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Effects of conditioning time and activated sodium bentonite on pellet quality, performance, intestinal morphology, and nutrients retention in growing broilers fed wheat-soybean meal diets

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ABSTRACT

This study was conducted to investigate the effect of two conditioning times and different levels of activated sodium bentonite (ASB) on pellet quality, pellet mill energy usage, broiler performance, internal organ weights, jejunal morphometry, and nutrients retention in wheat-soybean meal basal diets during grower period (day 11–24). During feed production, the electrical usage of the feed mill was recorded to measure relative electrical energy usage (REEU). Pelleted feed was sampled to evaluate pellet quality indices. Five hundred and forty day-old male broiler chickens (Ross 308) were received crumbled starter diet until day 10. On day 11, chickens were individually weighed and randomly placed in 36 floor pens containing 15 birds each. Birds were assigned to a completely randomised design in factorial arrangement of 2 conditioning times (2 and 4 min) × 3 ASB levels (0.0, 7.5 and 15.0 g/kg). Feed intake and weight gain were recorded to calculate performance. On day 24, the relative weight of the carcass, inner organs, and intestinal segments were measured. Jejunal segment and excreta samples were collected to study villi morphology and nutrients retention, respectively. Results showed that the interaction of 15 g/kg ASB and 2 min conditioning increased ($P < 0.05$) pellet quality and REEU. Conditioning time and ASB levels had no significant effect on performance, relative weight and length of intestinal segments, relative weight of internal organs and carcass. The interaction of 2 min conditioning time and 15 g/kg ASB increased ($P < 0.05$) villus height, villus width, and villus surface area. The interaction of 2 min conditioning and 15 g/kg ASB increased ($P < 0.05$) AME, Ca, and P retention. In conclusion, the interaction of 2 min conditioning and 15 g/kg ASB could improve pellet quality, jejunal morphometry, and nutrients retention in growing chickens fed wheat-soybean meal basal diets.

1. Introduction

The most costly index in poultry production is related to feed (approximately 60–70% of the total production cost). In addition, feed intake should be maximised to achieve the genetic potential of modern broilers (Abdollahi et al., 2019). Feed pelleting is a common strategy for increasing feed intake in broilers. Pelleting is the most prevalent hydrothermal operation in the poultry feed that increases the production cost (Nolan et al., 2010). However, the advantages of feeding pelleted diets to poultry are already proved by several studies (McKinney and Teeter, 2004; Skinner-Noble et al., 2005; Latshaw and Moritz, 2009; Abdollahi et al., 2013a, 2018; 2019). A

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previous study showed that increasing pellet inclusion from 30% to 60% and 90% in broiler diets resulted in higher feed intake (FI) and subsequently increased body weight gain (Lilly et al., 2011). Furthermore, pellet quality is an influencing factor in poultry feed processing. Kenny (2008) showed that by increasing fine particles in pellets (50 and 100 %) in both corn or wheat basal diets, chickens gained lower weight (4.5% and 19%, respectively) and higher feed to gain ratio (2.2% and 6.1%, respectively) than those received a good pellet quality diet. Therefore, the pelleting process is not the only index for improving broiler performance and pellet quality needs to be considered (Briggs et al., 1999). Reimer (1992) showed that the pellet quality is dependent on different factors including diet formulation (40%), particle size (20%), conditioning (20%), die specifications (15%), and cooling and drying processes (5%).

Steam-conditioning of dry mash feeds for a specific time before pelleting is a major step in the pelleting process. Prior to the conditioning, the main factors, such as steam, pressure, temperature, and retention time in conditioner, must be optimised (Skoch et al., 1981; Abdollahi et al., 2010a, 2010b; 2011). It has been reported that higher conditioning temperatures (i.e. > 80°C) than that of its optimised temperature reduced weight gain and increased feed to gain ratio (Bedford et al., 2003; Creswell and Bedford, 2006; Kirkpinar and Basmacioglu, 2006). Plattner (2002) demonstrated that longer conditioning time (> 4 min) allowed moisture penetration into the feed facilitated hydration and heat transfer to be more uniform. Briggs et al. (1999) suggested that pellet durability index (PDI) improves (average 4.5%) as a consequence of higher retention time of the mash diet inside the steam conditioner and by changing mixing paddle pitch. Massuquetto et al. (2018) reported that PDI and pellet hardness were increased by increasing conditioning time (0 up to 80 s).

Abdollahi et al. (2013a) reported that pellet binders improve pellet quality. Preconditioning and adding water, molasses, lignin sulphonate, and sodium bentonites are common pellet binders in poultry industry (Blakely et al., 1955; Young and Pfost, 1962; Abdollahi et al., 2012; Attar et al., 2017, 2019; Moradi et al., 2018). Sodium bentonite is a tri-layered aluminosilicate clay having exchangeable cations which absorbs more water than those of other aluminosilicate clays (Onal, 2006). Moradi et al. (2018) indicated that the inclusion of 20 g/kg sodium bentonite in the corn-soybean meal based diet in the starter and finisher periods enhanced PDI and

Table 1
Composition of experimental grower diets (11-24 days of age) fed to broiler chickens.

Ingredient (g/kg)	Control	ASB (7.5 g/kg)	ASB (15 g/kg)
Wheat	597.2	597.2	597.2
Soybean meal (CP, 440 g/kg)	317.8	317.8	317.8
Soybean oil	26.8	26.8	26.8
Di-calcium phosphate	14.5	14.5	14.5
Limestone	8.7	8.7	8.7
Salt	2.2	2.2	2.2
Sodium bicarbonate	2.4	2.4	2.4
Mineral-vitamin premix[1]	5.0	5.0	5.0
DL-Methionine	2.7	2.7	2.7
L-Lysine HCl	1.6	1.6	1.6
L-Threonine	0.6	0.6	0.6
Enzyme[2]	0.5	0.5	0.5
Sand[3]	20.0	12.5	5.0
ASB[4]	0.0	7.5	15.0
Calculated nutrients (g/kg)			
AME (kcal/kg)	2800	2800	2800
Crude protein	208.5	208.5	208.5
Crude fiber	40.0	40.0	40.0
Crude fat	43.7	43.7	43.7
Calcium	7.85	7.85	7.85
Available phosphorus	3.92	3.92	3.92
Sodium	1.76	1.76	1.76
Chlorine	1.76	1.76	1.76
Methionine	5.5	5.5	5.5
Methionine + cysteine	8.94	8.94	8.94
Lysine	11.65	11.65	11.65
Threonine	7.94	7.94	7.94
Analysed nutrients (g/kg)			
Crude protein	209.1	209.4	208.7
Crude fat	42.5	44.4	43.1
Calcium	7.65	8.00	7.78

[1] Added per kg of feed: vitamin A, 9000 IU; vitamin D3, 5000 IU; vitamin E, 50 IU; vitamin K3, 3 mg; thiamine, 2 mg; riboflavin, 6 mg; pyridoxine, 3 mg; cyanocobalamin, 0.016 mg, pantothenic acid, 15 mg; folic acid, 1.75 mg; biotin, 0.1 mg; iron, 40 mg; zinc, 100 mg; manganese, 120 mg; copper, 16 mg; iodine, 1.25 mg; selenium, 0.3 mg.

[2] Endofeed W (GNC Bioferm Inc., Bradwell, Saskatchewan, Canada).guaranteed analysis: Beta-Glucanase (minimum), 700 unit per gram; Xylanase (minimum), 2250 unit per gram.

[3] Soft sand as filler.

[4] ASB: activated sodium bentonite (G.Bind™) is a sodium bentonite which has been undergone basic process in Paya Farayand H.N. Co. Mashhad, Iran and is commercially available.

hardness. Abdollahi et al. (2012) reported that the addition of pellet binder to diet conditioned at 90°C increased PDI and pellet hardness and subsequently increased weight gain and FI and improved feed to gain ratio of chickens when compared to those conditioned at 90°C without pellet binder. High conditioning temperature (i.e. 90°C) improved physical pellet quality, but it had a negative effect on nutrient availability in broilers (Moritz and Lilly, 2010; Abdollahi et al., 2012). Attar et al. (2017, 2019) showed that conditioning a corn-soybean meal based diet containing 15 g/kg processed sodium bentonite for 2 min at 70°C had no effect on performance of broilers during grower and finisher periods. However, they revealed that conditioning a diet containing 15 g/kg processed sodium bentonite for 2 min increased PDI and pellet hardness, decreased electrical energy usage of pelleting process, and improved nutrients retention (Attar et al., 2017, 2019). Although several previous studies separately examined the effects of binders and conditioning process in the poultry industry, scarce information is available on the effects of binders and conditioning time in wheat-soybean meal based diets on pellet quality and broiler performance. Therefore, the current experiment was conducted to study the effects of different conditioning times and selected sodium bentonite levels on energy consumption of pellet mill process, pellet quality, performance, digestive tract development and morphology and nutrients retention in male broiler chickens fed wheat-soybean meal based diets in grower period (11–24 day).

2. Materials and methods

2.1. Experimental diet preparation

Treatments were assigned in a completely randomised design with a factorial arrangement of 2 conditioning time (2 and 4 min) × 3 levels of activated sodium bentonite (ASB: 0, 7.5 and 15 g/kg). Physicochemical characteristics of ASB were tested and reported previously (Nazparvar soufiani et al., 2016). Diets were formulated based on the Ross 308 recommendations (2019) for the growing period (11–24 d). Diets were diluted by 10% with sand to prepare optimum conditions for pelleting wheat-soybean meal based feed. The composition of experimental grower diets is shown in Table 1. All ingredients were ground through a 2-mm screen size in a hammer mill (Asiab Co., Tehran, Iran), mixed in a double-shaft paddle mixer (Venver, Vilanova del Camí, Spain), and then divided into the two equal batches. Two batches were conditioned at 70°C, one for 2 and the other for 4 min in a super conditioner (Stolz, Paris, France) and then pelleted through a 3-mm die using a pellet mill (Model 660.228, Manufacturing Co., Munch, Germany).

2.2. Pellet quality

All feed samples were collected after pelleting process to assess pellet durability index (PDI) and pellet hardness. PDI was measured at different time intervals (30, 60, 90, and 120 s) using a Holmen Pellet Tester (New Holmen NHP100 Portable Pellet Durability Tester, TekPro Ltd., Willow Park, North Walsham, Norfolk, UK) as described by Abdollahi et al. (2012). Pellet hardness was evaluated using a hardness tester machine (Amandus Kahl, GmbH & Co. KG, Hamburg, Germany) as described by Svihus et al. (2004). Relative electrical energy usage (REEU) of the pellet mill motor was recorded when different experimental diets passed through the pellet mill machine and the REEU calculated using the formula described by Payne et al. (2001):

$$\text{REEU (kWh/ton)} = (\text{A} \times \text{voltage} \times \sqrt{3} \times \text{power factor})/1000 \text{ kg of feed}$$

kWh was kilowatt per hour, A is the amperage of the pellet mill motor, and the power factor was set at 0.93.

2.3. Birds and housing

All experimental procedures were approved by the Ferdowsi University of Mashhad Animal Care and Use Committee (protocol No. 3/30167).

A total of 540 day-old male chicks (Ross, 2019) were purchased from a commercial hatchery and placed on floor pens (1 m × 1.3 m) covered with wood shavings. At the starter phase (days 0–10), birds were fed with a standard starter crumbled feed. During the growing period (days 11–24), chicks fed the pelleted experimental diets (Table 1). On day 11, all the birds were individually weighed and allocated to 6 treatments of 6 replicates containing 15 birds in each replication. The temperature was at 31°C on placement day and gradually decreased to 22°C by day 24. Birds had free access to feed and water throughout the study. The lighting program was set to 23 L:1D throughout the experimental periods.

2.4. Growth performance

Live body weight and feed consumption were recorded per pen on days 11 and 24 to calculate performance attributes. If any, mortality was recorded daily for each pen to adjust the performance data accordingly. Feed conversion ratio (FCR) was corrected for the gained weight of the dead birds.

2.5. Carcass characteristics, relative weight and length of small intestinal segments

On day 24, two birds per pen were randomly selected, weighed, and euthanised by cervical dislocation. The skinless carcass percentage and the empty weight of inner organs, abdominal fat pad, and weights of thigh and breast relative to live body weight were measured. The length and weight of various segments of the small intestine were measured and expressed as relative to live body weight. The small intestine was carefully cleaned, emptied from the remaining digesta, and dissected into the duodenum (from the pyloric junction to the duodenal mesentery), jejunum (from the duodenal mesentery to the Meckel`s diverticulum), and ileum (from Meckel's diverticulum to the ileocecal junction).

2.6. Villi morphology of jejunum

Intestinal morphometry samples were prepared by a method described by Daneshmand et al. (2017). Briefly, 2 cm from the midpoint section of each jejunal sample was taken, cleaned with phosphate-buffered saline (PBS), and kept in 10% neutral formalin for 48 h for fixation. The samples were embedded in paraffin, sectioned at 5 μm, mounted on slides, and stained with haematoxylin and eosin. Five slides were prepared from each jejunal sample, and ten well-oriented villi were measured in each slide (50 villi per bird). Slides were analysed using an optical microscope (Carl Zeiss, Oberkochen, Germany). The prepared slides were evaluated for villus height (VH), villus width (VW), crypt depth (CD), villus height to crypt depth ratio (VH/CD), and villus surface area (VSA).

2.7. Nutrient retention measurement

The total collection method was used to determine the apparent retention of nutrients. Briefly, three birds per pen were moved to individual cages on day 19 and fed experimental diets for two days (19–20). On day 21, the birds were subjected to 8 h of starvation. The cleaned trays were placed under each cage to collect excreta samples. Excreta samples were collected and weighed twice daily from day 21 to day 24. Daily collections were immediately dried, pooled within a cage, weighed, ground through a 0.5-mm sieve, and stored in airtight plastic containers (−20°C) until laboratory analysis. Feed intake of the birds in each cage was recorded during the excreta collection period. Dry matter (DM), crude protein (CP), ether extract (EE), calcium (Ca), and total phosphorus (P) content of excreta and diet samples were analysed by method of 934.01, 976.06, 954.02, 978.02 and 946.06, respectively, according to the standard procedures of the Association of Official Analytical Chemists (AOAC, 2005).

Apparent total tract retention coefficients in the dietary treatments were calculated as described by Dilger and Adeola (2006) using the following formula (Adeola, 2001):

$$\text{Apparent nutrient retention coefficient (\%)} = (\text{total ingested nutrient} - \text{total excreta nutrient/ total ingested nutrient}) \times 100$$

Feed and excreta samples were ignited in an adiabatic bomb calorimeter (C5003 ika, GMBIT Co., Staufen, Germany) to assess gross energy based on the method explained by Harjo and Teeter (1994). The apparent metabolisable energy was calculated by the following formula:

$$\text{AME (kcal/kg diet)} = [(\text{DFI} \times \text{GE diet}) - (\text{dry Excreta output} \times \text{GE excreta})]/\text{DFI}$$

Table 2
Effects of conditioning time and dietary supplementation of activated sodium bentonite (ASB) on pellet durability index (PDI) measured at different time periods, hardness and relative electrical energy usage (REEU).

Interaction effects		PDI (%)				Hardness (kg)	REEU (kWh/ton)
Conditioning time (min)	ASB (g/kg)	30 s.[1]	60 s.	90 s.	120 s.		
	0.0	77.3[b]	50.4[b]	43.9[b]	38.6[b]	4.00[b]	16.3[a]
2	7.5	71.2[b]	52.7[b]	41.0[b]	31.2[b]	3.90[b]	14.5[b]
	15.0	86.5[a]	76.7[a]	66.8[a]	50.0[a]	6.80[a]	16.2[a]
	0.0	73.3[b]	56.1[b]	45.7[b]	35.2[b]	3.70[b]	13.4[c]
4	7.5	77.4[b]	58.7[b]	41.0[b]	33.2[b]	4.30[b]	12.9[c]
	15.0	75.0[b]	59.4[b]	45.6[b]	36.0[b]	4.80[b]	12.9[c]
SEM[2]		1.77	2.17	2.54	2.12	0.294	0.25
Main effects							
Conditioning time (min)							
2		78.3	59.9	50.5	39.9	4.90	15.7
4		75.2	58	44.1	34.8	4.26	13.1
SEM		1.02	1.25	1.47	1.22	0.169	0.14
ASB level (g/kg)							
0.0		75.3	53.2	44.8	36.9	3.85	14.9
7.5		74.3	55.7	41.0	32.2	4.10	13.7
15.0		80.7	68.1	56.2	43.0	5.80	14.5
SEM		1.25	1.54	1.80	1.50	0.208	0.18
P-value							
Conditioning time		0.053	0.012	0.009	0.008	0.014	0.001
ASB level		0.712	0.445	0.285	0.075	0.122	0.006
Conditioning time × ASB level		0.001	0.001	0.001	0.001	0.001	0.011

[a-c] Means in each column with different superscripts are significantly different (P< 0.05).
[1] Sec.: seconds.
[2] SEM: standard error of means.

Where AME is apparent metabolisable energy, DFI is dried feed intake, and GE is gross energy.

2.8. Data analysis

Data were analysed as a 2 (conditioning times) × 3 (ASB levels) factorial arrangement using two-way ANOVA of the General Linear Model procedure of SAS (2004) to evaluate the main effects and 2-way interactions. Differences between means were compared with Tukey's test, and $P < 0.05$ was considered significant.

3. Results

3.1. Pellet quality and relative electrical energy usage

The effects of conditioning time and ASB levels in the diet on pellet quality (PDI and hardness) and REEU are shown in Table 2. Diets containing 15 g/kg ASB and conditioned for 2 min had higher ($P < 0.05$) PDI (in different time intervals) and hardness than those of other treatments. Diets conditioned for 2 min and contained 0 or 15 g/kg ASB had higher ($P < 0.05$) energy consumption for pelleting than those of other treatments, while 4 min conditioning time in all ASB levels showed the lowest REEU index ($P < 0.05$).

3.2. Growth performance

The results of the present study showed growth performance parameters (Table 3) were not affected ($P > 0.05$) by conditioning time and ASB levels in both main and interaction effects during 11–24 days of age.

3.3. Relative weight and length of intestinal segments

The effects of dietary ASB levels and conditioning times on relative weight and length of intestinal segments are summarised in Table 4. No significant effects on relative weight and length of intestinal segments were observed ($P > 0.05$).

3.4. Carcass characteristics and relative weight of internal organs

The effect of conditioning times and ASB levels on carcass characteristics and relative weight of some internal organs are shown in Table 5. These parameters were not affected by conditioning times and inclusion rate of ASB in the diet in any main or interaction effects. However, breast yield numerically showed an increasing trend ($P > 0.055$) in the birds fed diets containing 15 g/kg ASB when compared to those of other treatments.

Table 3
Effect of conditioning time and dietary supplementation of activated sodium bentonite (ASB) on performance parameters in broiler chickens during 11-24 days of age.

Interaction effects				
Conditioning time (min)	ASB (g/kg)	ADG[1] (g)	ADFI (g)	FCR
	0.0	79.3	91.7	1.15
2	7.5	74.8	89.1	1.19
	15.0	76.0	87.1	1.14
	0.0	76.4	88.6	1.16
4	7.5	76.5	91.0	1.19
	15.0	79.6	92.2	1.15
SEM[2]		0.91	1.28	0.009
Main effects				
Conditioning time (min)				
2		76.7	89.3	1.16
4		77.5	90.6	1.17
SEM		1.33	1.90	0.012
ASB level (g/kg)				
0.0		77.8	90.2	1.15
7.5		75.6	90.1	1.19
15.0		77.8	89.6	1.15
SEM		1.62	2.33	0.015
P-value				
Conditioning time		0.677	0.631	0.853
ASB level		0.552	0.986	0.174
Conditioning time × ASB level		0.349	0.461	0.980

Means in each column with no superscripts are not significantly different ($P > 0.05$).
[1] ADG: average daily gain; ADFI: average daily feed intake; FCR: feed conversion ratio.
[2] SEM: standard error of means.

Table 4
Effect of conditioning time and dietary supplementation of activated sodium bentonite (ASB) on relative empty weight and length of different segments of small intestine in broiler chickens measured at 24 day of age.

Interaction effects		Relative to live body weight (g/kg)			Relative length (cm/kg live body weight)		
Conditioning time (min)	ASB (g/kg)	Duodenum	Jejunum	Ileum	Duodenum	Jejunum	Ileum
	0.0	11.4	25.8	23.4	17.41	40.35	42.23
2	7.5	10.7	23.9	21.4	16.45	41.08	42.46
	15.0	10.6	26.2	23.1	16.83	41.93	41.23
	0.0	11.9	26.6	22.8	17.30	41.31	41.38
4	7.5	10.3	25.9	23.4	16.29	42.89	40.81
	15.0	11.0	27.4	27.1	13.50	39.00	47.49
SEM[1]		0.53	2.18	2.14	1.195	1.192	2.134
Main effects							
Conditioning time (min)							
2		10.9	25.3	22.6	16.90	41.12	41.97
4		11.1	26.6	24.4	15.70	41.07	43.23
SEM		0.31	1.25	1.23	0.690	0.688	1.232
ASB level (g/kg)							
0.0		11.6	26.2	23.1	17.36	40.83	41.80
7.5		10.5	24.9	22.4	16.37	41.99	41.63
15.0		10.8	26.8	25.1	15.17	40.46	44.36
SEM		0.37	1.54	1.52	0.845	0.843	1.510
P-value							
Conditioning time		0.685	0.457	0.298	0.229	0.956	0.477
ASB level		0.086	0.699	0.447	0.202	0.421	0.370
Conditioning time × ASB level		0.658	0.963	0.563	0.317	0.123	0.142

Means in each column with no superscripts are not significantly different ($P > 0.05$).
[1] SEM: standard error of means (means of 6 replicates).

3.5. *Villi morphology*

The effects of ASB inclusion levels and conditioning times on morphological characteristics of jejunal villi are shown in Table 6. Birds fed diets conditioned for 2 min and contained 15 g/kg of ASB had higher villus height and villus width than those fed other dietary treatments ($P < 0.05$). Birds fed diet conditioned for 4 min with no ASB had the highest ($P < 0.05$) CD, whereas the highest VSA was observed in the birds fed diets conditioned for either 2 or 4 min and contained 15 g/kg ASB ($P < 0.05$). Inclusion of ASB (7.5 and 15 g/kg) into the diets increased VH/CD ratio of birds when compared to those with no ASB in their diet ($P < 0.05$).

3.6. *Nutrients retention*

The effects of conditioning time and ASB levels on nutrients retention in broiler chickens during 21–24 days of age are summarised in Table 7. Inclusion of ASB (7.5 and 15 g/kg) increased ($P < 0.05$) AME of diets conditioned for 2 min, while 4 min conditioning time and 15 g/kg ASB decreased ($P < 0.05$) diet AME. Higher ($P < 0.05$) Ca retention was observed in the diet containing 15 g/kg ASB and conditioned for 2 min. Birds fed a diet conditioned for 2 min and contained 15 g/kg ASB showed the highest P retention ($P < 0.05$). Chickens fed the diets conditioned for 2 min showed the highest DM and CP retention than those conditioned for 4 min.

4. Discussion

The findings of this study showed that better physical quality of wheat-soy pelleted diets was attributed to the inclusion of 15 g/kg pellet binder and conditioning for 2 min. Previous studies showed the positive effects of increasing conditioning time (Maier and Briggs, 2000; Briggs et al., 1999) and temperature on the physical quality of pellet in wheat-soybean meal (Abdollahi et al., 2010a, 2011), corn-sorghum (Abdollahi et al., 2010b), and barley–wheat–soybean meal diets (Spring et al., 1996). In agreement with the present study, the positive effects of bentonites on the physical quality of pellets have been well-documented (Pfost, 1963; Abdollahi et al., 2012; Moradi et al., 2018). Moradi et al. (2018) reported that 10 and 20 g/kg sodium bentonite in corn-based diet improved PDI in starter and finisher diets, whereas 20 g/kg sodium bentonite increased pellet hardness in the finisher period compared to control diet. In another study, the addition of Na or Ca bentonite to pelleted turkey diets improved PDI (Almquist et al., 1967). Abdollahi et al. (2012) reported that the addition of 24 g moisture/kg in a wheat-based starter diet, individually or in combination with a 3 g/kg pellet binder, conditioned at 60°C not only enhanced PDI and pellet hardness but also resulted in more durable pellets than that of the diet conditioned at 90°C without pellet binder. Similar to the current results, Attar et al. (2017; 2019) showed that the inclusion of 15 g/kg processed sodium bentonite in a corn-based grower and finisher diets conditioned for 2 min improved PDI and pellet hardness. The increasing retention time of mash feed inside the steam conditioner may distribute moisture and heat more uniformly in the feed (Plattner, 2002) and subsequently improves pellet quality. Bentonites are used as pellet binder in commercial diets due to their strong colloidal properties and water holding capacity resulting in swelling and a manifold increase in volume (Moran, 1989), and giving rise to a thixotropic gelatinous substance (Pasha et al., 2008). Wheat has high concentrations of gluten proteins and pentosan/hexosan

Table 5
Effect of conditioning time and dietary supplementation of activated sodium bentonite (ASB) on relative weight of internal organs and skinless body parts in broiler chickens measured at 24 day of age.

Interaction effects		Relative to live body weight (g/kg))									
Conditioning time (min)	ASB (g/kg)	carcass	thigh	breast	proventriculus	gizzard	liver	pancreas	heart	spleen	abdominal fat
2	0.0	586	176	216	4.6	15.3	28.8	3.5	6.5	1.1	8.7
	7.5	622	178	274	4.9	14.4	26.6	3.4	6.4	1.0	9.6
	15.0	618	180	238	5.1	15.5	26.8	3.1	5.9	1.2	9.7
4	0.0	600	173	234	4.8	16.0	29.9	3.3	6.6	1.1	7.2
	7.5	617	172	239	4.7	16.1	29.0	3.0	6.3	1.0	9.3
	15.0	524	176	238	4.7	14.4	27.9	3.1	6.3	1.1	8.8
SEM[1]		39.6	4.3	12.8	0.23	0.74	1.06	0.19	0.38	0.09	0.83
Main effects	Conditioning time (min)										
2		609	178	243	4.9	15.1	27.4	3.3	6.3	1.1	9.3
4		580	173	237	4.7	15.5	28.9	3.1	6.4	1.0	8.4
SEM		22.9	2.4	7.4	0.13	0.43	0.61	0.11	0.22	0.05	0.48
ASB level (g/kg)											
0.0		593	174	225	4.7	15.6	29.4	3.4	6.5	1.1	8.0
7.5		619	175	257	4.8	15.2	27.8	3.2	6.4	1.0	9.5
15.0		571	178	238	4.9	15.0	27.3	3.1	6.1	1.1	9.2
SEM		28.0	3.0	9.0	0.16	0.53	0.75	0.14	0.27	0.07	0.59
P-value											
Conditioning time		0.377	0.174	0.603	0.552	0.466	0.083	0.339	0.711	0.538	0.213
ASB level		0.485	0.726	0.055	0.642	0.657	0.147	0.365	0.531	0.831	0.176
Conditioning time × ASB level		0.358	0.944	0.126	0.333	0.160	0.769	0.675	0.729	0.831	0.787

Means in each column with no superscripts are not significantly different ($P > 0.05$).

[1] SEM: standard error of means (means of 6 replicates).

Table 6
Effect of conditioning time and dietary supplementation of activated sodium bentonite (ASB) on jejunal morphology in broiler chickens measured at 24 day of age.

Interaction effects						
Conditioning time (min)	ASB (g/kg)	villus height (μm)	villus width (μm)	crypt depth (μm)	VH/CD	VSA (μm[2])
	0.0	737[c]	171[b]	214[b]	3.4	395[c]
2	7.5	917[b]	182[b]	204[b]	4.5	526[c]
	15.0	1076[a]	319[a]	231[b]	4.6	902[a]
	0.0	900[b]	237[b]	291[a]	3.1	670[b]
4	7.5	794[c]	207[b]	203[b]	4.0	519[c]
	15.0	902[b]	236[b]	249[ab]	3.6	798[ab]
SEM[2]		19.0	14.9	11.7	0.31	43.0
Main effects						
Conditioning time (min)						
2		910	224	216	4.2	608
4		865	227	248	3.6	662
SEM		10.9	8.6	6.7	0.17	24.8
ASB level (g/kg)						
0.0		818	204	253	3.2[b]	533
7.5		856	195	203	4.2[a]	522
15.0		989	278	240	4.1[a]	850
SEM		13.5	10.6	8.2	0.22	30.4
P-value						
Conditioning time		0.0002	0.002	0.004	0.453	0.001
ASB level		0.001	0.007	0.001	0.007	0.004
Conditioning time × ASB level		0.001	0.002	0.011	0.438	0.001

[a-c]Means in each column with different superscripts are significantly different ($P< 0.05$).
[1]VH: villus height; CD: crypt depth; VH/CD: villus height to crypt depth ratio; VSA: villus surface area (Daneshmand et al., 2017).
[2] SEM: standard error of means (means of 6 replicates).

Table 7
Effect of conditioning time and dietary supplementation of activated sodium bentonite (ASB) on nutrients retention in broiler chickens measured during 21-24 days of age.

Interaction effects							
Conditioning time (min)	ASB (g/kg)	AME[1] (kcal/kg)	DM (%)	CP (%)	EE (%)	Ca (%)	P (%)
	0.0	3091[bc]	68	62	82	24[c]	54[ab]
2	7.5	3242[ab]	69	64	82	40[ab]	55[ab]
	15.0	3294[a]	75	70	89	49[a]	65[a]
	0.0	2940[c]	66	61	81	28[c]	59[ab]
4	7.5	3075[bc]	63	59	81	21[c]	45[b]
	15.0	2842[d]	63	59	80	39[b]	49[b]
SEM[2]		42.7	2.7	3.29	3.9	.4	4.0
Main effects							
Conditioning time (min)							
2		3209	71[a]	65[a]	84	38	58
4		2952	64[b]	60[b]	80	29	51
SEM		49.2	1.5	1.8	2.2	3.1	2.3
ASB level (g/kg)							
0.0		3015	67	62	81	26	56
7.5		3158	66	61	82	31	50
15.0		3068	69	645	84	44	57
SEM		30.2	1.9	2.3	2.7	2.2	2.8
P-value							
Conditioning time		0.001	0.013	0.044	0.259	0.006	0.008
ASB level		0.001	0.507	0.575	0.706	0.003	0.210
Conditioning time × ASB level		0.001	0.212	0.281	0.540	0.009	0.041

[a-d] Means in each column with different superscripts are significantly different ($P< 0.05$).
[1] AME: apparent metabolisable energy; DM: dry matter; CP: crude protein; EE: ether extract; Ca: calcium; P: total phosphorous.
[2] SEM: standard error of means (means of 6 replicates).

hemicellulose contents and has a higher dough forming capability than that of corn which acts as a natural pellet binder (Jensen, 2000). However, wheat has a lower energy content than corn. Therefore, more oil inclusion, especially during the grower and finisher periods, is needed to meet the energy requirement of broilers in a wheat-based diet. High dietary inclusion of fat and oils leads to lower pellet quality due to reduced friction force in the die holes (Abdollahi et al., 2013a).

Winowiski (1998) reported a longer retention time in conditioner enhanced moisture content of pelleted feed and consequently decreased pellet quality indices, which was in agreement with the results of the current study with 4 min conditioning time. Mortiz et al. (2003) and Abdollahi et al. (2012) showed that the addition of 25 and 50 g/kg water in a corn-based diet and 24 g/kg moisture in a wheat-based diet reduced starch gelatinisation and resulted in lower pellet quality indices. Based on the published data, it might be assumed that 4 min conditioning time increased moisture content of the feed and hence, decreases feed retention time in the die holes and therefore, less heat friction produced in the holes of the die decreases starch gelatinisation that finally decreases physical pellet quality, which is confirmed by reduced REEU in diets conditioned for 4 min in the current study. A significant decrease for REEU was observed by diets containing 7.5 g/kg ASB and conditioned for 2 min. The result of the current study was not consistent with the results of Attar et al. (2017, 2019), who showed that the interaction effect of conditioning time and level of processed sodium bentonite was not significant for REEU in the corn-based grower and finisher diets. This contradiction may be explained by differences in wheat- or corn-based diets.

The outcomes of the present study indicated that dietary treatments did not have a significant effect on growth performance parameters. The positive effect of physical pellet quality on birds performance has been well-documented (Kenny, 2008; Lilly et al., 2009; Abdollahi et al., 2012). In agreement with the recent findings, Attar et al. (2017) reported that feed conditioned for 2 min and contained 15 g/kg processed sodium bentonite significantly improved PDI and pellet hardness, but birds performance was not affected by dietary treatments during 11–24 days of age. In another study (Massuquetto et al., 2018), chickens' performance was similar when diets conditioned for 60, 80, 100, and 120 s.

Our study showed that conditioning time and ASB levels had no effects on the weight and length of different segments of the small intestine and relative weight of internal organs. Abdollahi et al. (2010a) showed increasing conditioning temperature from 60°C to 90°C enlarged the length of the small intestine in broiler chicks during the starter period. In a corn-soybean meal diet, the relative length of jejunum decreased in the chickens fed diet conditioned for 2 min and contained 15 g/kg processed sodium bentonite, while other parts of the small intestine was not affected (Attar et al., 2019).

Based on the literature, studies on the effect of conditioning factors (time or temperature) and sodium bentonite on intestinal morphology are limited. It was shown that villus height and crypt depth in both the duodenum and jejunum were increased by steam conditioning (Amerah et al., 2007). Zang et al. (2009) reported that pelleted diets improved VH and VH/CD compared to mash diet in chickens. These changes might be a general response of the digestive and absorptive capacity of the gut to the greater load of nutrients in the steam conditioned feed (Zaefarian et al., 2016). The observed improvement in VSA, VH, and VW in the current study might be related to both the conditioning process and the inclusion of ASB through providing more nutrients for growth and development of villi by feed processing and longer retention time of digesta in the gut (Amerah et al., 2007; Zang et al., 2009). The observed improvement of AME, Ca, and P retention in the present study by 2 min conditioning time and 15 g/kg ASB may relate to longer retention time of digesta in the gut. Pasha et al. (2008) suggested that the presence of bentonites in diet might delay feed passage time and improve nutrient metabolism resulted in a higher VH/CD, which is similar to the results of the current study in birds fed diets containing 7.5 and/or 15 g/kg ASB.

Published data on the effects of steam conditioning on the nutrient digestibility of wheat-based diets for broiler chickens have been somewhat inconsistent. Lundblad et al. (2009) showed that conditioning broiler chicken diets containing wheat, fish meal, and soybean meal resulted in more starch digestibility compared to the unconditioned feed. The increased AME from 11.6 to 11.8 MJ/kg in a steam conditioned wheat-based diet was observed (Svihus et al., 2004). In contrast, adverse effects of steam conditioning on some nutrients retention such as nitrogen-corrected AME (Amerah et al., 2007), starch (Svihus, 2001; Svihus and Hetland, 2001; Zimonja et al., 2007), starch, AME, and N (Abdollahi et al., 2011), starch, AME, fat, N, Ca, and P (Abdollahi et al., 2013b) were reported. In another study, Hussar and Robblee (1962) revealed that pelleting had no effect on AME and energy retention of wheat–oats–soybean meal diets. Pelleted feed dissolves in the crop immediately after ingestion, but the disappearance rate of pellets can be different by their size and hardness (Nir et al., 1995). Thus, the improvements in AME, Ca, and P retention in the birds fed diets conditioned for 2 min and contained 15 g/kg ASB in the present study could be explained, in part, by improved PDI and pellet hardness in these diets overcoming the negative effects of steam conditioning. It has been revealed that harder and more durable pellets remain for a longer time in the digestive tract, especially in the gizzard, and provide a better chance for substrates to mix with digestive enzymes (Abdollahi et al., 2013c) resulted in improvement of nutrients retention. Massuquetto et al. (2018) demonstrated a positive correlation between pellet durability and energy retention values. In agreements with the results of the current study, Parsons et al. (2006) indicated that offering hard texture pellets to broilers increased N and lysine retention compared to those fed soft pellets. Diets conditioned for 2 min significantly increased DM and CP retention compared to those conditioned for 4 min. Although previous studies did not consider the effect of conditioning time, some similarities can be found between the present and past findings (Abdollahi et al., 2011, 2013a). Previous research showed that increasing conditioning temperatures from 60 and 75°C–90°C in wheat-based diets reduced apparent ileal nitrogen retention. Since the Maillard reaction occurs in high processing temperatures, it was speculated that impaired N retention at 90°C might be due to the formation of Maillard products (Thomas et al., 1998). In the present study, a possible reason for the deteriorated nutrient retention in birds fed diet conditioned for 4 min at 70°C might be related to the formation of Millard products.

5. Conclusion

The present study demonstrated that diet conditioned for 2 min and contained 15 g/kg ASB impoved physical pellet quality which may subsequently enhance VSA, VH, and VW in the jejunum and consequently affect retention of AME, Ca, and P, but had no effect on broiler chickens performance. A positive correlation between harder and more durable pellets and nutrients retention was observed. Therefore, more attention should be taken to PDI value and pellet hardness in the wheat-based diet.

Declaration of Competing Interest

The authors report no declarations of interest.

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