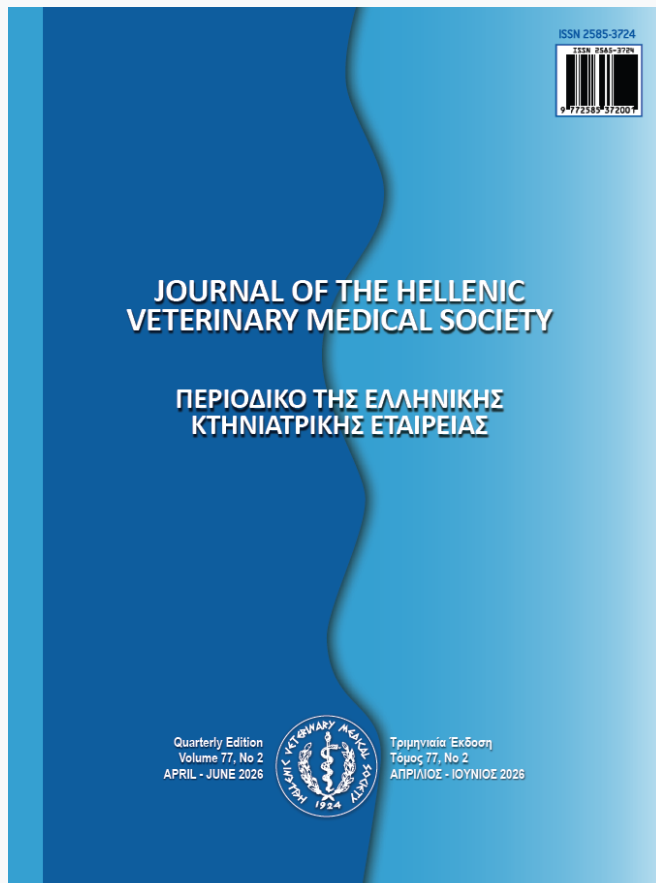


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Studying the effect of different levels of oil and pellet binders on jejunum morphology, performance and feed quality in broilers

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ABSTRACT: To assess the effect of different levels of soybean oil (SO: 1, 2%) and different types of pellet binders (sodium bentonite (SB), calcium lignosulfonate (Ca-Ls), and plant compounds (PC) on the pellet quality, performance and jejunum morphology, 480 one-day-old male broiler chickens (Ross 308) with an initial weight of 44.89±1.36 g were assigned to eight treatments with five replicates based on the completely randomized design. Treatments included: 1) 1% SO+1% SB (1-SB), 2) 1% SO+0.5 % Ca-Ls (1- Ca-Ls), 3) 1% SO+0.5% PC (1-PC), 4) 1% SO+ no pellet binder (1-None), 5) 2% SO+1% SB (2-SB), 6) 2% SO+0.5% Ca-Ls (2- Ca-Ls), 7) 2% SO+0.5% PC (2-PC), 8) 2% SO+ no pellet binder (2-None). The results showed that in the starter diet, 1-PC group had the most pellet durability index (PDI) ($P < 0.05$). The PDI of the grower diets containing SB and PC was higher than others ($P < 0.05$). The highest pellet hardness was observed in groups 1-SB, 1-PC, 2-SB, and 2-PC for starter diet ($P < 0.05$). The pellet hardness in finisher diets containing SB and PC was higher ($P < 0.05$). During the starter phase, the best feed conversion ratio was obtained in 1-SB ($P < 0.05$). During the finisher phase, the lowest and highest daily feed intake was observed in groups 2-PC and 1-SB, respectively. During the finisher phase the most daily body weight gain was observed in SB group ($P < 0.05$). Sodium bentonite increased the villus height (VH) and VH to crypt depth (CD) ratio ($P < 0.05$). In general, diets with PC and SB had the highest PDI, and although the pellet quality improved, the presence of PC decreased the amount of feed the birds consumed during the finisher period. Additionally, SB enhanced a few intestinal metrics.

Keyword: Bentonite; Birds; Body weight; Feed processing; Pellet durability; Soybean oil

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INTRODUCTION

The most common thermal processing method of poultry feed is pelleting. The positive effects of pelleting on the feed intake (FI), feed conversion ratio (FCR), and body weight gain (BWG) of broilers have been well investigated (Svihus et al., 2024; Heydari et al., 2024). Using pellet diets has been shown to improve palatability, decrease material separation and energy expenditure during feed consumption, and improve digestibility (Moradi et al., 2018a). Nevertheless, the impact of the pellet process on the bird's performance is variable and markedly depends on the quality of the pellets produced. According to the research, factors such as the diet formulation (40%), size of feed particles (20%), conditioning of feed (20%), diet characteristics (15%), and cooling and drying have a significant effect on the pellet quality (Iravani et al., 2024). As a result, diet composition has a considerable effect on the physical quality of pellets. Dorrani and Rezvani (2023) observed that increasing the level of binders could improve the pellets durability index (PDI). Furthermore, they reported that the PDI was higher in soybean oil (SO) than that in diets containing fat powder. However, factors such as the increase in the price of fat and the negative effects of mixer-added fat on the quality of pellets have led feed manufacturers to reduce the amount of fat added to the diets (Abadi et al., 2021). As a result, the use of suitable fat substitutes as pellet binders has attracted the attention of feed manufacturers. Binders connect the feed components in the pellet to each other and as a result, its structure remains compact (Supriadi et al., 2021). Calcium lignosulfonate (Ca-Ls) (a by-product of the paper production) is considered as pellet binders in poultry feed (Saleh et al., 2021). Abadi et al. (2019) stated that the use of lignosulfonates improved pellet quality (pellet hardness). Serish (*Eremurus Luteus*) is one of the rhizome plants belonging to the *Asphodelaceae* family that is cultivated in Iran (Javidi and Razavi, 2016). Its roots and tubers are rich in low-cost and non-toxic carbohydrates and its roots are used as glue (Shahrampour and Razavi, 2022). Gums are a large group of polysaccharides that are characterized by their ability to produce products with high viscosity at low concentrations. Mellouk et al. (2024) reported that the use of guar gum in the broilers diet caused a significant reduction in performance. Sodium bentonite (SB) is a tri-layered aluminosilicate clay owning exchangeable cations that absorbs more humidity than those of other clays (Abbasi pour et

al. (2021). Moradi et al. (2018b) showed that the inclusion of 20 g/kg SB in the corn-soybean meal based diets improved PDI and hardness.

Various studies have been conducted on the effects of using fat and pellet binders on pellet quality, which have resulted in different outcomes (Abadi et al., 2019; Dorrani and Rezvani, 2023). Considering the negative effects reported about the addition of fat on the efficiency of the pellet machine and the quality of produced pellets, the purpose of this study is to investigate the main and interaction effects of two levels of SO and three types of pellet binders (SB, Ca-Ls, and PC) on the pellet quality, performance and intestinal morphology in broiler chickens.

MATERIAL AND METHODS

Ethical Statement

This study was carried out based on procedures and guidelines approved by the Animal Care Committee of AREEO (Agricultural Research, Education and Extension Organization; No. IR. AREEO.14365.125.264 On April,2023).

Birds, Diets, and Management

A total of 480 one-day-old Ross 308 broiler male chicks with an initial weight of 44.89 ± 1.36 g were reared until 42 days old. Twelve chickens were assigned in each pen and fed with eight diets during the starter (1-10 d), grower (11-24 d), and finisher (25-42 d) phases. Treatments included 1) 1% SO + 1% SB (1-SB), 2) 1% SO + 0.5% Ca-Ls (1-Ca-Ls), 3) 1% SO + 0.5% PC (guar gum: 0.2% + Serish: 0.3%) (1-PC), 4) 1% SO + no pellet binder (1-None), 5) 2% SO + 1% SB (2-SB), 6) 2% SO + 0.5% Ca-Ls (2-Ca-Ls), 7) 2% SO + 0.5% PC (guar gum: 0.2% + Serish: 0.3%) (2-PC), 8) 2% SO + no pellet binder (2-None). Five repetitions were considered for each group. Ingredients and nutrient composition of diets are shown in Table 1 (NRC, 1994) and diets were formulated to meet Ross 308 requirements (Aviagen, 2014). In each phase, diets were isocaloric and isonitrogenous. All materials were milled via a hammer mill (Asiab Company, Tehran, Iran). Soybean oil and pellet binders were added to the mixer (Feed tech, Türkiye) and diets were conditioned in a conditioner (Feed tech, Türkiye, pellet system, and Yemmak). Starter and grower diets were pelleted by a mill with a 2 mm die, while finisher diets with 4 mm die (Graf GmbH, Germany). The temperature of the rearing house was set at 32°C for the first 3 days and decreased by 3°C every week until it reached

Table 1. Ingredients and nutrient composition of the starter, grower and finisher diets (as-fed basis).

Ingredients (%)	Starter		Grower		Finisher	
	1% SO	2% SO	1% SO	2% SO	1% SO	2% SO
Corn	57.82	54.89	62.71	58.98	68.38	65.72
Soybean meal (44%)	32.99	35.96	28.62	32.48	22.89	26.75
Corn gluten (62%)	3.30	1.50	3.20	1.40	2.98	0.70
Wheat Bran	0.23	1.00	0.20	0.98	0.80	1.00
Soybean oil (SO)	1.00	2.00	1.00	2.00	1.00	2.00
Calcium carbonate	1.05	1.86	0.96	0.95	0.89	0.88
Dicalcium phosphate	1.89	1.04	1.65	1.63	1.46	1.43
Sodium chloride (salt)	0.25	0.28	0.28	0.31	0.27	0.27
Vitamin premix ¹	0.25	0.25	0.25	0.25	0.25	0.25
Mineral premix ²	0.25	0.25	0.25	0.25	0.25	0.25
L-Lysine HCl	0.40	0.32	0.33	0.25	0.33	0.24
DL-Methionine	0.33	0.35	0.27	0.29	0.24	0.26
L-Threonine	0.13	0.12	0.10	0.09	0.08	0.07
Sodium Bicarbonate	0.10	0.10	0.10	0.05	0.10	0.10
Choline chloride (60%)	0.08	0.08	0.08	0.09	0.08	0.08
Nutrient composition (Calculated:%)						
Metabolizable energy (kcal/kg)	2880	2880	2940	2940	3000	3000
Crude protein	22.08	22.08	20.39	20.39	18.28	18.24
Lysine	1.38	1.38	1.24	1.22	1.08	1.08
Methionine	0.67	0.68	0.60	0.60	0.54	0.54
Methionine + Cystine	1.03	1.03	0.93	0.93	0.85	0.85
Threonine	0.93	0.93	0.83	0.83	0.73	0.73
Calcium	0.92	0.92	0.82	0.82	0.74	0.74
Available Phosphorus	0.46	0.46	0.41	0.41	0.37	0.37
Sodium	0.15	0.15	0.15	0.15	0.15	0.15
Potassium	0.84	0.90	0.77	0.82	0.68	0.74
Chlorine	0.17	0.17	0.16	0.29	0.15	0.15

SO: Soybean oil. Treatments in all of phases: T1) 1% SO + 1% Sodium bentonite, T2) 1% SO +0.5% Calcium lignosulfonate, T3) 1% SO + 0.5% Plant compounds (guar gum + Serish, T4) 1% SO + no pellet binder, T5) 2% SO + 1% Sodium bentonite, T6) 2% SO +0.5% Calcium lignosulfonate, T7) 2% SO + 0.5% Plant compounds (guar gum + Serish, T8) 2% SO + no pellet binder.

¹Provided the followings per kg of diet: vitamin A (trans-retinyl acetate), 12100 U; vitamin D3 (cholecalciferol), 5000 U; vitamin E (D L- α tocopherol acetate), 80 U; vitamin K (menadione), 3.20 mg; riboflavin, 8.60 mg; pantothenic acid (D-Ca pantothenate), 18.00 mg; pyridoxine (pyridoxine-HCl), 4.60 mg; thiamine, 3.20 mg; vitamin B12 (cyanocobalamin), 0.02 mg; biotin, 0.20 mg; folic acid, 2.2 mg; nicotinic acid, 60.00 mg; ethoxyquin (antioxidant), 2.5 mg. ²Provided the following per kg of diet: Fe, 20 mg; Zn, 110 mg; Mn, 120 mg; Cu, 16 mg; I, 1.25 mg; Se, 0.30 mg.

21°C and considered fixed until the end of the experiment. Relative humidity was between 60-70%. The first two days were set with a 24-hour light program followed by 18:6 hours (light: darkness).

Pellet Durability Index

Pellet durability was determined after feed manufacturing in a Holmen Pellet Tester (New Holmen

NHP100 Portable Pellet Durability Tester, TekPro Ltd., Willow Park, North Walsham, and Norfolk, UK). 100 grams of pellet samples were circulated pneumatically in a closed chamber for 30 sec before being passed through a sieve and the PDI was determined according to the Abbasi pour et al. (2021) method.

Pellet Hardness

To measure the pellet hardness, a hardness tester (Amandus Kahl, GmbH & Co. KG, Hamburg, Germany) was used (Svihus et al., 2004).

Performance

The broilers were weighed at the end of each age phase (11, 25, and 42d). The daily body weight gain (DWG), daily feed intake (DFI), and FCR were measured for each pen according to the method described by Aziz-Aliabadi et al. (2023a).

Carcass Characteristics

On day 42, two birds per replicate were selected and weighed. The killing of birds was carried out by cervical dislocation. The weights of the carcass, thigh, breast, liver, and heart were determined as the percentage of live weight.

Jejunum Morphology

Two birds from each pen were randomly chosen and euthanized by cervical dislocation on 42 d of age. The whole digestive tract was removed, and approximately 1 cm sections were obtained from the middle segment of the jejunum. The sections were fixed in 10% neutral buffered formalin solution and infixed in paraffin wax later. All histological morphometric assessments are done on 5 µm parts and hematoxylin and eosin were used to stain samples. To assess the jejunum morphology, a computer-connected optical microscope was applied to gain images of the samples, and ultimately, the villus height (VH), villus width (VW), crypt depth (CD), and the thickness of muscle layer were determined by the relevant software (Garcia et al., 2007).

Statistical Analysis

This experiment was done based on a completely randomized design (CRD) in a factorial test of 2 × 4 with two levels of SO and three types of pellet with five replications by the General Linear Model (GLM) procedure (SAS, 2012). Data normalization was done and difference between the treatments was investigated using ANOVA. Tukey's test was chosen to compare means (P<0.05).

RESULTS

Pellet Durability Index

The PDI data of starter, grower, and finisher diets at regular intervals after feed manufacturing are highlighted in Table 2. With respect to the main effects of pellet binders on the PDI of starter and grower diets, the PDI was higher in pellets containing SB and PC

during all four measurement periods (0, 15, 30, and 45 days after feed manufacturing) (P<0.05). In the starter diets, the interaction effects of SO and pellet binders on the durability of pellets were significant (P<0.05). Thereby, pellets containing 1% SO and PC (1-PC) had the most PDI, which was significantly different from treatments 1-Ca-Ls, 1-None, 2-SB, 2-Ca-Ls, and 2-None (P<0.05).

Pellet Hardness

The results of pellet hardness for starter, grower, and finisher diets at regular intervals after manufacturing (day 0, day 15, day 30, and day 45) are shown in Table 3. About the main effects of pellet binders on the pellet hardness of starter diet, the pellet hardness was higher in pellets containing SB and PC at 0 and 15 days after pellet production (P<0.05). In relation to the interaction effects of SO and pellet binders, the highest hardness was obtained in groups 1-SB, 1-PC, 2-SB, and 2-PC in 15 days after diets production, which were significantly different from other groups (P<0.05). At 30 days after feed manufacturing, a significant difference was observed between treatments 1-SB and 2-None (P<0.05). At 45 days after pellet production for finisher diet, the hardness of pellets containing SB and guar gum + Serish (PC) was significantly higher than other groups (P<0.05).

Performance

The performance data (DWG, DFI, and FCR) for the starter, grower and finisher periods are given in Table 4. Regarding the main effects of SO, during the starter period, chickens consuming diets containing 1% SO showed a better FCR (1.28) compared to the chickens consuming diets containing 2% SO (1.34) (P<0.05). About the main effects of pellet binders, during the finisher phase, broilers fed diets containing SB had more DWG and DFI (P<0.05). Regarding the interaction effects, during the starter period, the improved FCR was observed in groups 1-SB which were significantly different from others (P<0.05). During the finisher, the lowest and highest DFI was observed in groups 2-PC and 1-SB, respectively (P<0.05).

Carcass Characteristics

Carcass weight percentage and none of its components (thigh, breast, liver, and heart) were affected by experimental treatments (Table 5) (P>0.05).

Jejunum Morphology

Data on jejunal morphology are shown in Table 6. The results showed that the main effect of pellet

Table 4. Effect of different levels of oil and different types of pellet binders on the performance of broilers.

Treatments	Starter (1-10 d of age)			Grower (11-24 d of age)			Finisher (25-42 d of age)		
	DWG (g)	DFI (g)	FCR (g:g)	DWG (g)	DFI (g)	FCR (g:g)	DWG (g)	DFI (g)	FCR (g:g)
Main effects*									
SO (%)									
1	21.61	27.79	1.28 ^b	45.99	72.01	1.58	71.35	144.48	2.03
2	21.22	28.39	1.34 ^a	47.42	74.10	1.50	71.12	140.71	1.93
<i>P</i> -value	0.44	0.29	0.02	0.05	0.10	0.12	0.92	0.05	0.08
<i>SEM</i>	0.36	0.39	0.01	1.17	0.89	0.03	1.65	2.63	0.04
Pellet binders									
SB	21.96	28.24	1.29	46.75	72.92	1.58	77.42 ^a	147.05 ^a	1.90
Ca-Ls	21.54	28.74	1.33	47.76	71.94	1.51	70.57 ^b	143.57 ^{ab}	2.04
PC	21.21	27.51	1.31	48.21	73.79	1.53	68.87 ^b	134.41 ^b	1.96
None	20.96	27.87	1.31	48.08	73.57	1.54	68.06 ^b	137.35 ^b	2.02
<i>P</i> -value	0.55	0.46	0.73	0.92	0.73	0.73	0.03	0.04	0.32
<i>SEM</i>	0.50	0.56	0.02	1.66	1.26	0.04	2.33	3.72	0.05
Interaction effects*									
1-SB	20.92	27.03	1.24 ^c	46.94	72.71	1.65	76.64	149.41 ^a	1.96
1- Ca-Ls	21.98	28.70	1.30 ^b	45.94	71.58	1.56	67.66	144.04 ^{ab}	2.13
1- PC	21.90	28.48	1.33 ^{ab}	45.67	73.57	1.61	73.07	143.83 ^{ab}	1.97
1-None	21.64	28.25	1.30 ^b	47.71	70.18	1.50	68.02	140.65 ^{ab}	2.08
2- SB	22.99	30.12	1.30 ^b	48.87	73.14	1.51	78.20	144.70 ^{ab}	1.85
2- Ca-Ls	21.08	29.08	1.38 ^a	49.59	72.30	1.46	73.48	143.10 ^{ab}	1.95
2- PC	20.03	27.55	1.37 ^a	50.76	74.00	1.46	64.68	134.99 ^b	2.06
2-None	20.76	28.49	1.37 ^a	48.46	76.97	1.58	68.11	134.05 ^{ab}	1.97
<i>P</i> -value	0.06	0.90	0.01	0.82	0.22	0.28	0.20	0.04	0.77
<i>SEM</i>	0.72	0.79	0.03	2.35	1.79	0.06	3.30	5.24	0.08

^{a,c} Means within a column without a common superscript significantly differ ($P < 0.05$); DWG: daily body weight gain; DFI: daily feed intake; FCR: Feed conversion ratio; SO: Soybean oil; SB; Sodium bentonite; Ca-Ls: Calcium lignosulfonate; PC: Plant compounds (guar gum+Serish); SEM: Standard error of mean.

*Treatments: (1-SB: 1% SO + 1% SB); (1- Ca-Ls: 1% SO + 0.5% Ca-Ls); (1-PC:1% SO + 0.5% PC); (1-None:1% SO + no pellet binder); (2-SB: 2% SO + 1% SB); (2- Ca-Ls: 2% SO + 0.5% Ca-Ls); (2-PC:2% SO + 0.5% PC); (2-None:2% SO + no pellet binder).

binders on the VH and VH:CD ratio was significant ($P < 0.05$). So that the treatments containing 1% SB had the highest VH and VH:CD ratio. In the groups receiving SB, the VH was significantly higher than the PC and None groups ($P < 0.05$). In the case of the VH:CD ratio parameter, the use of SB significantly increased this ratio compared to the PC group ($P < 0.05$). Other effects were not significant ($P > 0.05$).

DISCUSSION

The benefits of feeding poultry with pelleted diets have already been confirmed by numerous studies (Abdollahi et al., 2018; 2019). Glover et al. (2016)

showed that improvement of pellet quality parameters such as PDI considerably amended the FCR during the starter and finisher phases. Excessive use of certain feed ingredients in the diet, even if they are affordable sources, is not possible because they negatively affect pellet quality. For example, the calorific value of fat can be somewhat underestimated due to the reduction in pellet quality (Rigby et al., 2018). Due to the effects of lubrication, fats reduce friction force created in the die holes and lead to a decrease in pellet quality. In addition, the high level of dietary fat can partially cover the feed particles, create a barrier for steam penetration into the particles, and

Table 5. Effect of different levels of oil and different types of pellet binders on carcass characteristics on 42 d of age.

Experimental treatments		Carcass characteristics (% of live weight)				
Main effects*		carcass	Thigh	Breast	Liver	Heart
SO (%)						
	1	66.59	27.18	24.76	2.35	0.65
	2	64.70	27.05	23.69	2.37	0.69
	<i>P</i> -value	0.07	0.86	0.15	0.87	0.27
	<i>SEM</i>	0.007	0.005	0.005	0.0006	0.0002
Pellet binders						
	SB	67.03	27.44	24.80	2.30	0.58
	Ca-Ls	64.47	27.01	23.88	2.36	0.72
	PC	64.21	27.98	24.65	2.31	0.69
	None	66.88	26.04	23.58	2.48	0.69
	<i>P</i> -value	0.11	0.32	0.59	0.45	0.06
	<i>SEM</i>	0.010	0.007	0.006	0.0008	0.0003
Interaction effects*						
	1-SB	66.85	26.14	25.59	2.20	0.54
	1- Ca-Ls	66.08	27.32	23.56	2.34	0.72
	1- PC	66.24	27.95	25.35	2.24	0.68
	1-None	67.22	27.33	24.55	2.64	0.64
	2- SB	67.23	28.74	24.01	2.40	0.61
	2- Ca-Ls	62.86	26.70	24.19	2.37	0.72
	2- PC	62.18	28.01	23.95	2.37	0.70
	2-None	66.55	24.76	22.62	2.32	0.73
	<i>P</i> -value	0.39	0.13	0.61	0.17	0.82
	<i>SEM</i>	0.014	0.010	0.011	0.0012	0.0005

SO: Soybean oil; SB; Sodium bentonite; Ca-Ls: Calcium lignosulfonate; PC: Plant compounds (guar gum+Serish); SEM: Standard error of mean. *Treatments: (1-SB: 1% SO + 1% SB); (1- Ca-Ls: 1% SO +0.5% Ca-Ls); (1-PC:1% SO + 0.5% PC); (1-None:1% SO + no pellet binder); (2-SB: 2% SO + 1% SB); (2- Ca-Ls: 2% SO +0.5% Ca-Ls); (2-PC:2% SO + 0.5% PC); (2-None:2% SO + no pellet binder).

prevent starch gelatinization and binding of feed particles to each (Salahshour et al., 2023). However, in the present study, pellet quality was not affected by SO levels, probably due to the level of SO in the diets. Fairfield (2015) also reported that adding more than 2% of fat in the mixer reduced the pellet quality in the corn-soybean meal diets. The durability of the pellet is an important factor in determining its quality, and it expresses the pellet's resistance to damage during handling, transportation, and storage (Siyal et al., 2021). In the current study, the highest PDI for starter diets found in 1-PC group were 75.83%, 73.52%, 72.28%, and 70.50% on 0, 15, 30, and 45 days after feed manufacturing, respectively. After a long period of using mineral pellet binders such

as bentonite, various organic pellet binders such as sodium carboxymethyl cellulose, modified starch and humic acid, polyacrylamide, lignin sulfonate, guar gum and molasses were developed (Claremboux and Kawatra, 2023; Zhao et al., 2023). These organic materials were more water-soluble and had higher cementitious properties, which considerably enhanced the sphericity and strength of pellets at low temperatures. Nonetheless, using more of these pellet binders reduced the rupturing temperature of the pellets and decomposes by burning after roasting at high temperatures. This reaction created residual pores in the pellets and probably reduced the durability of the pellets at high temperatures (Prusti and Barik, 2020). Karim et al. (2022) while investigating

Table 6. Effect of different levels of oil and different types of pellet binders on the jejunum morphology on 42 d of age.

Experimental treatments		Jejunum morphology characteristics				
Main effect*		Villus height (µm)	Villus width (µm)	Crypt depth (µm)	VH: CD	Muscle thickness (µm)
SO (%)						
	1	1048.60	120.39	234.65	4.63	249.66
	2	1091.61	122.94	234.52	4.67	243.91
<i>P</i> -value		0.82	0.57	0.98	0.78	0.46
<i>SEM</i>		21.84	3.14	4.09	0.10	5.36
Pellet binders						
	SB	1173.40 ^a	122.17	233.97	5.04 ^a	249.82
	Ca-Ls	1068.11 ^{ab}	119.55	232.35	4.50 ^{ab}	238.08
	PC	1058.12 ^b	122.71	237.40	4.46 ^b	248.17
	None	1052.80 ^b	122.23	234.60	4.59 ^{ab}	251.05
<i>P</i> -value		0.02	0.95	0.94	0.03	0.61
<i>SEM</i>		30.88	4.45	5.78	0.14	7.58
Interaction effects						
	1-SB	1186.55	124.07	241.55	4.94	261.41
	1- Ca-Ls	1049.81	116.66	229.25	4.60	235.22
	1- PC	1034.35	120.21	233.40	4.44	259.93
	1-None	1067.64	120.62	234.40	4.55	242.05
	2- SB	1160.30	120.27	226.39	5.14	238.24
	2- Ca-Ls	1055.78	122.45	239.50	4.41	240.95
	2- PC	1081.85	125.23	241.38	4.49	236.41
	2-None	1068.58	123.82	230.81	4.63	260.05
<i>P</i> -value		0.86	0.86	0.39	0.80	0.14
<i>SEM</i>		43.67	6.29	8.18	0.20	10.72

^{a,c} Means within a column without a common superscript significantly differ ($P < 0.05$); SO: Soybean oil; SB; Sodium bentonite; Ca-Ls: Calcium lignosulfonate; PC: Plant compounds (guar gum+Serish); SEM: Standard error of mean.

*Treatments: (1-SB: 1% SO + 1% SB); (1- Ca-Ls: 1% SO + 0.5% Ca-Ls); (1-PC: 1% SO + 0.5% PC); (1-None: 1% SO + no pellet binder); (2-SB: 2% SO + 1% SB); (2- Ca-Ls: 2% SO + 0.5% Ca-Ls); (2-PC: 2% SO + 0.5% PC); (2-None: 2% SO + no pellet binder). VH: CD: villus height to crypt depth ratio; SEM: Standard error of mean.

the effects of three starch binders (wheat gluten, pea starch, and guar gum), stated that treatments containing guar gum showed better pelletability. In the present study, for starter diet, the highest hardness of pellets was observed in 1-SB, 1-PC, 2-SB, and 2-PC groups. This shows that even with 2% fat, the pellets containing SB and PC had adequate hardness. Attar et al. (2018) showed that 2 min steam conditioning of a diet containing 15 g/kg SB enhanced the pellet durability index and hardness. Adding 2% of bentonite to diets comprising high amounts of fat is ineffective to alter PDI but with low levels

of fat (1.50 %), it improved pellet quality (Abadi et al., 2019).

In the present study, the interaction effects showed that diets containing 1% SO and SB (1-SB) showed a better FCR during the starter phase. In addition, at 10 days of age, broilers consuming diets containing 1% SO showed a better FCR (1.28) rate than diets containing 2% soybean oil (1.34). The reason for this increase can be attributed to the age of the bird, because at a young age, due to the limited capacity to produce bile and lipase, the bird has trouble digesting and absorbing fat and will not

be able to use fat sources properly (Aziz-Aliabadi et al., 2023b). Aziz-aliabadi et al. (2021) also reported that at 7 days of age, the highest body weight gain was observed in treatments without SO and tallow, while at the age of 14 days, the highest body weight was obtained in groups containing 0.5% of SO. They attributed such an effect to the age of the bird and stated that the ability of the bird to use SO increases with the age of the bird due to the development and evolution of the digestive system (Aziz-Aliabadi et al., 2021). It has been found that the addition of pellet binders to the diets improved broilers performance parameters (Subakir et al., 2021; Moradi et al., 2018a). In the present study, bentonite could significantly increase FI and BWG compared to the control. Conversely, Attar et al. (2019) stated that the use of different levels of bentonite (0.00, 7.50, 15.00 g/kg) in the broilers' diet did not affect the broilers' performance. The difference in the aluminosilicate materials used in different experiments can explain the variation in the results of the studies. Saleh et al. (2021) reported that the use of Ca-Ls decreased FCR significantly compared to the control. It can be said that dietary Ca-Ls inclusion may affect pellet quality and broilers' performance, but further experiments are needed to obtain the amount of inclusion of Ca-Ls required for optimal pellet quality and performance. It has been stated that adding soluble fiber such as pectin and guar gum to the diets reduced feed efficiency in birds (Tejeda and Kim, 2021). In our study, chickens receiving diets containing guar gum and Serish (PC group) showed a higher FCR. In line with our results, Rodrigues de Oliveira et al. (2024) also stated that the use of soluble fiber sources (citrus pulp) in the diet decreased body weight and worsened FCR. Soluble fibers inhibit nutrient absorption and impair bird performance by increasing the viscosity of digested materials in the digestive tract (Rodrigues de Oliveira et al., 2024). Hassan et al. (2013) reported that the use of guar gum (1.35%) in the diet increased the FCR at 22-35 days. This effect was attributed to the presence of beta-mannan in β -mannan in guar.

The present data showed that treatments did not influence the relative weight of carcass, thigh, breast, liver, and heart. In agreement with our results, Abdollahi and Ravindran (2014) reported that increasing pellet hardness and improving PDI had no significant effect on the thigh weight. While studying

the effect of bentonite and wheat starch on the performance of broilers, Ebrahimi et al. (2020) reported that carcass traits were not affected by the treatments.

Higher VH:CD ratio is an indicative of slower intestinal mucosal turnover, which in turn reduces the need for intestinal tissue maintenance and lead to higher nutrient digestibility and growth performance of broilers (Abadi et al., 2019). The positive effects of clays on animal performance (possibly through increased nutrient utilization and positive effects on gut physiology) has been confirmed. However, their exact mechanisms of action are not fully understood (Damato et al., 2022). In the present study, SB ameliorated intestinal (VH and VH:CD ratio) and performance (FCR and DWG) parameters. Bentonite and pelleting probably improved the villi height by providing more nutrients for villi growth and development and by increasing the retention time of digesta in the digestive tract (Abbasi Pour et al., 2021). Attar et al. (2018) also declared that the use of processed sodium bentonite (7.5 and 15 g/kg) improved significantly the VH:CD ratio in broilers.

CONCLUSIONS

It was concluded that diets containing sodium bentonite and plant compounds showed the highest pellet durability index. Despite the presence of 2% soybean oil, the pellets containing the plant compounds were able to obtain an acceptable pellet durability index and hardness, which proves the existence of a suitable pellet binder to improve the quality of the pellet. Concerning performance, birds consuming diets containing 1% soybean oil and sodium bentonite showed the lowest feed conversion ratio during the starter period. The presence of guar gum and Serish in the diets, despite the improvement of pellet quality, caused a decrease in feed consumption during the finisher phase. In addition, sodium bentonite enhanced considerably villus height and villus height to crypt depth ratio.

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CONFLICTS OF INTEREST

No potential conflict of interest was reported by the author(s).

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