
Ingredients	Control	FS10,	FS20,	Control	FS10,	FS20,	Control	FS10,	FS20,
	Control	RFS10	RFS20	Control	RFS10	RFS20	Control	RFS10	RFS20
Corn	533.60	490.30	426.10	568.60	524.20	466.60	615.90	572.60	517.6
Soybean Meal	405.00	368.00	335.00	364.50	328.00	294.00	323.00	286.00	251.00
FS/RFS ¹	0.000	100	200	0.000	100	200	0.000	100	200
Vegetable oil	20.0	2.00	0.000	25.0	7.00	0.000	28.0	10.00	0.000
Salt	2.50	2.30	2.50	2.50	2.30	2.50	2.50	2.30	2.50
Bicarbonate sodium	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Vitamin premix ²	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Mineral premix ³	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Dicalcium phosphate	16.0	16.0	16.0	14.0	14.0	14.0	12.0	12.0	12.0
Limestone	9.00	8.00	7.00	8.00	7.00	6.00	7.00	6.00	6.00
L-Lysine. HCl	2.00	2.00	2.20	1.50	1.50	1.70	1.20	1.30	1.30
DL-Methionine	3.70	3.40	3.20	3.20	3.00	2.70	2.90	2.50	2.30
Choline chloride (60%)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
L-Threonine	1.20	1.00	1.00	0.700	1.00	0.500	0.500	0.300	0.300
Titanium dioxide	0.000	0.000	0.000	5.00	5.00	5.00	0.000	0.000	0.000
Nutrient values									
ME (Kcal/kg)	2900	2900	2900	2980	2980	2980	3050	3050	3050
Crud protein	220	220	220	205	205	205	190	190	190
Calcium	9.60	9.60	9.60	8.70	8.70	8.70	7.90	7.90	7.90
Available phosphorus	4.80	4.80	4.80	4.40	4.40	4.40	4.00	4.00	4.00
Lysine	11.8	11.8	11.8	10.5	10.5	10.5	9.50	9.50	9.50
Methionine	4.50	4.50	4.50	4.20	4.20	4.20	3.90	3.90	3.90
Methionine + Cystine	9.5	9.5	9.5	8.7	8.7	8.7	8.0	8.0	8.0

¹Flaxseed/ Irradiated flaxseed.

Vitamin premix; Supplied per Kg feed: Vitamin A, 8000 UI; vitamin D3, 2000 UI; vitamin E, 30 UI; vitamin K3, 2 mg; thiamine, 2 mg; riboflavin, 6 mg; pyridoxine, 2.5 mg; cyanocobalamin, 0.012 mg, pantothenic acid, 15 mg; niacin, 35 mg; folic acid, 1 mg; biotin, 0.08 mg.

³Mineral premix supplied per Kg feed; iron, 40 mg; zinc, 80 mg; manganese, 80 mg; copper, 10 mg; iodine, 0.7 mg; selenium, 0.3 mg.

Broiler chicken performance, carcass characteristics and blood sample collection

During the experiment, body weight and feed intake (FI) were measured for each pen in three phases of the experiment (starter, grower and finisher), and then body weight gain (BWG) and feed conversion ratio (FCR) were calculated. At the end of the experiment (42 days), 12 birds per treatment (three birds/pen) were randomly selected, weighed, and then sacrificed by cervical dislocation. Tissue samples from each chicken including liver, breast and thigh muscle (pectoralis major and biceps femoris, without skin), and abdominal fat pad (including fat surrounding the gizzard, bursa of fabricius, and cloaca) were collected and weighed.

At days 21 and 42 of the experiment, eight birds from each treatment (two birds/replicate) were selected for blood analysis. Samples were collected from wing vein, collected in heparinized tubes and centrifuged for 10 min at $2000 \times g$. Plasma was collected, and stored at - 20° C until analysis. Plasma was measured for triglycerides, cholesterol concentrations and aspartate aminotransferase (AST) activity using an auto-analyzer (HITACHI 902 automatic autoanalyzer) from specific commercial kits (Pars Azmoon, Tehran, Iran).

Nutrients digestibility and viscosity

Titanium dioxide (Ti O_2) was added to the feed of all birds at a rate of 5 g/kg as a dietary marker from day 14 to 20. On day 21, two birds were randomly selected from each pen and euthanized by cervical dislocation. The content of the ileum (from Meckel's diverticulum to 1 cm above the ileocecal junction) was collected and pooled for two birds to yield four replicate samples per each treatment. The ileal digesta samples were frozen, freeze-dried, ground, and analyzed for Ti O_2 using a UV spectrophotometer (Short *et al.*, 1996), and for DM, EE and OM as per AOAC (2005).

At day 42, ileal digesta (1.5 g) of two sacrificed birds in each replicate were collected and centrifuged at $12000 \times g$ for 4 min. Viscosity of the supernatant was determined at 40°C using the Brookfield digital viscometer (model DVII+LV, Brookfield Engineering Laboratories, Mashhad, Iran). The ileal digesta samples were frozen, freeze-dried, ground, and analyzed TiO₂ using a UV spectrophotometer (Short *et al.*, 1996), and for DM, EE and OM as per AOAC (2005). Apparent ileal digestibility coefficients of

OM, DM, and EE were calculated using TiO_2 in the diets and digesta by using the following equation: Apparent ileal digestibility coefficient = 1 - [diet TiO_2 / ileal TiO_2] × [ileal nutrient / diet nutrient].

Statistical analysis

The data were analyzed using Mixed procedure of SAS software version 9.4 (SAS, 2013) as a Control plus a 2 × 2 factorial with completely randomized design. The main factors were flaxseed and irradiation. Studentized residuals were calculated for both fixed and random effects and normality of studentized residuals was checked using Shapiro-Wilk test (Zar, 2009). Tukey and Dunnett comparison procedures used to compare means when F-test was significant. All statements of significance are based on P < 0.05.

Results

The effects of electron radiation on chemical composition, TCG, and FA of flaxseed are shown in Table 2. There were no significant differences among treatments, except for crude fiber content which was statistically lower in irritated flaxseed (P < 0.05).

Tuble 4 That y 2cd chemical composition of taw and intudated hasseed (g) kg/	Table 2. Anal	yzed chemical	composition of raw	and irradiated flaxseed	l (g/kg)
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Composition	Raw flaxseed	Electron beam (20 kGy)*	SEM	<i>P</i> -value
Organic matter	965	965	0.142	0.1125
Crude protein	191	189	0.067	0.1248
Ether extract	342	362	0.056	0.5333
Crude fiber	210ª	164 ^b	0.086	0.04850
TCG ¹ (ppm)	230	197.6	0.600	0.2074
C16:0	63.3	67.0	0.024	0.8728
C18:0	56.5	61.6	0.027	0.7664
C18:1 n-9	209	209	0.046	0.3862
C18:2 n-6	122	123	0.018	0.4694
C18:3 n-3	548	537	0.040	0.2556
Total SFA	119	128	0.033	0.9678
Total MUFA	209	209	0.046	0.3862
Total n-6 FA	122	123	0.018	0.4694
Total n-3 FA	548	537	0.040	0.2556

¹Total cyanogenic glycosides

* Flaxseed ground after irradiation.

Total SFA = Total saturated fatty acids (14:0 + 16:0 + 17:0+ 18:0 + 20.0); Total MUFA = Total monounsaturated fatty acids (16:1 + 18:1 + 20:1 + 22:1); Total n-6 polyunsaturated fatty acids (18:2 n-6 + 20:2 n-6 + 20:3 n-6 + 20:4 n-6 + 22:5 n-6); Total n-3 polyunsaturated fatty acids (18:3 n-3 + 20:5 n-3 + 22:5 n-3). Total LC n-6 FA = Total long chain n-6 fatty acids (20:2 n-6 + 20:3 n-6 + 20:4 n-6 + 22:4 n-6 + 22:5 n-6). Total LC n-3 FA = Total long chain n-3 fatty acids (20:5 n-3 + 22:6 n-3). Values within a row with different superscripts differ significantly P < 0.05.

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$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	Bit Model Bit Model <t< th=""><th></th><th>l ukey test</th><th>Control</th><th>FS10</th><th>RFS10</th><th>FS20</th><th>RFS20</th><th>Yes</th><th>No</th><th>10%</th><th>20%</th><th>SEM²</th><th>FS 3</th><th>R 4</th><th>FS×R</th></t<>		l ukey test	Control	FS10	RFS10	FS20	RFS20	Yes	No	10%	20%	SEM ²	FS 3	R 4	FS×R
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$		Starter (0-10d)													
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	$ \begin{array}{llllllllllllllllllllllllllllllllllll$	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	$FI^{5}(g)$		194.72	186.25	188.75	188.99	187.12	191.74	190.49	188.37	5.90	0.726	0.449	0.526
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	$ \begin{array}{c} \mbox{FCR} & 0.920 & 0.80 & 0.970 & 0.870 & 0.970 & 0.870 & 0.970 & 0.920 & 0.020 & 0.065 & 0.05 \\ \mbox{Grower} (11-2d) & 1328.22 & 1314.79 & 1059.89 & 138.827 & 1336.53 & 1194.10 & 1321.55 & 1290.08 & 155.23 & 0.482 & 0.334 \\ \mbox{Fuilsher} (23-42a) & 542.92 & 671.08 & 855.18 & 674.51 & 672.79a & 614.05 & 657.00 & 29341 & 145 & 0.086 & 0.000 & 0.005 \\ \mbox{Fuilsher} (23-42a) & 2.933.2 & 2.735.72 & 284.98 & 2803.22 & 2769.47 & 2844.09 & 2759.47 & 2849.09 & 0.01 & 0.001 & 0.005 \\ \mbox{Fuilsher} (24-21a) & 2.933.2 & 2.757.2 & 284.88 & 2803.22 & 2769.47 & 2844.09 & 2759.47 & 2849.09 & 0.07 & 0.001 & 0.003 \\ \mbox{Fuilsher} (24-21a) & 1.279 & 1.199 & 1.129 & 1.299 & 1.239 & 1.229 & 1.139 & 0.022 & 0.001 & 0.001 & 0.003 \\ \mbox{Fuilsher} (26-212) & 1.190 & 1.499 & 1.299 & 1.239 & 1.229 & 1.239 & 0.022 & 0.001 & 0.001 & 0.003 \\ \mbox{Full} (26-212) & 1.129 & 1.139 & 1.299 & 1.284.09 & 2759.47 & 2844.09 & 2759.47 & 2844.09 & 0.022 & 0.001 & 0.001 & 0.003 \\ \mbox{Full} (26-212) & 1.129 & 1.139 & 1.299 & 1.239 & 1.229 & 1.239 & 1.229 & 1.239 & 0.025 & 0.005 \\ \mbox{Full} (26-212) & 1.2192 & 1.299 & 1.68.51 & 1.499 & 1.299 & 1.88.52 & 188.79 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.68.85 & 1.$	BWG ⁶ (g)		162.85	163.82	146.39	168.61	166.22	154.62	163.33	157.50	5.70	0.326	0.064	0.087
	Clower (11-2d) Fig 533.21 134.79 10598 1358.27 1336.55 1194.10 1321.55 1209.08 155.23 0.482 0.376 0.337 Fig 532.32 671.479 1539 1.74 1.529 1.539 1.459 0.031 0.035 0.036 0.001 0.035 FCR 1.559 1.499 1.74 1.529 1.539 1.653 1.529 1.653 0.142 0.035 0.009 0.035 FUG 1.446 11496 11496 11496 1.529 1.529 1.529 1.529 1.529 0.011 0.001 0.001 0.001 0.005 BWG (g) 1.226 1.348 1.229 1.229 1.229 1.229 1.229 1.229 0.021 0.001 0.001 0.005 Dumett test 5.34 0.926 0.880.70 0.9709 0.871.90 1.229 1.229 1.229 1.229 1.229 1.229 0.022 0.001	$ \begin{array}{{ccccccccccccccccccccccccccccccccccc$	FCR7		0.920	0.880	0.970	0.870	0.870 b	0.950 a	0.900	0.920	0.020	0.403	0.005	0.165
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	Grower (11-22d)	-												
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$			FI (g)		1328.32	1314.79	1059.89	1358.27	1336.53	1194.10	1321.55	1209.08	155.23	0.482	0.376	0.334
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	FCR 1.55° 1.49° 1.74° 1.52° 1.65° 1.65° 1.65° 0.030 0.005 0.009 0.035 Finisher(23-42d) 2793.22 2753.27 2894.86 3803.22 2769.47 2844.09 2779.47 2849.09 50.7 0.112 0.142 0.835 FCR 1.27° 1.13° 1.149° 1.25° 1.22° 1.22° $1.338.86$ $2122.789.27$ 0.001 0.001 0.001 0.003 Dummettest 1.27° 1.13° 1.12° 1.22° 1.22° 1.23° 1.22° 1.23° 0.022 0.001 0.001 0.005 Dummettest 1.275° 1.29° 1.22° 1.22° 1.22° 1.23° 1.23° 0.022 0.001 0.001 0.005 BWG (g) 172.57° 190.26 194.72 186.61° 1.22° 1.22° 1.23° 1.23° 0.022 0.001 0.001 BWG (g) 172.57° 194.63° 686.1° 0.379° $0.866.1^{\circ}$ 0.970° 0.870° 0.870° 0.002 0.005 0.005 BWG (g) 112.57° $132.83.22$ 131.47° $138.85.2$ $135.82.27$ $0.886.1^{\circ}$ $0.323.28^{\circ}$ $0.323.28^{\circ}$ $0.323.28^{\circ}$ $0.323.28^{\circ}$ 0.005 0.005 0.005 BWG (g) 1.490° 1.38° 1.38° $1.38.22^{\circ}$ $1.38.22^{\circ}$	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	BWG (g)		642.92	671.08	585.18	674.51	672.79 a	614.05 ^b	657.00	629.84	14.5	0.086	0.001	0.057
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	FCR		1.55^{b}	1.49^{b}	1.74^{a}	1.52^{b}	1.50^{b}	1.65^{a}	1.52^{b}	1.63^{a}	0.030	0.005	0.00	0.036
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	H(g) 2793.22 2725.72 2894.86 2803.22 759.47 2844.09 50.7 0.102 0.112 0.815 BWG (g) 1470.60 1139.60 112.50 112.50 1235.60 1235.76 2349.06 50.7 0.102 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.00	Finisher(23-42d)													
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	BWG (g) 134406 1419.69 1600.73 1344.83 1382.26 1252.40 1381.88 122.778 21.7 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001<	BWG (g) 1344.06 1419.69 11360.73 1344.83 1352.26 1352.40 1381.88 1227 0.01 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 </td <td>FI (g)</td> <td></td> <td>2793.22</td> <td>2725.72</td> <td>2894.86</td> <td>2803.22</td> <td>2769.47</td> <td>2844.09</td> <td>2759.47</td> <td>2849.09</td> <td>50.7</td> <td>0.102</td> <td>0.142</td> <td>0.815</td>	FI (g)		2793.22	2725.72	2894.86	2803.22	2769.47	2844.09	2759.47	2849.09	50.7	0.102	0.142	0.815
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	FCR 1.27b 1.18b 1.49a 1.25b 1.22b 1.38a 0.022 0.001 0.001 0.001 Dunnett test 2.34 1.47a 1.45a 1.45a 1.25b 1.38a 0.022 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 <td< td=""><td>$\begin{array}{cccccccccccccccccccccccccccccccccccc$</td><td>BWG (g)</td><td></td><td>1344.06^a</td><td>1419.69ª</td><td>1160^b.73</td><td>1344.83^{a}</td><td>1382.26^{a}</td><td>1252.40 b</td><td>1381.88^{a}</td><td>1252.78^{b}</td><td>21.7</td><td>0.001</td><td>0.001</td><td>0.028</td></td<>	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	BWG (g)		1344.06 ^a	1419.69ª	1160 ^b .73	1344.83^{a}	1382.26^{a}	1252.40 b	1381.88^{a}	1252.78^{b}	21.7	0.001	0.001	0.028
	Dunnett test Starter 5.34 0.693 5.34 0.693 5.69 0.005 5.69 0.005 5.69 0.005 5.69 0.005 5.69 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 <	$ \begin{array}{llllllllllllllllllllllllllllllllllll$	FCR		1.27^{5}	1.18^{b}	1.49ª	1.25 ^b	1.22 ^b	1.38 ^a	1.22 ^b	1.38^{a}	0.022	0.001	0.001	0.006
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	Starter F1 (g) 190.26 194.72 186.25 188.75 187.99 186.61a 5.34 0.693 5.34 0.693 5.69 0.005 5.69 0.005 5.69 0.005 5.69 0.005 5.69 0.005 5.69 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005 0.005	Dunnett test													
	H (g) 190.26 194.72 186.25 187.75 187.79 187.79 187.59 5.49 0.693 BWG (g0 172.57a 162.85a 163.82a 146.39b 168.61a 5.69 0.005 5.69 0.005 FCR 0.860a 0.920a 0.880a 0.970b 0.870a 6.861a 5.69 0.005 Grower FL 1310.21 1328.32 1314.79 1059.89 1358.27 1440.40 0.736 BWG (g) 704.92a 642.92b 671.08a 585.18b 674.51a 140.04 0.736 BWG (g) 704.92a 642.92b 671.08a 583.18b 674.51a 1.140 1.77.19 0.022 FCR 1.41 1.55 1.49 1.352 1.49 1.352 50.3 0.043 BWG (g) 1459.55a 1344.00b 1410.06a 1160.73b 1344.83b 50.3 0.043 BWG (g) 1459.55a 1.49b 1.25a 0.024 0.001 FCR 1.14a 1.27a 1.18a 1.25a 0.024 0.010	H (g)190.26194.72186.25187.79187.59187.99186.61a5.340.693BWG (g0172.57a162.85a163.82a146.39b168.61a5.390.0055.690.005CrowerCrower0.920a0.920a0.870a0.870a0.02200.005Grower1310.211328.321314.791059.891358.27135.221440.40.736FCR1.411.551.491.381.521.400.40.736BWG (g)704.92a642.92b671.08a585.18b674.51a1.100.40.736BWG (g)1.411.551.491.381.521.400.40.736FCR1.411.551.491.381.520.0130.023BWG (g)2738.28a2793.28a2793.28a2793.28a2793.28a200.43FCR1.14a1.27a1.13b1.13b2.738.25a200.43FCR1.14a1.27a1.13b1.25a0.0240.002Control, FSI0, RFS10, FS20 and RFS20, represent corn-soybean meal basal diet, diet containing %10 raw flaxeed, diet containing %20 flaxeed and diet containing %20 flaxeed, respectively. ab Values within a row with different superscripts differ significantly $P < 0.05.$	Starter													
	BWG (g0 172.57a 162.85a 146.39b 168.61a 5.69 0.005 FCR 0.860a 0.920a 0.880a 0.970b 0.870a 0.0320 0.005 Grower Grower 0.920a 0.880a 0.970b 0.870a 0.070a 0.005 Grower Grower 1.310.21 1328.32 1314.79 1059.89 1358.27 140.04 0.736 BWG (g) 704.92a 642.92b 671.08a 585.18b 674.51a 17.19 0.022 FCR 1.41 1.55 1.49 1.38 1.52 0.180 0.734 FCR 1.41 1.55 1.49 1.348.3b 1.52 0.134.35b 0.043 BWG (g) 1499.56a 1344.83b 1.25a 0.013 2.758 0.013 BWG (g) 1.14a 1.27a 1.18b 1.49b 1.25a 0.024 0.001 FCR 1.14a 1.27a 1.49b 1.25a 0.022 2.78 0.013	$ \begin{array}{llllllllllllllllllllllllllllllllllll$	FI (g)	190.26	194.72	186.25	188.75	187.99					5.34	0.693		
	FCR 0.860 ^a 0.920 ^a 0.880 ^a 0.970 ^b 0.870 ^a Grower FI (g) 1310.21 1328.32 1314.79 1059.89 1358.27 140.04 0.736 BWG (g) 704.92 ^a 642.92 ^b 671.08 ^a 585.18 ^b 674.51 ^a 1.719 0.022 BWG (g) 704.92 ^a 642.92 ^b 671.08 ^a 585.18 ^b 674.51 ^a 1.52 1.40 0.736 BWG (g) 704.92 ^a 642.92 ^b 671.08 ^a 585.18 ^b 674.51 ^a 0.152 1.40 0.736 FCR 1.41 1.55 1.49 1.32 1.52 0.180 0.734 FI(g) 2738.28 ^a 2793.28 ^a 2725.72 ^a 2894.96 ^b 2803.22 ^a 50.3 0.043 BWG (g) 1459.56 ^a 1419.06 ^a 1.49 ^b 1.25 ^a 0.013 0.024 0.001 FCR 1.14 ^a 1.27 ^a 1.18 ^a 1.49 ^b 1.25 ^a 0.024 0.001 FCR 1.14 ^b <	FCR 0.860 ^a 0.920 ^a 0.870 ^a 0.970 ^b 0.870 ^a Grower FI (g) 1310.21 1328.32 1314.79 1059.89 1358.27 140.04 0.736 BWG (g) 704.92 ^a 642.92 ^b 671.08 ^a 585.18 ^b 674.51 ^a 1.52 1.49 1.36 0.734 FCR 1.41 1.55 1.49 1.38 1.52 0.013 0.734 FCR 1.41 1.55 1.49 1.35 1.49 1.35 0.43 0.024 0.010 FCR 1.14 ^a 1.27 ^a 1.18 ^a 1.49 ^b 1.25 ^a 50.3 0.043 50.3 0.024 0.010 FCR 1.14 ^a 1.27 ^a 1.18 ^a 1.49 ^b 1.25 ^a 50.3 0.043 50.3 0.043 BWG (g) 1.14 ^a 1.27 ^a 1.18 ^b 1.14 ^b 1.27 ^a 1.18 ^b 1.25 ^a 50.3 0.043 FCR 1.14 ^a 1.27 ^a 1.18 ^b 1.25 ^a	BWG (g0	172.57 ^a	162.85 ^a	163.82^{a}	146.39^{b}	168.61^{a}					5.69	0.005		
	GrowerH (g)1310.211328.321314.791059.891358.27140.04 0.736 BWG (g)704.92a642.92b671.08a585.18b $674.51a$ 17.19 0.022 FCR1.411.551.491.381.52Finisher2738.28a2793.28a2725.72a2894.96b $2803.22a$ 0.180 0.734 FI (g)2738.28a2793.28a2725.72a2894.96b $2803.22a$ 0.043 0.043 BWG (g)1459.56a1344.06b11160.73b1344.83b 27.8 0.010 FCR1.14a1.27a1.18a1.49b1.25a 0.024 0.010 FCR1.14a1.27a1.18a1.49b1.25a 0.024 0.001 FCR1.14a1.27a1.18a1.49b1.25a 0.024 0.001 FCR1.14a1.27a1.18a1.49b1.25a 0.024 0.001 FCR1.14a1.27a0.18a1.49b1.25a 0.024 0.001 FCR1.14a1.27a1.18a1.49b1.25a 0.024 0.001	Grower H (g) 1310.21 1328.32 1314.79 1059.89 1358.27 140.04 0.736 BWG (g) 704.92a 642.92b 671.08a 585.18b 674.51a 17.19 0.022 FCR 1.41 1.55 1.49 1.38 1.52 0.180 0.734 FUR 1.41 1.55 1.49 1.32 1.52 0.043 0.734 Finisher 2738.28a 2793.28a 2793.28a 2894.96b 2803.32a 50.3 0.043 BWG (g) 1459.56a 1344.06b 1419.06a 1160.73b 1344.83b 27.78 0.043 BWG (g) 1.14a 1.27a 1.14b 1.25a 27.8 0.010 FCR 1.14a 1.27a 1.49b 1.25a 27.8 0.010 FCR 1.14a 1.27a 1.49b 1.25a 27.8 0.010 FCR 1.14a 1.27a 1.44.8b 1.25a 27.8 0.001 FCR 1.	FCR	0.860^{a}	0.920a	0.880^{a}	0.970 ^b	0.870 ^a					0.020	0.005		
g) 1310.21 1328.32 1314.79 1059.89 1358.27 140.04 704.92^{a} 642.92^{b} 671.08^{a} 585.18^{b} 674.51^{a} 17.19 17.19 1.41 1.55 1.49 1.38 1.52 $0.1802738.28^{a} 2793.28^{a} 1.49^{b} 1.49^{b} 1.25^{a} 1.49^{b} 1.25^{a} 0.024$	FI (g) 1310.21 1328.32 1314.79 1059.89 1358.27 140.04 0.736 BWG (g) 704.92a 642.92b 671.08a 585.18b 674.51a 1.719 0.022 FCR 1.41 1.55 1.49 1.38 1.52 Finisher 1.41 1.55 1.49 1.38 1.52 Finisher 2738.28a 2793.28a 2725.72a 2894.96b 2803.22a BWG (g) 1459.56a 1344.06b 1419.06a 1160.73b 1344.83b FCR 1.14a 1.27a 1.18a 1.49b 1.25a BWG (g) 1.14a 1.27a 1.18a 1.25a 0.013 FCR 1.14a 1.27a 1.18a 1.25a 0.024 0.001 FCR 1.14a 1.27a 1.19a 1.25a 0.024 0.001 FCR 1.14a 1.27a 1.49b 1.25a 0.024 0.001 FCR 1.14a 1.27a 1.49b 1.25a 0.024 0.001 FCR 1.14a 1.27a 1.49	FI (g)1310.211328.321314.791059.891338.27140.040.736BWG (g)704.92a642.92b671.08a585.18b674.51a17.190.022FCR1.411.551.491.381.520.1800.734Finisher1.411.551.491.381.52Fi (g)2738.28a2793.28a2725.72a2894.96b2803.22a50.30.043BWG (g)1459.56a1344.06b11419.06a1160.73b1344.83b27780.010FCR1.14a1.27a1.18a1.49b1.25a0.0240.001FCR1.14a1.27a1.18a1.49b1.25a0.0240.001FCR1.14a1.27a1.18a1.49b1.25a0.0240.001FCR1.14a1.27a1.18a1.49b1.25a0.0240.001FCR1.14a1.27a1.18a1.49b1.25a0.0240.001FCR1.14a1.27a1.18a1.49b1.25a0.0240.001FCR1.14a1.27a1.18a1.49b1.25a0.0240.001FCR1.14a1.27a1.18a1.49b1.25a0.0240.001FCR1.14a1.27a1.18a1.49b1.25a0.0240.001FCR1.14a1.27a1.14b1.27a1.49b1.25a0.0240.001FCR1.14a1.27a1.14b1.26a1.49b <t< td=""><td>Grower</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></t<>	Grower													
g) 704.92^{a} 642.92^{b} 671.08^{a} 585.18^{b} 674.51^{a} 17.19 1.41 1.55 1.49 1.38 1.52 0.180 0.180 2738.28a 2793.28a 2793.28a 2793.28a 2793.28a 2793.22a 2894.96b 2803.22a 1.459.56a 1344.06b 1419.06a 1160.73b 1344.83b 27.8 1.14a 1.27a 1.18a 1.49b 1.25a 0.024	BWG (g) 704.92a 642.92b 671.08a 585.18b 674.51a 17.19 0.022 FCR 1.41 1.55 1.49 1.38 1.52 0.180 0.734 Finisher 573.8a 2793.28a 2725.72a 2894.96b 2803.22a 50.3 0.043 FI (g) 2738.28a 2793.28a 2795.72a 2894.96b 2803.22a 50.3 0.043 BWG (g) 1459.56a 1344.06b 1160.73b 1344.83b 2778 0.010 FCR 1.14a 1.27a 1.18a 1.49b 1.25a 0.024 0.001 FCR 1.14a 1.27a 1.19b 1.25a 0.024 0.001 FCR 1.14a 1.27a 1.49b 1.25a 0.024 0.001	$ \begin{array}{llllllllllllllllllllllllllllllllllll$	FI(g)	1310.21	1328.32	1314.79	1059.89	1358.27					140.04	0.736		
	FCR 1.41 1.55 1.49 1.38 1.52 Finisher 1.41 1.55 1.49 1.38 1.52 Finisher 50.3 0.734 0.734 Filisher 2738.28a 2793.28a 2725.72a 2894.96b 2803.22a BWG (g) 1459.56a 1344.06b 1419.06a 1160.73b 1344.83b 27.8 0.010 FCR 1.14a 1.27a 1.18a 1.49b 1.25a 0.024 0.001 rotoriaining %20 flaxseed and diet containing %20 electron irradiated flaxseed, respectively. 0.024 0.001 0.024 0.001 containing %20 flaxseed and diet containing %20 electron irradiated flaxseed, respectively. 1.25a <t< td=""><td>FCR 1.41 1.55 1.49 1.38 1.52 0.180 0.734 Finisher Finisher 0.180 0.734 0.734 Finisher 1.16 1.55 1.49 1.38 1.52 FI (g) 2738.28a 2793.28a 2725.72a 2894.96b 2803.22a BWG (g) 1459.56a 1344.06b 1419.06a 1160.73b 1344.83b 27.8 0.010 FCR 1.14a 1.27a 1.18a 1.49b 1.25a 0.024 0.001 FCR 1.14a 1.27a 1.18a 1.25a 0.024 0.001 FCR 1.14a 1.27a 1.18a 1.25a 0.024 0.001 FCR 1.14a 1.27a 1.18a 1.25a 0.024 0.001 FCR 1.14b 1.27a 1.18a 1.25a 0.024 0.001 FCN 1.14b 1.27a 1.15a 1.25a 0.024 0.001 FCN 1.14b 1.25a</td><td>BWG (g)</td><td>704.92ª</td><td>642.92^b</td><td>671.08^{a}</td><td>585.18^{b}</td><td>674.51^a</td><td></td><td></td><td></td><td></td><td>17.19</td><td>0.022</td><td></td><td></td></t<>	FCR 1.41 1.55 1.49 1.38 1.52 0.180 0.734 Finisher Finisher 0.180 0.734 0.734 Finisher 1.16 1.55 1.49 1.38 1.52 FI (g) 2738.28a 2793.28a 2725.72a 2894.96b 2803.22a BWG (g) 1459.56a 1344.06b 1419.06a 1160.73b 1344.83b 27.8 0.010 FCR 1.14a 1.27a 1.18a 1.49b 1.25a 0.024 0.001 FCR 1.14a 1.27a 1.18a 1.25a 0.024 0.001 FCR 1.14a 1.27a 1.18a 1.25a 0.024 0.001 FCR 1.14a 1.27a 1.18a 1.25a 0.024 0.001 FCR 1.14b 1.27a 1.18a 1.25a 0.024 0.001 FCN 1.14b 1.27a 1.15a 1.25a 0.024 0.001 FCN 1.14b 1.25a	BWG (g)	704.92ª	642.92 ^b	671.08^{a}	585.18^{b}	674.51 ^a					17.19	0.022		
2738.28a 2793.28a 2725.72a 2894.96b 2803.22a g) 1459.56a 1344.06b 1419.06a 1160.73b 1344.83b 1.14a 1.27a 1.18a 1.49b 1.25a	Finisher Finisher 50.3 2793.28a 2725.72a 2894.96b 2803.22a 50.3 0.043 FI (g) 2738.28a 2793.28a 2725.72a 2894.96b 2803.22a 50.3 0.043 BWG (g) 1459.56a 1344.06b 1419.06a 1160.73b 1344.83b 27.8 0.010 FCR 1.14a 1.27a 1.18a 1.49b 1.25a 0.024 0.001 FCR 1.14a 1.27a 1.18a 1.25a 0.024 0.001 FCR 1.14a 1.27a 1.49b 1.25a 0.024 0.001 rootrol, FS10, FS20 and RFS20, represent corn-soybean meal basal diet, diet containing %10 raw flaxseed, diet containing %20 flaxseed and diet containing %20 electron irradiated flaxseed, respectively. 0.024 0.001	FinisherFinisher $50.3 \ 2793.28^{a} \$	FCR	1.41	1.55	1.49	1.38	1.52					0.180	0.734		
$\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$	FI (g) 2738.28 ^a 2725.72 ^a 2894.96 ^b 2803.22 ^a 50.3 0.043 BWG (g) 1459.56 ^a 1344.06 ^b 1419.06 ^a 1160.73 ^b 1344.83 ^b 27.8 0.010 FCR 1.14 ^a 1.27 ^a 1.18 ^a 1.49 ^b 1.25 ^a 0.024 0.001 FCR 1.14 ^a 1.27 ^a 1.18 ^a 1.25 ^a 0.024 0.001 routrol, FS10, FS20 and RFS20, represent corn-soybean meal basal diet, diet containing %10 raw flaxseed, diet containing %10 electron irradiated flaxseed, respectively. 0.024 0.001	FI (g) 2738.28^{a} 2793.28^{a} 2725.72^{a} 2894.96^{b} 2803.22^{a} 50.3 0.043 BWG (g) 1459.56^{a} 1344.06^{b} 1160.73^{b} 1344.83^{b} 27.8 0.010 FCR 1.14^{a} 1.27^{a} 1.18^{a} 1.49^{b} 1.25^{a} 0.024 0.001 Control, FS10, FS10, FS20 and RFS20, represent corn-soybean meal basal diet, diet containing %10 raw flaxseed, diet containing %10 electron irradiated flaxseed, diet containing %10 raw flaxseed, diet containing %10 electron irradiated flaxseed, di ^{a,b} Values within a row with different superscripts differ significantly $P < 0.05$. 0.05 0.043 0.043	Finisher													
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	BWG (g)1459.56a1344.06b1419.06a1160.73b1344.83b27.80.010FCR1.14a1.27a1.18a1.49b1.25a0.0240.001FCR1.14a1.27a1.18a1.49b1.25a0.0011Control, FS10, FFS10, FFS20, represent corn-soybean meal basal diet, diet containing %10 raw flaxseed, diet containing %20 flaxseed and diet containing %20 flaxseed, respectively.0.0240.001	BWG (g)1459.561344.06b1419.06a1160.73b1344.83b27.80.010FCR1.14a1.27a1.18a1.49b1.25a0.001FCR1.14a1.27a1.18a1.49b1.25a1Control, FS10, FS10, FS20 and RFS20, represent corn-soybean meal basal diet, diet containing %10 raw flaxseed, diet containing %10 electron irradiated flaxseed, diet containing %20 flaxseed and diet containing %20 flaxseed, respectively.25andard error of means; ³ Flax seed; ⁴ Irradiation; ⁵ Feed intake; ⁶ Body weight gain; ⁷ Feed conversion ratio.	FI (g)	2738.28 ^a	2793.28 ^a	2725.72 ^a	2894.96 ^b	2803.22 ^a					50.3	0.043		
1.14^{a} 1.27^{a} 1.18^{a} 1.49^{b} 1.25^{a} 0.024	FCR1.14a1.27a1.49b1.25a0.0011Control, FS10, FFS10, FFS20, represent corn-soybean meal basal diet, diet containing %10 raw flaxseed, diet containing %20 flaxseed and diet containing %20	FCR 1.14 ^a 1.27 ^a 1.18 ^a 1.49 ^b 1.25 ^a 0.001 ¹ Control, FS10, FS20 and RFS20, represent corn-soybean meal basal diet, diet containing %10 raw flaxseed, diet containing %10 electron irradiated flaxseed, diet containing %20 flaxseed and diet containing %20 electron irradiated flaxseed, respectively. ^{a,b} Values within a row with different superscripts differ significantly $P < 0.05$.	BWG (g)	1459.56^{a}	1344.06^{b}	1419.06^{a}	1160.73 ^b	1344.83 ^b					27.8	0.010		
	¹ Control, FS10, FS20, FS20 and RFS20, represent corn-soybean meal basal diet, diet containing %10 raw flaxseed, diet containing %20 flaxseed and diet containing %20 flaxseed and diet containing %20 flaxseed and diet containing %20 electron irradiated flaxseed, respectively.	¹ Control, FS10, RFS10, FS20 and RFS20, represent corn-soybean meal basal diet, diet containing %10 raw flaxseed, diet containing %10 electron irradiated flaxseed, diet containing %20 flaxseed and diet containing %20 flaxseed, respectively. ^{a,b} Values within a row with different superscripts differ significantly <i>P</i> < 0.05.	FCR	1.14^{a}	1.27a	1.18^{a}	1.49^{b}	1.25^{a}					0.024	0.001		

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There were no significant interactions in FI, BWG, and FCR, during starter and grower periods, though this effect was significant for BWG and FCR during finisher period (P < 0.05; Table 3). Irradiation of flaxseed significantly increased (P < 0.05) BWG in grower and finisher periods, and improved FCR in all periods of the experiment. Significant differences were observed between the control and other treatments for FI in finisher periods, as well as for BWG and FCR in all three phases of the experiment (P < 0.05).

Relative weights of thigh, breast, liver, and abdominal fat of birds are shown in Table 4. F20 diets increased thigh and decreased breast percentage (P < 0.05). Feeding irradiated FS increased fat pad yield from 1.45% to 1.91% (P < 0.05). Flaxseed had a significant effect on liver weight. Chicks fed FS20 had lower liver percentage compared to chicks fed FS10 (P < 0.05). However, a significant interaction was observed in liver percentage (P < 0.05). There were significant differences between control and other treatments for thigh, fat pad, and liver percentage (P < 0.05).

Table 4. Effects of experimental diets on carcass characteristics of broilers at day 42 (% of live body weight)

Tukey		Dietar	y Treatme	ents ¹		Irrad	iation	Flax	seed	CTM 2		P-value	
test	Control	FS10	RFS10	FS20	RFS20	Yes	No	10%	20%	SEM ²	FS ³	R 4	FS×R
Thigh		27.1	27.6	29.3	28.3	27.9	28.2	27.4 ^b	28.8 a	0.510	0.008	0.556	0.163
Breast		34.5	34.6	32.6	32.5	33.6	33.6	34.6 ^a	32.6 ^b	0.600	0.003	0.950	0.887
Fat pad		1.55	1.91	1.35	1.91	1.91 a	1.45 ^b	1.73	1.63	0.105	0.540	0.006	0.515
Liver		3.08	3.20	3.06	2.80	3.00	3.07	3.14 a	2.93 ^b	0.090	0.039	0.458	0.050
Dunnett													
test													
Thigh	27.3 ^b	27.1 ^b	27.6 ^b	29.3ª	28.3 ^b					0.460	0.006		
Breast	33.8	34.5	34.6	32.6	32.5					0.560	0.242		
Fat pad	1.97 ^a	1.55 ^b	1.91ª	1.35 ^b	1.91ª					0.150	0.049		
Liver	3.26 ^a	3.08 ^a	3.20 ^a	3.06 ^a	2.80 ^b					0.080	0.009		

¹Control, FS10, RFS10, FS20 and RFS20, represent corn-soybean meal basal diet, diet containing %10 raw flaxseed, diet containing %10 electron irradiated flaxseed, diet containing %20 flaxseed and diet containing %20 electron irradiated flaxseed, respectively.

²Standard error of means; ³Flaxseed; ⁴Irradiation.

^{a,b}Values within a row with different superscripts differ significantly P < 0.05.

As shown in table 5, there were no interactions in cholesterol, triglyceride, and AST activity on days 21 and 42. Neither flaxseed nor irradiation had significant effects on serum cholesterol, triglyceride, and AST concentration at day 21, while the effect of flaxseed on AST activity on day 42 was significant (P < 0.05; Table 5). Broilers fed FS20 had significantly lower (P < 0.05) cholesterol and AST concentrations at 42 days of age. However, there were insignificant differences between the treatments for cholesterol, triglyceride and AST concentrations at 21 days of age.

The effects of irradiation dose and flaxseed levels on the apparent digestibility of EE, DM and OM in the ilea of broilers are shown in Table 6. Apparent digestibility of DM, OM, and EE increased in birds fed irradiated FS diets (P < 0.05). However, feeding FS20 reduced apparent ileal digestibility DM, OM, and EE when compared to FS10 (P < 0.05). There was a significant difference for EE, DM and OM between the control and FS treatments. Irradiation decreased (P < 0.05) digesta viscosity of birds fed FS diets (Table 6). Dietary FS levels had significant impact on digesta viscosity in birds fed FS20, as these birds had a higher viscous digesta than those fed FS10 (P < 0.05). There was a significant difference in digesta viscosity between the control and other treatments.

I0 RFS10 FS 50 121.25 11 2 51.1 53 4 121.88 105 5 82.6 66 2 59.5 26 2 59.5 26 3 21.125 11 50 121.25 11 50 121.25 11 5 51.1 53 2 51.1 53 2 51.1 53 2 51.1 53 3 82.6 66 5 59.5a 26 5 59.5a 26 5 59.5a 26 5 59.5a 26 sent corn-soybean r iated flaxseed, respection, ⁵ Aspartate amir ots differ significantl 00 105 78 78 60.8a 78 78 61.64 78 78 63.8a 76 <th>RFS20 116.20 50.0 60.5 116.57 74.8 34.5 116.57a 74.8 34.5b 76.05</th> <th>Yes 11 118.73 11 51.2 5 55.8 5 55.8 5 55.8 5 119.22 11 78.7 6 47.0 4 47.0 4 t containing %10</th> <th>No 10 116.25 12 54.5 4 58.0 5 58.0 5 69.8 7 7 40.0 5 40.0 5 10 raw flaxseed,</th> <th>10% 20% 121.88 113.10 48.7 57.0 56.7 57.1 121.16 111.22 78.0 70.4 56.4a 30.7b d, diet containing</th> <th>6 7.00 10 8.08 1 9.27 1 9.27 2 7.82 4 4.39 5 7.82 8.93 8.93 7.89 8.02 8.93 8.93 7.31 4.53 8.02 8.02 8.03 8.02 8.03 8.03 8.03 8.02 8.03 8.02 8.03 8.02 8.03 8.03 8.03 8.02 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03</th> <th>R 00 00 00 00 00 00 00 00 00 00 00 00 00</th> <th>FS ³ 0.300 0.322 0.962 0.962 0.099 0.099 0.004 0.58 0.004 0.58 0.004 0.001 0.337 0.010 ated flaxseed,</th> <th>R⁴ 0.766 0.679 0.817 0.443 0.055 0.279 0.279 diet conta</th> <th>FS×R 0.654 0.205 0.353 0.357 0.957 0.914</th>	RFS20 116.20 50.0 60.5 116.57 74.8 34.5 116.57a 74.8 34.5b 76.05	Yes 11 118.73 11 51.2 5 55.8 5 55.8 5 55.8 5 119.22 11 78.7 6 47.0 4 47.0 4 t containing %10	No 10 116.25 12 54.5 4 58.0 5 58.0 5 69.8 7 7 40.0 5 40.0 5 10 raw flaxseed,	10% 20% 121.88 113.10 48.7 57.0 56.7 57.1 121.16 111.22 78.0 70.4 56.4a 30.7b d, diet containing	6 7.00 10 8.08 1 9.27 1 9.27 2 7.82 4 4.39 5 7.82 8.93 8.93 7.89 8.02 8.93 8.93 7.31 4.53 8.02 8.02 8.03 8.02 8.03 8.03 8.03 8.02 8.03 8.02 8.03 8.02 8.03 8.03 8.03 8.02 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03 8.03	R 00 00 00 00 00 00 00 00 00 00 00 00 00	FS ³ 0.300 0.322 0.962 0.962 0.099 0.099 0.004 0.58 0.004 0.58 0.004 0.001 0.337 0.010 ated flaxseed,	R ⁴ 0.766 0.679 0.817 0.443 0.055 0.279 0.279 diet conta	FS×R 0.654 0.205 0.353 0.357 0.957 0.914
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st Dietary Treatments Control FS10 RFS10 55.6c 69.8a 74.5c 78.5a	ent digestibil	lity (at d 21 d)), and digesta	a viscosity (a	at 42 d) of b	roilers			
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74.5c 78.5a	9а 68.5ь	69.1 ^a	53.2^{b}	62.7 ^a	59.7 ^b (0.240 (0.0001	0.0001	0.0001
	3d 77.3b	77.9a	71.9 ^b	76.5 ^a	73.3 ^b (0.130 (0.0001	0.0001	0.0001
70.4c 79.5a	65.5 ^d 78.6 ^b	79.0 ^a	68.0 ^b	74.9ª	72.0 ^b (0.130 (0.0001	0.0001	0.0001
(centipoise) 3.78 2.99		3.20^{b}	4.49^{a}	3.39 ^b		0.340 (0.0164	0.0016	0.1563
EE 71.4 ^a 55.6 ^b 69.8 ^b 50.9 ^b	9b 68.5b				-	0.240 (0.0001		
74.5 ^b 78.5 ^b							0.0001		
70.4 ^b 79.5 ^b							0.0001		
3.78a 2.99a							0.0224		
FS10, RFS10, FS, and RFS20, represent corn-sovbean meal	sal diet, diet con	taining %10 raw	flaxseed, diet co	ontaining %10 e	electron irradie	ated flaxse	eed, diet con	ntaining %2	20 flaxsee
and diet containing %20 electron irradiated flaxseed, respectively.)))	
²⁵ tandard error of means; ³ Flax seed; ⁴ Irradiation; ⁵ Ether extract; ⁶ Dry matter; ⁷ Organic matters.	matter; 7Organi	c matters.							

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Discussion

Feed intake was not affected by FS inclusion level which is in agreement with previous findings that supplemented corn-soybean meal diets with FS (2.5-10%) was not effective (Mridula et al., 2011; 2015). In the present study, inclusion of 20% FS in grower and finisher phases decreased BWG by 16% and 21% compared to the control group, respectively. Ajuyah et al. (1993) reported a 17% decline in body weight of birds fed 15% FS compared to chicks fed corn-soybean diet. Birds fed diets containing flaxseed had greater FCR compared to chicks fed control corn-soy diet. This result is in agreement with findings of Beheshti Moghadam et al. (2017) who reported that FCR was higher in chicks fed diets containing 15% FS compared to corn-soy diet. Mridula et al. (2015) also observed increases in FCR in broilers fed diets containing 15% flaxseed. The depression in bird performance of broilers fed raw flaxseed appears to be due to poor energy availability (Rodriguez et al., 2001) and ANF (Hernandez, 2013) such as cyanide. High levels of fiber and cvanide adversely affect digestibility and utilization of nutrients by birds (Esonu and Udedibie, 1993). Irradiation improved FCR and BWG of birds fed F20 compared to control, FS10 and RFS10 diets.

Nayefi et al. (2015) reported that broilers fed diets containing 10% electron irradiated cotton seed meal had higher feed intake and BWG compared to birds fed diet containing raw cotton seed meal. The greater BWG was attributed to the reduction in gossypol by irradiation. Previously, Chamani et al. (2009) reported that gamma irradiation (15-45 kGy) decreased glucosinolate and improved apparent ileal digestibility of amino acids in canola meal fed to broiler breeders. The observed effects of irradiated diets on birds' performance in the current study could be due to the effects of ionizing radiation on linatine, though these effects have not previously been reported in the literature. It is possible that using the high levels of irradiated flaxseed can have positive impacts on performance indices by decreasing the cyanide content in broiler chickens fed FS diets.

The increase in the relative weight of thigh of birds fed FS20 compared to FS10 is in contrast with that of Mridula *et al.* (2011; 2015) who indicated no changes in the thigh percentage at 2.5-15% level of flaxseed in the diets of broilers. Feeding FS20 led to decrease in fat deposition

which is in line with findings of Najib et al. (2011). However, this is in contrast to Arshami et al. (2010) who reported no adverse effects of flaxseed (5-10%) on breast weight and abdominal fat of chickens. In the present study, the experimental diets were iso-energetic, so the reduction of fat deposits could be due to fatty acid composition of the diets. Esteve-Garcia (2012) stated that poultry diets that are high in polyunsaturated fatty acid can improve FCR and reduce fat deposition compared to diets containing monounsaturated fatty acid from tallow or vegetable oil sources. In other words, there is an optimum ratio of n-6 and n-3 fatty acid that leads to a decrease in adipose tissue. In the present study, feeding diets containing flaxseed (at 10% and 20%) to broilers had no effect on liver weight. Feeding RFS20 diet to broilers decreased liver percentage compared to other diets. Similar results were observed when 5-10% flaxseed were fed to pullet chicks (Arshami et al., 2010). The reduction of liver weight may be a result of reduction in cyanogenic glycosides content as a function of irradiation. Gharaghani et al (2008) observed that liver weight decreased in broilers fed irradiated (10-30 kGy) canola meal. In contrast, Nayefi et al. (2015) observed no significant effect of irradiation of cotton seed meal at doses of 30 kGy on the relative weight of liver and other organs of broiler.

The current study did not show any impacts of experimental diets on blood plasma lipid parameters. Our findings are in agreement with results of Nayefi et al. (2015) who reported that feeding electron irradiated cotton seed meal had not significant effect on blood parameters triglyceride including and cholesterol concentrations. The activity of AST at day 42 decreased as the dietary flaxseed levels increased to 20% in the diets. Similarly, Omer et al. (2013) reported that AST activity decreased in rabbits receiving 15% flaxseed in their diets. In contrast to this result, Yassein et al. (2015) showed that feeding moderate levels of flaxseed (5-10%) had no significant effect on AST activity on laying hens. However, high dose of flaxseed (12-16%) increased blood AST activity in broilers (Al-Nawass, 2015). These researchers attributed this effect to the presence of hydrogen cyanide in flaxseed, which can lead to the accumulation of toxins in the liver and increase secretion of liver enzymes into the blood.

We found that irradiation decreased 15% and 22% of total cyanide and fiber contents of flaxseed, respectively. These results could confirm one of the reasons for increasing digestibility of irradiated flaxseed diets. Although in the present study, irradiation improved apparent DM, OM and EΕ digestibility of flaxseed containing diets, RFS diets still had lower digestibility compared to the control group. Chamani et al. (2009) fed gamma irradiated (15-45 kGy) canola meal to the broiler breeders and showed an increase in apparent digestibility of amino acids with increasing doses of irradiation. Glucosinolate levels also decreased by 58% in gammairradiated canola meal at 45 kGy. Shawrang et al. (2013) conducted a digestion trail and showed an increase in energy and protein digestion of electron irradiated barley (10-30 kGy) as compared to control group.

In the present study, feeding FS20 to broilers increased ileal viscosity compared with FS10 and control diets. Irradiation decreased intestinal viscosity of broilers fed FS20. Studies using gamma or electron radiation showed a decrease in viscosity of rice and barley (Wu *et al.*, 2002). Shawrang *et al.* (2013) reported that electron irradiation (10-30 kGy) linearly decreases viscosity of barley grain by 78%. Byun *et al.* (2008) showed that radiolysis of the glycosidic bonds of beta-glucan decreased the

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molecular weight, water solubility of polysaccharides, granule size and viscosity. Gamma irradiation at doses lower than 50 kGy could change β -glucan (purified from black yeast) with high solubility and low viscosity (Byun *et al.*, 2008). The depolymerization of starch (Wu *et al.*, 2002) has also been associated with the decrease in viscosity caused by ionizing irradiation.

Conclusion

In summary, results of the current study show that electron beam irradiation at 20 kGy of flaxseed is an effective way to improve performance, ileal digestibility, and reduce digesta viscosity of broiler chickens. Further research on the use of irradiated flaxseed in combination with carbohydrase enzymes and its impact on broiler performance and nutrient utilization are warranted.

Acknowledgements

This study was financially supported by Sari Agricultural Sciences and Natural Resources University, Sari, Iran. Authors wish to thank Mrs. Nayefi and Zarbal Company (Amol, Iran) for providing technical assistance to carry out this work. Also, a special thanks to Professor Howard Bradbury that provide Cyanide kit from the Australian National University, Canberra, Australia.

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