DOI: 10.1002/vms3.827

ORIGINAL ARTICLE

Effect of dietary roasted and autoclaved full-fat soybean on the performance of laying hens and egg quality traits

Zohreh Karimi | Mehran Torki | Alireza Abdolmohammadi

Animal Science Department, College of Agriculture and Natural Resources, Razi University, Kermanshah, Iran

Correspondence
Mehran Torki, Animal Science Department, College of Agriculture and Natural Resources, Razi University, 6715685423, Kermanshah, Iran.
Email: torki@razi.ac.ir

Abstract

Context: Full fat soybean (FFSB) can be used in poultry diets as a source of fat and protein, without extra cost for oil extraction; however, raw FFSB contains several anti-nutritional factors.

Aims: Investigating the effects of replacing dietary soybean meal (SBM) with processed (roasted or autoclaved) FFSB on the performance of laying hens and egg quality traits.

Methods: A total of 324 Bovans White strain laying hens were randomly selected and distributed in 54 replicate cages. Based on a completely randomized design with a 2×4 factorial arrangement of treatments plus a control group, nine diets in which SBM were replaced with 25%, 50%, 75% and 100% roasted or autoclaved FFSB, with six replicates (with six hens each), were evaluated during an 8-week trial period (60–68 weeks).

Key results: Significantly increased feed intake (FI) was observed in hens fed diets including autoclaved FFSB ($p < 0.05$). The interactions between SBM replacement level and processing on feed conversion ratio (FCR), egg production (EP) and egg mass (EM) were significant ($p < 0.01$). Hens fed the diet with 100% roasted FFSB instead of SBM showed poor performance in terms of FCR, EP and EM during the experimental period. The main effect of SBM-replacing level on Haugh unit was significant ($p < 0.05$). The main effect of processing on shell thickness was significant ($p < 0.05$), so autoclaved FFSB caused higher eggshell thickness than control and roasted FFSB.

Conclusions: Replacement of dietary SBM with autoclaved FFSB can improve laying hens' performance in terms of FCR, EP, EM and eggshell quality and yolk colour.

Implications: The use of autoclaved FFSB to replace commercial SBM and its oil in the diet of laying hens is recommended. Feed factories can formulate the diets of laying hens with autoclaved FFSB without extra cost due to oil extraction soybeans.

KEYWORDS
autoclaving, egg, full-fat soybean, laying hens, performance, roasting

1 | INTRODUCTION

Soybean meal (SBM) is an excellent source of protein in the diets of poultry. However, in addition to the supply fluctuations and seasonal scarcity in some parts of the world, the price of SBM has been increasing over the years (Erdaw et al., 2017). Therefore, the use of ground raw soybean to replace commercial SBM and its oil in the diet is recommended (Popescu & Crist, 2003). Both SBM and its oil can be partially substituted by including ground raw soybean in the diet (Erdaw et al., 2017). Full fat soybean (FFSB), due to its high-fat content (18%–22%), can be used as a source of fat and protein (37%–42%) in broiler diets without extra cost for oil extraction (Simovic et al., 1972). According to the USDA nutritional database, soybean seeds consist of approximately 36.5% proteins, 19.9% lipids, 30% carbohydrates and 9.3% fibre (Vagadia et al., 2017). One of the main advantages observed in using soybeans in laying hens is improvement in egg size because egg weight depends fundamentally on four factors, including dietary levels of methionine, linoleic acid, fat and energy (Lazaro et al., 2006). The inclusion of 15% raw FFSB in the feed involved the supplementation of approximately 3% fat, a level that has been recommended to improve egg production (EP) (Lazaro et al., 2006).

Raw FFSB contains several anti-nutritional factors (ANFs), such as protease inhibitors, lectins (haemagglutinins) and allergens (glycinin and β-conglycinin) (Rocha et al., 2014). Approximately 2% of SBM and 2%–6% soybean protein contain protease inhibitors (Vagadia et al., 2017). Trypsin inhibitors are one of the most important ANFs in raw soybean because of their effect on enzymes secreted by the pancreas (Herkelman et al., 1991; Vagadia et al., 2017). The presence of these inhibitors in unprocessed soybeans inhibits the activity of trypsin and chymotrypsin enzymes, which play an important role in protein digestion and stimulate pancreatic secretion, which not only reduces growth due to increased pancreatic secretion but also causes the pancreas to enlarge (Waldroup & Cotton, 1974). Primary data showed that raw FFSB, if properly processed, could be used at high levels (more than 20%) in commercial poultry diets (Lazaro et al., 2006). According to reports, the most effective method for inactivating ANFs such as trypsin inhibitors in legumes is to use dry and wet heat (Kaur et al., 2012). Autoclaving and roasting are some common heat treatment methods used for the elimination of trypsin inhibitors. Roasting is the use of dry heat at temperatures varying between 110°C and 170°C, which can inactivate trypsin inhibitory activity (TIA) up to 85%, and autoclaving is the use of wet heat and requires much temperature and pressure (Vagadia et al., 2017). Heat treatment in addition to the destruction of ANFs, by opening the third structure of the protein, improves the digestibility of the protein (Lazaro et al., 2006). Therefore, the main objective of the current study was to investigate the effects of replacing dietary SBM with processed (roasted or autoclaved) FFSB on the performance of laying hens and egg quality traits.

2 | MATERIALS AND METHODS

The experimental protocol was approved by the Animal Care Committee of the Razi University, Kermanshah, Iran. A total of 324 Bovans White laying hens (60 weeks of age) were used in a 56-day experimental period. Based on a 2×4 factorial arrangement of treatment including four replacement levels (25%, 50%, 75% and 100%) of SBM with roasted full fat soybean (RFFSB) or autoclaved full fat soybean (AFFSB), as well as a corn–soybean meal-based control diet, nine isocaloric and isonitrogenous diets were evaluated in a completely randomized design with six replicates of six birds each (Table 1). Approximate analysis of FFSB was conducted, and dry matter (DM), ether extract, crude fiber, crude protein, and Ash were analysed according to the AOAC (1995) procedure (Table 2). The following formula was used to measure the nitrogen-corrected Metabolisable Energy of FFSB (NRC, 1994):

$$ME_n = 2.769 - 59.1 \times CF \div 62.1 \times EE$$

Based on the study by Anderson-Hafermann et al. (1992), FFSB were autoclaved at 121°C for 20 minutes and left in the open air for 24 hours to remove excess moisture and equalize the moisture content of raw soybeans. Based on the study by Ordonez and Palencia (1998), FFSB were roasted at 130°C for 10 minutes in a cooking machine and then quickly exposed to the open air for 24 hours. Feed intake (FI) was recorded weekly, whereas egg production (EP) and egg weight (EW) were recorded daily. Egg mass (EM) and feed conversion ratio (FCR) were calculated. Mortality rate was recorded and feed intake was adjusted accordingly. Egg quality characteristics, including egg shape and yolk indexes, specific gravity, Haugh unit (HU) and yolk, egg white and shell weight, were evaluated by randomly selecting two eggs per replicate (12 eggs/treatment).

2.1 | Specific gravity

Egg specific gravity was measured within 24 hours after the eggs had been laid. Eggs were dropped into a series of six different concentrations of normal saline solutions of known specific gravity that ranged from 1.085 to 1.25. When the eggs floated in the saline solution at a specified level, this was known as their specific gravity (Thompson & Hamilton, 1982).

2.2 | Egg yolk colour

After measuring egg's specific gravity, the eggs were broken and the egg yolk colour was assessed by visual comparison, with a standard Roche Colour Fan ranging from 1 (yellow) to 15 (red) as reported by (Vuilleumier, 1969).

2.3 | Haugh unit

The yolk colour, albumen and yolk heights and widths were measured for HU and yolk indexes. Then, HU was calculated as reported by Haugh (1937) using the following formula: HU = 100 log (AH + 7.57 − 1.7 $EW^{0.37}$), where AH is albumen height (mm) and EW is egg weight (g).

2.4 | Yolk, egg white and eggshell weight

The egg yolk was separated with a strainer and weighed to calculate the average yolk weight. Egg white and eggshell weight were also determined. After weighing the egg yolk, the shell residue was dried in an oven to determine shell weight and thickness.

TABLE 1 Ingredients and nutrient composition of the experimental diets

	Replacing level (%) of soybean meal with full fat soybean				
Ingredients (%)	0	25%	50%	75%	100%
Corn	57.84	55.36	54.21	52.26	50.29
Full fat soybean	0	7.43	14.87	22.31	29.74
Soybean meal	25.24	19.31	12.87	6.44	0
Wheat bran	0	0.92	1.01	1.89	2.82
Soybean oil	3.74	3.74	3.74	3.74	3.74
Limestone	10.14	10.15	10.16	10.17	10.18
Dicalcium phosphate	1.63	1.64	1.64	1.64	1.64
Common Salt	0.4	0.4	0.4	0.4	0.4
Vitamin premix[a]	0.25	0.25	0.25	0.25	0.25
Mineral premix[b]	0.25	0.25	0.25	0.25	0.25
Lysine	0.3	0.35	0.4	0.45	0.5
Methionine	0.2	0.2	0.2	0.2	0.2
Calculated nutrient composition					
ME (kcal/kg)	2840	2840	2840	2840	2840
Crude protein (%)	16.5	16.5	16.5	16.5	16.5
Ether extract (%)	5.77	7.03	8.36	9.68	10.99
Crude fibre (%)	3.04	3.26	3.56	3.88	4.2
Calcium (%)	4.3	4.3	4.3	4.3	4.3
Available phosphorus (%)	0.42	0.42	0.42	0.42	0.42
Sodium (%)	0.18	0.18	0.18	0.18	0.18
Chlorine (%)	0.16	0.19	21	0.23	0.25
Arginine (%)	1.01	1.11	1.19	1.29	1.39
-Lysine HCl (%)L	1.05	1.08	1.11	1.13	1.16
Methionine (%)-DL	0.45	0.45	0.45	0.45	0.45
Methionine + cystine (%)	0.72	0.72	0.72	0.72	0.73
Threonine (%)	0.6	0.61	0.62	0.63	0.64

[a]Vitamin premix was supplied per kg of diet: vitamin A, 360,000 IU; vitamin D3, 800,000 IU; vitamin E, 14.4 g; vitamin K3, 1.6 g; vitamin B_1, 0.72 g; vitamin B_2, 3.3 g; vitamin B_3 (calcium panthothenate), 12.16 g; vitamin B_5 (Niacin), 12 g; vitamin B_6, 6.2 mg; vitamin B_{12}, 0.6 g; biotin, 0.2 g; and choline chloride, 440 mg.
[b]Mineral premix supplied per kg of diet: Manganese, 64 mg; iron, 100 mg; zinc, 44 mg; copper, 16 mg; iodine, 0.64 mg and selenium, 8 mg.

TABLE 2 Proximate analysis of full-fat soybean (percentage DM)

Parameters	Percentage (w/w)	Method number
Dry matter	93.23	930.15
Crude protein	37.95	984.13
Crude fat	18.62	920.39
Crude fibre	9.3	920.85
Ash	5.11	942.51

2.5 | Statistical analyses

Data were analysed using SAS version 9.1 (SAS Institute, 2008). The statistical model for performance data was as follows: Yijk = μ + Ai + Bj + ABij + eijk, in which Yij is observations, μ is the overall mean, Ai is the effect of treatments or the FFSB level, Bj is the effect of the processing method, ABij is the interaction between Ai and Bj (Ai × Bj) and eijk is the residual error. Means were compared by Duncan's multiple range tests. Treatment differences were considered significant at $p < 0.05$. Significantly different means were separated by orthogonal contrast tests.

3 | RESULTS AND DISCUSSION

The effect of diet inclusion of processed FFSB on the FI, EP and FCR of laying hens during the experimental period (60–68 weeks of age) is shown in Table 3. The level of processed FFSB in diet had no significant effect on FI during 60–68 weeks of age, but the processing method had a significant effect on FI. Roasting significantly decreased FI during the 60–68 weeks of age (p ˂0.05). The interactions between

TABLE 3 Effect of diet inclusion of roasted and autoclaved full-fat soybean (FFSB) on feed intake (FI), feed conversion ratio (FCR) and egg production (EP) of laying hens

	Feed intake (g/day)			Feed conversion ratio (g.g)			Egg production (%)		
				Age (weeks)					
Treatments	60–64	64–68	60–68	60–64	64–68	60–68	60–64	64–68	60–68
Replacing level (%) of soybean meal with full fat soybean									
25	104.54	104.21	104.37	1.95	1.86	1.91	84.42	88.86	86.52
50	104.55	104.35	104.46	2.04	2.05	2.04	84.76	83.68	84.1
75	102.76	101.08	101.92	2.28	2.28	2.27	76.18	74.69	75.31
100	101.91	102.15	102.02	2.98	2.99	2.98	67.67	68.57	68.38
SEM	0.91	1.06	0.92	0.14	0.14	0.11	2.41	2.09	2.04
Processing									
Roasting	102.24^{a}	101.56^{b}	101.91^{a}	2.65	2.71	2.67	70.85	69.04	69.87
Autoclaving	104.64^{b}	104.33^{b}	104.49^{b}	1.97	1.88	1.92	85.67^{b}	88.89	87.31
SEM	0.64	0.75	0.65	0.1	0.1	0.08	1.7	1.5	1.4
p Value									
Replacing	0.1112	0.0962	0.0831	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Processing	0.0119	0.0127	0.0072	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Replacing × processing	0.1144	0.3304	0.1618	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
0	104.83	104.8	104.82	1.90^{c}	1.87^{c}	1.88^{c}	89.31^{a}	88.68^{b}	88.99^{b}
25 Roasted	104.36	103.69	104.03	1.91^{c}	1.84^{c}	1.87^{c}	88.22^{a}	89.46^{a}	88.57^{b}
25 Autoclaved	104.72	104.71	104.72	2.01^{a,c}	1.88^{c}	1.94^{c}	80.65^{a}	88.27^{a}	84.46^{a,b}
50 Roasted	104.42	104.06	104.24	2.14^{a,c}	2.22^{a,c}	2.18^{a,c}	80.24^{b}	76.38^{a}	78.32^{a}
50 Autoclaved	104.68	104.64	104.69	1.94^{a,c}	1.88^{c}	1.91^{c}	89.28^{a}	90.97^{a}	89.88^{a}
75 Roasted	101.18	98.92	100.04	2.54^{a}	2.61^{a}	2.55^{a}	68.05^{a}	65.2^{c}	66.62^{c}
75 Autoclaved	104.35	103.25	103.79	2.02^{a,c}	1.96^{c}	1.98^{c}	84.32^{b}	84.21^{a,b}	84.04^{a,b}
100 Roasted	98.1	99.58	99.28	4.03^{b}	4.17^{a}	4.09^{b}	46.92^{c}	45.10^{d}	45.97^{d}
100 Autoclaved	104.8	104.73	104.76	1.92^{c}	1.81^{c}	1.86^{c}	88.42^{b}	92.19^{b}	90.79^{b}
SEM	1.21	1.42	1.22	0.19	0.19	0.15	3.23	2.85	2.75
P value	0.0105	0.0199	0.0074	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

Abbreviation: SEM, standard error means.
$^{a–d}$Means within a column with no common superscript differs ($p < 0.01$).

SBM replacement level and processing on FI were not significant during the experimental periods, including (60–64), (64–68) and (60–68) weeks of age. According to the literature, these results can be partly due to the presence of trypsin inhibitor residues in roasted soybeans (Lazaro et al., 2006). Saponins are heat-stable compounds of FFSB and have a bitter taste; the reason for the reduction in feed consumption was due to the residual saponins in heated soybeans (Zhaleh et al., 2015). Increased FI was observed in laying hens fed diets including 10%, 15% and 20% FFSB compared to the control group (Pitala et al., 2016). An increased dietary level of FFSB from 20% to 35% significantly reduced FI in broiler chickens (Hanson & Persia 2014). These researchers assumed that increased concentrations of indigestible and anti-nutritional substances along with increased dietary levels of FFSB are the main involved factor (Hanson & Persia, 2014).

The interactions between SBM replacement level and processing on FCR were significant ($p < 0.01$), so that hens fed 100% SBM replaced by RFFSB showed significant attenuation performance during experimental periods (60–64, 64–68 and 60–68 weeks of age) ($p < 0.01$). Improved FCR was observed in birds fed the diets with 100% AFFSB and the control during the experimental periods. The results of the present study are consistent with the results of the study, in which the use of RFFSB (20–40 minutes of processing time) in broiler diets significantly increased the FCR compared to steamed soybeans (5 minutes of processing time) (Lazaro et al., 2006). They indicated the inability of roasting to destroy the trypsin inhibitor of soybean. The FCR in hens fed the diet with 10% RFFSB was significantly improved compared to the control group (Pitala et al., 2016). Metabolic energy and FCR in broiler chickens were significantly reduced by increasing the level of extruded FFSB (40–160 g/kg) in the diet compared to when SBM was used combined with oil in the diet. The lowest fat digestion and highest TIA occurred at the highest levels of FFSB in the diet (Foltyn et al., 2013).

TABLE 4 Effect of diet inclusion of roasted and autoclaved full-fat soybean (FFSB) on egg mass (EM) and egg weight (EW) of laying hens

	Age (weeks)					
	Egg mass (g/hen/day)			Egg weight (g)		
Treatments	60–64	64–68	60–68	60–64	64–68	60–68
Replacing level (%) of soybean meal with full fat soybean						
25	53.51	56.12	54.66	62.13	63.01	62.55
50	52.01	51.72	51.78	61.1	61.6	61.33
75	46.41	46.5	46.56	61.4	61.62	61.5
100	41.51	42.54	42.7	61.12	62.03	61.55
SEM	1.43	1.26	1.23	0.42	0.5	0.4
Processing						
Roasting	43.44	42.86	43.11	61.21	61.74	61.42
Autoclaving	53.21	55.51	54.74	61.67	62.42	62.05
SEM	1.01	0.89	0.86	0.3	0.35	0.28
p Value						
Replacing	0.0001	0.0001	0.0001	0.3	0.13	0.16
Processing	0.0001	0.0001	0.0001	0.27	0.18	0.13
Replacing × processing	0.0001	0.0001	0.0001	0.04	0.23	0.1
0	55.44[a]	56.17[a]	55.81[a]	62.11	62.94	62.52
25 Roasted	55.06[a]	56.47[a]	55.55[a]	62.02	63.41	62.61
25 Autoclaved	53.05[a]	55.51[a]	53.77[a]	62.24	62.76	62.52
50 Roasted	49.83[a]	47.66[b]	48.74[b]	61.83	61.55	61.7
50 Autoclaved	54.02[a]	55.78[a]	54.82[a]	60.36	61.63	61.02
75 Roasted	40.6[b]	39.87[c]	40.22[c]	60.51	60.55	60.51
75 Autoclaved	52.22[a]	53.12[a]	52.91[a,b]	62.28	62.7	62.5
100 Roasted	28.35[c]	27.46[d]	27.90[d]	60.44	61.46	60.91
100 Autoclaved	54.6[a]	57.63[a]	57.51[a]	61.82	62.6	62.21
SEM	1.93	1.74	1.67	0.62	0.68	0.57
P value	0.0001	0.0001	0.0001	0.11	0.11	0.06

Abbreviation: SEM, standard error means.

[a–d]Means within a column with no common superscript differs ($p < 0.01$).

The interactions between SBM replacement level and processing on EP were significant ($p < 0.01$), so that hens fed the diets including 100% and 75% SBM replaced with RFFSB had significantly less EP during the experiment ($p < 0.01$). Increased EP was observed in hens fed the control diet at 60–64 weeks of age and the diet with 100% AFFSB at 64–68 and 60-68 weeks of age. This finding is in agreement with that of Lazaro et al. (2006), who reported the positive effect of autoclaving, which is likely involved in inactivating the trypsin inhibitor. Using steam for 15 minutes has been reported to reduce the anti-trypsin activity of FFSB by 92% in comparison to roasting (13% and 28 %). Lazaro et al. (2006) suggested that laying hens' access to dietary oil could also be another factor in increased production, such that the digestibility of roasted soybeans was 77.2% and extruded soybeans was 82.8%. No significant effect on pancreatic weight or EP was detected in laying hens fed a diet with extruded soybean instead of SBM. The use of high levels of RFFSB significantly reduced the EP (Lazaro et al., 2006).

The effects of dietary groups on EM and EW during the experimental periods are shown in Table 4. The interactions between SBM replacement level and processing on EM were significant ($p < 0.01$). Increased levels of RFFSB significantly reduced EM. Hens fed the diet with 100% and 75% SBM replaced by RFFSB (60–64 weeks of age), and hens fed the diet with 100&, 75% and 50% SBM replaced by RFFSB (64–68 and 60–68 weeks of age) showed poor performance compared to other groups ($p < 0.01$), but there was no significant difference between the 50% RFFSB and 75% AFFSB groups from 60–68 weeks of age.

By including processed pigeon pea in laying hen diets, the best and worst EM were observed in the birds fed boiled and roasted pigeon pea, respectively (Amaefule et al., 2007). Laying hens fed diets including 50 to 100 g/kg roasted guar showed a significantly reduced EM (Rao et al., 2015).

The interactions between SBM replacement level and processing on EW were significant only in the first period ($p < 0.05$). The results of the

TABLE 5 Effect of diet inclusion of roasted and autoclaved full-fat soybean (FFSB) on egg quality characteristics

Treatments	Yolk weight (g)	White weight (g)	Shell weight (g)	Shell thickness (mm10^{-2})	Egg gravity (cm^3/g)	Shape index (%)	Haugh unit (Score)	Yolk index (%)	Yolk colour (Roche)
Replacing level (%) of soybean meal with full fat soybean									
25	17.82	36.43	6.24	0.41	1.14	75.76	86.22^{a,b}	41.78	6.75
50	19.05	36.37	6.08	0.39	1.12	75.73	82.91^{b}	40.72	6.58
75	18.35	36.51	6.06	0.40	1.12	75.96	89.21^{a}	41.8	7.08
100	18.78	36.83	6.33	0.41	1.16	73.76	87.47^{a}	41.44	7.00
SEM	0.51	0.50	0.14	0.60	0.01	0.85	1.51	0.43	0.12
Processing									
Roasting	18.33	36.52	6.04	0.39^{b}	1.13	74.70	86.96	41.55	6.77
Autoclaving	19.07	36.55	6.32	0.41^{a}	1.14	76.03	85.95	41.32	6.94
SEM	0.36	0.35	0.10	0.42	0.001	0.62	1.06	0.30	0.08
P value									
Replacing	0.053	0.92	0.50	0.37	0.07	0.23	0.03	0.27	0.02
Processing	0.162	0.96	0.06	0.01	0.20	0.13	0.51	0.60	0.18
Replacing× processing	0.24	0.51	0.50	0.51	0.47	0.08	0.29	0.0001	0.001
0	18.73	36.50	5.82	0.38	1.11	74.90	86.41	40.20^{b,c}	6.08^{d}
25 Roasted	17.44	36.33	6.04	0.40	1.24	76.58	84.74	43.26^{a}	6.33^{c,d}
25 Autoclaved	18.23	36.54	6.43	0.41	1.15	75.04	87.70	41.09^{b,c}	7.16^{a,b}
50 Roasted	19.92	37.02	6.14	0.38	1.12	76.91	82.86	40.35^{b,c}	6.58^{b,c,d}
50 Autoclaved	19.36	35.74	6.02	0.40	1.14	73.86	82.96	41.85^{a,b}	6.58^{b,c,d}
75 Roasted	17.48	36.26	5.88	0.39	1.13	76.07	90.04	41.75^{a,b}	7.33^{a}
75 Autoclaved	19.22	36.72	6.23	0.40	1.21	74.92	88.41	43.06^{a}	6.83^{a,b,c}
100 Roasted	18.07	36.47	6.11	0.39	1.63	72.60	90.11	43.83^{c}	6.83^{a,b,c}
100 Autoclaved	19.51	37.18	6.57	0.42	1.65	76.26	84.84	41.93^{a,b}	7.17^{a,b}
SEM	0.81	0.62	0.21	0.90	0.01	1.26	2.09	0.61	0.19
P value	0.16	0.92	0.23	0.11	0.10	0.115	0.13	0.001	0.0004

Abbreviation: SEM: Standard error means.
[a–d]Means within a column with no common superscript differs ($p < 0.01$).

present study are in agreement with the findings of Lazaro et al. (2006), who reported that replacing SBM with roasted and extruded soybeans had no significant effect on the average EW, although extruded soybeans slightly reduced EW. The main reason for this is related to the higher absorption of oil compared to heated soybean, which in turn can be effective for the absorption of linoleic acid (Lazaro et al., 2006). No significant effect of dietary FFSB on the EW of laying hens was observed when the levels increased from 0% to 22% (Senkoylu et al., 2005).

The effects of dietary groups on egg quality characteristics are presented in Table 5. Limited publications regarding the effects of diet inclusion of FFSB on egg quality characteristics in laying hens are in the literature. The main effects of replacing SBM with FFSB were significant on the HU ($p < 0.05$), and the highest HU was assigned to the level of 75% SBM replacing level; however, there was a significant difference between 75% and 50% SBM replacing level with FFSB. Harms et al. (1967) reported the variation in the HU in hens fed diets with different levels of protein. Rao et al. (2015) reported no significant influence of dietary toasted guar (from 0 to 150 g/kg) on the HU of eggs. Dietary inclusion of 20% raw pigeon pea significantly decreased HU compared to layers fed diets including toasted and soaked pigeon pea (Amaefule et al., 2007).

The main effects of the FFSB processing method on the shell thickness were significant, so autoclaving increased the shell thickness compared to roasting. This might be partly due to the reduced phytic acid in FFSB because Ari et al. (2012) reported reduced phytic acid by 72% after roasting. Reduced phytic acid in turn caused improved calcium and phosphorus digestibility (Sebastian et al., 1996). Increased dietary calcium led to an increase in eggshell specific gravity (Roland & Gordon, 1997). Senkoylu et al. (2005) reported no significant effect of increased dietary FFSB levels from 0% to 20% on weight and shell thickness.

The interactions between SBM replacement level and processing on yolk index and yolk colour were significant ($p < 0.01$). The diet with 25% SBM replaced with AFFSB had a significantly higher yolk index. The yolk index was not significantly affected by the diet inclusion of 20% raw, roasted and boiled velvet beans (Tuleun et al., 2008). The diets with 75%replaced SBM with RFFSB had significantly higher yolk colour compared to other dietary groups ($p < 0.01$). The lowest yolk colour belonged to the control group. High oil quality in soybeans improved the absorption of pigment and egg yolk colour (Lazaro et al., 2006).

4 | CONCLUSIONS

Overall, based on the results of the current study, the inclusion of 100% AFFSB (20 minutes at 121°C) as a substitute for SBM could have a positive effect on the performance (FCR, EP, EM and EW) of laying hens.

ACKNOWLEDGEMENT

The authors appreciate Razi University for financially supporting the current study.

CONFLICT OF INTEREST

The authors have no conflict of interest to be declared.

FUNDING INFORMATION

No funding was received to assist with the preparation of this manuscript.

ETHICS STATEMENT

All experimental protocols adhered to the guidelines approved by the Animal Ethics Committee of Razi University, Kermanshsh, Iran, and were in accordance with the EU standards for the protection of animals and/or feed legislation.

AUTHOR CONTRIBUTIONS

Zohreh Karimi: Performed the experiment, collected and statistically analysed the experimental data, prepared the result tables and wrote the primary draft of the manuscript.

Mehran Torki: Designed and supervised the research, revising and correcting the manuscript.

Alireza Abdolmohammadi: Consultant of statistical data analysis.

DATA AVAILABILITY STATEMENT

The related pure data file is available upon request.

PEER REVIEW

The peer review history for this article is available at https://publons.com/publon/10.1002/vms3.827

ORCID

Mehran Torki https://orcid.org/0000-0001-5660-0273

REFERENCES

Amaefule, K. U., Oguike, M. A., Ironkwe, M. O., & Obioha, F. C. (2007). Pigeon Pea [*Cajanus cajan* (L.) Millsp.] Seed meal in layer diets: 3. Effect of higher inclusion level and prolonged feeding of raw or processed pigeon pea seed meal diets from pullet chick stage on the laying performance of pullets. *International Journal of Poultry Science*, *6*, 452–458.

Anderson-Hafermann, J. C., Zhang, Y., Parsons, C. M., & Hymowitz, T. (1992). Effect of heating on the nutritional quality of conventional and Kunitz trypsin inhibitor-free soybeans. *Poultry Science*, *71*, 1700–1709.

AOAC. (1995). *Official methods of analysis*, (16th ed.). Association of Official Analytical Chemists.

Ari, M. M., Ayanwale, B. A., Adama, T. Z., & Olatunji, E. A. (2012). Evaluation of the chemical composition and anti-nutritional factors (ANFs) levels of different thermally processed soybeans. *Asian Journal of Agricultural Research*, *6*, 91–98.

Erdaw, M. M., Perez-Maldonado, R. A., Bhuiyan, M., & Iji, P. A. (2017). Partial replacement of commercial soybean meal with raw, full-fat soybean meal supplemented with varying levels of protease in diets of broiler chickens. *South African Journal of Animal Science*, *47*, 61–71.

Foltyn, M., Rada, V., Lichovnikova, M., Safarik, I., Lohnisky, A., & Hampel, D. (2013). Effect of extruded full-fat soybeans on performance, amino acids digestibility, trypsin activity, and intestinal morphology in broilers. *Czech Journal of Animal Science*, *58*, 470–478.

Hanson, M. N., & Persia, M. E. (2014). Effects of dietary soy inclusion on broiler chick performance and metabolizable energy. *Iowa State University Animal Industry Report*, *11*, 234–239.

Harms, R. H., Lester, W. B., & Waldroup, P. W. (1967). Further studies on the relationship of egg production rate as affected by feed to Haugh units of eggs. *Poultry Science*, *41*, 578–580.

Haugh, R. R. (1937). The Haugh unit for measuring egg quality. *US Egg Poultry Magazine*, *43*, 522–555.

Herkelman, K. L., Cromwell, G. L., & Stahly, T. S. (1991). Effects of heating time and sodium metabisulfite on the nutritional value of full-fat soybeans for chicks. *Journal of Animal Science*, *69*, 4477–4486.

Kaur, S., Sharma, S., Dar, B. N., & Singh, B. (2012). Optimization of the process for the reduction of anti-nutritional factors in edible cereal brans. *Food Science and Technology International*, *18*, 445–454.

Lázaro, R., Mateos, G. G., Latorre, M. A., & Piquer, J. (2006). Whole soybeans in diets for poultry. *Disponible en:* https://www.thepoultrysite.com/articles/whole-soybeans-in-diets-for-poultry

NRC, National Research Council Nutrient Requirements of Poultry (1994). (9th revised ed.). National Academy Press.

Ordonez, L. F., & Palencia, J. C. (1998). Efecto de diferentes temperaturas de dostado seco sobre la calidad nutricional del frijol de soya integral empleado en alimentacion de pollos de engorde. Referenciado por Ruiz, N. en Quality Control of Commercial Full-fat Soybeans. Technical Bulletin. ASA Singapore, MITA (P) No. 070/10/2001.

Pitala, W., Sessi, K. M., Kulo, A. E., & Gbeassor, M. (2016). Effects of incorporation of roasted soybeans on the performance of laying and the financial profitability of laying hens. *International Journal of Poultry Science*, *15*, 373–378.

Popescu, A., & Criste, R. (2003). Using full-fat soybean in broiler diets and its effect on the production and economic efficiency of fattening. *Journal of Central European Agriculture*, *4*, 167–174.

Rao, S. R., Raju, M., Prakash, B., Reddy, E. P. K., & Panda, A. K. (2015). Effect of dietary inclusion of toasted guar (*Cyamopsis tetragonoloba*) meal as a source of protein on performance of White Leghorn layers. *British Poultry Science*, *56*, 733–739.

Rocha, C., Durau, J. F., Barrilli, L. N. E., Dahlke, F., Maiorka, P., & Maiorka, A. (2014). The effect of raw and roasted soybeans on intestinal health, diet digestibility, and pancreas weight of broilers. *Journal of Applied Poultry Research*, *23*, 71–79.

Roland Sr, D. A., & Gordon, R. (1997). Phosphorus, calcium optimization requires a new approach. *Feedstuffs (USA)*, 15–17.

Statistical Analysis System (SAS) Institute. (2008). *SAS/STAT User's Guide*. Version 9.1.' *SAS Institute*, *Cary*.

Sebastian, S., Touchburn, S. P., Chavez, E. R., & Lague, P. C. (1996). The effects of supplemental microbial phytase on the performance and utilization of dietary calcium, phosphorus, copper, and zinc in broiler chickens fed corn-soybean diets. *Poultry Science*, *75*, 729–736.

Senkoylu, N., Samli, H. E., Akyurek, H., Agma, A., & Yasar, S. (2005). Use of high levels of full-fat soybeans in laying hen diets. *Journal of Applied Poultry Research*, *14*, 32–37.

Simovic, R., Bilanski, W. K., & Summers, J. (1972). Heat treatment of full-fat soybeans. *Canadian Journal of Animal Science*, *52*, 183–188.

Thompson, B. K., & Hamilton, R. M. (1982). Comparison of the precision and accuracy of the flotation and Archimedes methods for measuring the specific gravity of egg. *Poultry Science*, *61*, 1599–1605.

Tuleun, C. D., Carew, S. N., & Ajiji, I. (2008). Feeding value of velvet beans (*Mucuna utilise*) for laying hens. *Bone*, *20*, 20–0.

Vagadia, B. H., Vanga, S. K., & Raghavan, V. (2017). Inactivation methods of soybean trypsin inhibitor–A review. *Trends in Food Science & Technology*, *64*, 115–125.

Vuilleumier, J. P. (1969). The Roche yolk colour fan, an instrument for measuring yolk colour. *Poultry Science*, *48*, 767–779.

Waldroup, P. W., & Cotton, T. L. (1974). Maximum usage levels of cooked full-fat soybeans in all-mash broiler diets. *Poultry Science*, *53*, 677–680.

Zhaleh, S., Golian, A., Mirghelenj, S. A., Akhavan, A., & Akbarian, A. (2015). Effects of feeding various levels of full-fat soybean extruded at high temperature on performance, serum components and intestinal morphology of broiler chickens. *Animal Production Science*, *55*, 580–586.

How to cite this article: Karimi, Z., Torki, M., & Abdolmohammadi, A. (2022). Effect of dietary roasted and autoclaved full-fat soybean on the performance of laying hens and egg quality traits. *Veterinary Medicine and Science*, *8*, 1603–1610. https://doi.org/10.1002/vms3.827