Performance and Carcass Components of Broilers Fed on Different Proportions of Maize and Dry Roasted Barley

Seid Ali[1*], Negassi Ameha[2], and Mengistu Urge[2]

[1]School of Animal and Range Sciences, Hawassa University, P.O. Box 05, Hawassa, Ethiopia
[2]School of Animal and Range Sciences, Haramaya University, P.O. Box 138, Dire Dawa, Ethiopia

Abstract

Background: Barley grain contains more protein and ash than maize. However, it is inherently high in β-glucans which are poorly utilized by poultry. Dry roasting could be a relatively inexpensive method to reduce the associated negative effects of β-glucans on poultry performance.

Objective: This study was conducted to investigate the effect of dry roasting on proximate composition and β-glucan content of barley and evaluate growth performance, and carcass parameters in broiler chickens fed maize-based diets substituted with graded levels of barley.

Material and methods: The experiment was conducted on 168 unsexed day-old broiler chickens (Cobb 500) reared to 56 days of age. The chickens were randomly assigned to four dietary treatments (T_1 - maize-based control diet, and experimental diets where maize was replaced with dry roasted barley at 33.3% - T_2, 66.7% -T_3 and 100% - T_4). Feed intake was recorded daily for each pen and body weight changes were measured weekly. Four randomly selected broilers per pen were slaughtered and eviscerated to determine carcass parameters at the end of the experiment. Average daily gain (ADG), feed conversion ratio (FCR) and mortality were computed for each phase of feeding.

Results: The results of chemical analysis revealed that dry roasting reduced the β-glucan content in row barley (83.2 g kg^{-1}) to 18.5 g kg^{-1}. The daily feed intakes of broilers in T_4 (100% roasted barley) was lower ($P < 0.01$) than those broilers fed T_3, T_2, and the control diet. The ADG of broilers on diet containing 100% roasted barley was significantly lower ($P < 0.01$) than the rest during the finisher phase. However, broilers in all treatments had similar ADG for the starter phase as well as the entire experimental period. The final body weights of broilers at day 56 were 2213.47 g (T_1), 2200.77 g (T_2), 2116.30 g (T_3) and 2019.17 g (T_4). Broilers in all treatments had similar ($P > 0.01$) FCR at all stages of this study. Neither ill health signs nor mortality occurred throughout the study period. The weight of primal carcass cuts and edible offals were unaffected ($P > 0.01$) by the treatment diets.

Conclusion: The application of dry roasting appeared to be simple and inexpensive processing technique in enhancing the growth efficiency and nutrient utilization of barley-based diets for enhanced productivity of chickens. The results imply that dry roasted barley can be included up to 330 and 435 g kg^{-1} in the starter and finisher broiler diets without affecting feed intake, growth performance, and carcass parameters.

Keywords: β-glucan; Carcass; Dry roasted barley; Feed conversion ratio; Growth performance

1. Introduction

With increased animal protein production and consumption, there will be increased demand for feed ingredients that are high in energy and protein. The animal feed industry has relied long enough on cereal grains-based formulations. In particular, maize has been used as the primary dietary source in commercial poultry diets due to its high energy and low fiber content. In regions where maize is expensive or unavailable, other cereals have been used as substitutes for poultry nutrition. In areas where barley is a dominant cereal crop, poultry farmers can use this cereal grain to replace maize. In comparison to maize, barley has lower energy but is better in protein and amino acid contents, including methionine, cysteine, lysine, and tryptophan (Shewry, 2009). Barley is also a good source of minerals, particularly calcium and potassium (Nikkhah, 2012). Unfortunately, barley is inherently high in dietary fiber of primarily insoluble non-starch polysaccharides (NSPs) (Onderci *et al.,* 2008; Sadeghi and Habibian, 2016). Past research has identified β-glucan as the most important NSPs found in barley grain (Jacob and Pescatore, 2014) and the level varies from 2.5 to 11.3% (Izydorczyk and Dextor, 2008). It was reported that ß-glucans can increase the viscosity of the intestinal content, thereby reducing the availability of nutrients and sacrificing chicken performance (Jacob and Pescatore, 2012).

*Corresponding Author: seid@hu.edu.et

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Nevertheless, barely contains more protein and ash than maize and utilization of this valuable feed ingredient in poultry nutrition is important (Seid Ali *et al.,* 2020).

Over the years, different methods such as heat treatment have been developed to reduce the negative effects of β-glucans on poultry performance. It was reported that heat treatment of barley grain modifies starch, protein, and fiber structure (Gracia *et al.,* 2003), gelatinizes starch (Gurbuz, 2017), and changes its physical, chemical, and nutritional properties (Abd El-Khalek and Janssens, 2010). For example, heat treatment (in an autoclave at 100 °C for 5 minutes) has been reported to positively affect the solubility of the fiber portion of barley and improved the digestibility of barley-based diets (Svihus *et al*., 2000). The feed processing industry has practiced several methods of heat applications (alone or in combination) (Gurbuz, 2017), where the most common once are pelleting, expanding, extrusion, steam flaking, cooking and micronisation (Gracia et al., 2003; Abd El-Khalek and Janssens, 2010). The study by Gracia *et al.* (2003) found that steam-cooked (99±2 °C for 50 minutes) and flaked barley improved digestibility and growth performance of starter broilers. Although improvement in the nutritional quality of barley is achieved, many are not economical and the process or technical procedure has not yet been optimized under local conditions. For instance, Mathison (1996) supposed that steam flaking of barley grain is usually not justified economically. To this end, it is difficult to access at small-scale farmers in developing countries like Ethiopia.

It is widely accepted that simple and relatively cheap processing techniques are required to improve the utilization of barley grain as poultry feedstuff. Dry roasting of barley could be a feasible alternative to other methods of heat treatment. The method appears to be cheap and can be employed in small and medium scale operations where expander or extruder is absent (Sharma *et al.,* 2011). Dry roasting involves heating dry grain on a hot plate (< 400 °C) for a shorter period (Gurbuz, 2017). Although this method can be applied to enhance nutritive value of all cereal grains, the impact of inclusion of dry roasted barley grain in poultry diets is not well documented. In this research, it was hypothesized that the use of dry roasting barley grain would enhance broilers performance by reducing the negative effects of β-glucans. The objective of this study was to investigate the effect of dry roasting of barley on its proximate composition and β-glucan content and evaluate growth performance, and carcass parameters of broilers fed on diets with different levels of dry roasted barley as a substitute for maize.

2. Materials and Methods

2.1. Description of the Study Area

The study was conducted at a poultry farm of Agarfa A-TVET College, Ethiopia. The College is located at geographical location ranging between 7°17'N Latitude and 39°49'E Longitude. It was located at 458 km South East of Addis Ababa. The lowest and highest altitude of the Agarfa district is 1000 m and 3000 m above sea level, respectively. The mean annual temperature of the district is 17.5 °C. The minimum and maximum temperatures were 10 °C and 25 °C, respectively. The average annual rainfall of the area based on 21-year meteorological data is 829 mm.

2.2. Barley Roasting Procedures

A single batch of warehouse barley was purchased from a local market and dry roasted to deactivate anti-nutritional factors. The barley was roasted for about five minutes using a traditional clay pan, which is practiced in many villages of Ethiopia. Briefly, the barley grains were spread thinly on a pre-heated clay pan while it was stirred continuously to ensure uniform roasting of grains. During the heat treatment, the moisture content of the whole barley is not adjusted (i.e., roasting implemented with the native moisture). The exiting time of 5 minutes was adapted based on color (viz. until the grains become light brown) and smell of the grains (viz. roasted fragrance), as well as degree of grain exploding into popcorn and grains became crispy to touch. When barley grains exit the roasting system, they are still hot (≈90 °C) which could allow the process of protein denaturation to continue until the grains are cooled or steeped to room temperature. Temperature was measured by using digital thermometer. Henceforth of heat action, cool water was sprinkled smoothly over the grains as well as sufficient ventilation and steeping of 30 minutes was maintained to cool the grains quickly. After cooling down, the roasted barley was ground with a hammer mill (5 mm-sieves) and stored in air-tight sacks until required for chemical analysis and incorporation into diets.

2.3. Formulation of Experimental Diets

The starter and finisher broiler diets were formulated by mixing maize or dry roasted barley with other processed feed ingredients (Table 1). The ingredients are noug seed cake, soybean meal, wheat short, di-calcium phosphate, limestone, vitamin premix, lysine, methionine, and common salt. Maize was ground with a hammer mill (5 mm-sieves). The control diet (T_1) contains maize and is mixed with other ingredients to meet or exceed the standard nutrient requirements of broilers (NRC, 1994). The maximum inclusion level of maize in broiler ration is 330 and 435 g kg^{-1} for the starter and finisher phases, respectively. Based on this, the maize was replaced weight for weight in experimental diets with different levels (33.3% -T_2, 66.7% -T_3 and 100.0% -T_4) of dry roasted barley (DRB).

Table 1. The proportions of ingredient of experimental diets (as-fed basis).

Ingredient	Starter diets				Finisher diets			
(g kg^{-1})	T_1	T_2	T_3	T_4	T_1	T_2	T_3	T_4
Maize	330	220	110	0	435	290	145	0
Roasted barley	0	110	220	330	0	145	290	435
Wheat short	170	170	170	170	176	176	176	176
Noug seed cake	267	267	267	267	244	244	244	244
Soybean meal	203	203	203	203	115	115	115	115
Limestone	9	9	9	9	1.0	1.0	1.0	1.0
Di-calcium phosphate	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Vitamin Premix	5	5	5	5	5	5	5	5
Salt	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Lysine	3.5	3.5	3.5	3.5	2.5	2.5	2.5	2.5
Methionine	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Total	1000	1000	1000	1000	1000	1000	1000	1000

Note: *T_1 = 100% maize; T_2 = 33.3% of maize replaced with dry roasted barley (DRB); T_3 = 66.7% of maize replaced with DRB; and T_4 = 100% of maize replaced with DRB.*

2.4. Broilers Management Setup

A total of 200 unsexed day old Cobb 500 broilers were procured from Alema farms, Debreziet, Ethiopia. About 168 chicks were randomly allocated into four dietary treatments with three replicate pens of 14 chicks each. The chickens were reared in deep-littered floor pens (1.5 × 1.5 m) for the experimental period of 56 days. Sawdust was used for litter. Each pen was equipped with feeder, waterer and heated using infrared lamp placed at the center of the pen. The initial daily temperature of 35 °C maintained at day one was reduced sequentially each week until a temperature of 21 °C is reached by 28 day. Temperature regulation was based on chick's behavior, and through gradual height adjustment of heat sources. Fifteen-watt lamps were switched on for 23 hours followed by an hour of darkness during the starter period. From week 4 onwards, lights-on, lights-off program was employed. Lamp spacing was one lamp per 2 m^2.

Chicks were vaccinated against Newcastle (HB1 strain on day 7 via eye drop and Lasota on day 21 with drinking water) and Gumboro (at day 14 via eye drop and 28 with drinking water) as recommended by the veterinarian. Moreover, health status and mortality were monitored daily throughout the study period. Feed and water were provided in each pen unit. The chickens were fed on the experimental diets from one-day-old to 56 days old. The starter ration was offered for three weeks (1 to 21 days) followed by the grower/finisher ration up to the last week (22 to 56 days) of the study period. The measured amount of the respective diet was offered twice a day regularly (8:30 and 16:30 hours) and refusal was recorded the next day. The daily feed offer was adjusted based on the intake of the previous day. Fresh clean water was available at all times.

2.5. Measurements and Data Collection

During the 56-day experimental period, daily feed intake was determined in each pen unit. Body weight was taken at the beginning of the experiment on a pen basis (considered as initial weight) and then on weekly basis between 7:00 and 8:00 am before feed was offered. The body weight taken at the end of the experiment was considered as final body weight. Each period, cumulative weight gain and feed intake were determined and the ratio of cumulative gain to feed was calculated. At the end of the feeding trial, four randomly selected broilers per pen were slaughtered. Blood was collected and weighted. After removing feather, heads and shanks, the remaining carcasses were dissected to breast, thigh, drumsticks, wings, neck, back, skin, gizzard, liver, abdominal fat and weighed. The total non-edible offals (TNEO) include blood, feather, shank and claw, head, lungs, heart, spleen, pancreas, digestive and urogenital parts. Gizzard, liver, and skin were treated as total edible offals (TEOs). Dressed carcass is the summation of the components of valuable cuts and TEOs. Dressing percentage (DP) was then calculated as (Dressed carcass weight/Pre-slaughter weight) × 100%.

2.6. Chemical Analysis

Feed samples were milled to pass through 1 mm sieve and analyzed for proximate composition following standard procedures of AOAC (2000) at Haramaya University. The metabolizable energy was calculated indirectly using the formula (ME (kcal kg^{-1} DM) = 3951 + 54.4 EE – 88.7CF – 40.8 Ash) developed by Wiseman (1987). The β-glucan content of roasted and non-roasted barley grain was determined following the methodology proposed by AOAC (2000) at Hawassa University.

2.7. Statistical Analysis

The general linear model procedure of the statistical analytical system (SAS, 2012) was used to analyze the effects of dietary treatments on body weight changes and carcass traits of broiler chickens. Differences among treatment means were compared by Duncan's multiple range test. The means were considered significant at $P < 0.01$. The model used was: $Y_{ij} = \mu + T_i + E_{ij}$; where, Y_{ij} = Dependent variable; μ = Overall mean; T_i = Effect of the i^{th} treatment diet; and E_{ij} = Effect of the random error.

3. Results and Discussion

3.1. Chemical Composition of Major Ingredients

The nutrient composition and energy values of feed ingredients utilized in the formulation of treatment diets are presented in Table 2. The DM, CP, CF and total ash contents of barley grain were higher than that of maize grain. However, the NFE, EE and the ME values of barley grain were lower than that of maize grain. Roasting slightly reduced the CP, EE and ME contents of barley grain. However, the DM, NFE, CF and ash contents were slightly increased due to roasting.

Table 2. Nutrient composition (g kg^{-1}) and ME value (kcal kg^{-1} DM) of feed ingredients.

Ingredient	DM	CP	EE	CF	Ash	NFE	β-glucan	ME
Raw barley	914	118	25	53	31	687	83.2	3490
Roasted barley	923	114	24	56	33	696	18.5	3450
Maize	908	98	34	27	27	722	–	3742
Wheat short	924	175	43	83	41	582	–	3281
NSC	932	328	98	171	92	243	–	2604
SBM	938	376	104	63	62	333	–	3668

Note: *NSC = Noug seed cake; SBM = Soybean meal; DM = Dry mater; CP = Crude protein; EE = Ether extract; CF = Crude fiber; NFE = Nitrogen free extract; and ME = Metabolizable energy.*

The results of the proximate analysis revealed more or less similar chemical composition of barley grain after dry roasting is affected at some level. Nonetheless, the DM, CF and ash content was higher in roasted than non-roasted barley. Lower DM content in roasted barley might be due to moisture escaping from the grains in the form of vapor. As expected, the moisture content of the grains decreased due to the high temperatures of the heating process (Gurbuz, 2017), because of the water escaping from the grains in the form of vapor. Consistent with this postulation, Bhuiyan *et al.* (2012) reported that an increase in the drying period at 105 °C resulted in a sharp decline in moisture content and a simultaneous increase in the concentration of the DM components, especially ash. Dry roasting of cereals tended to reduce the crude protein content possibly due to the vaporization of some nitrogenous compounds during the process (Emiola and Ologhobo, 2006).

The EE content of the barley decreased after heating, which could be attributed to the appearance of an amylose-fat complex that formed with the combination of free fat and amylose (Huang *et al.,* 2018). In addition, the fat may be decomposed into fatty acids and monoglycerides under high temperature, which may have also been responsible for the decreased EE content. The reduction of ME of roasted barley grain could be attributed to the rise of crude fiber and ash values. Teguia and Beynen (2005) indicated that an increase in dietary fiber lowers the metabolizable energy content of feedstuffs. It had generally been reported that heat treatment of cereal grains modifies the starch, protein, and fiber structure (Gracia *et al.,* 2003), and changes its physical, chemical, and nutritional properties (Abd El-Khalek and Janssens, 2010). It is obvious that important nutritional information could also be lost during the successive steps of proximate analysis.

It was noted that the pan roasting process caused a reduction in β-glucan content of barley grains (from 83.2 in raw to 18.5 g kg^{-1}), implying dry roasting technique is effective in deactivating β-glucan while applicable on small-holder farms. This finding is in line with earlier report by Sharma *et al.* (2011), who reported a decrease in β-glucan content (ranging from 49 to 253 g kg^{-1}) when barley is roasted in hot sand (280 °C). It was suggested elsewhere that elevated temperatures may cause the degradation of β-glucan into fragments of low molecular weight, or depolymerize the linear structure thus changing the concentration of β-glucan (Butt *et al.,* 2008). Besides heat action, the barley grain utilized in this study was stored for a long time before dry roasting, which may also be partially responsible for the decreased β-glucan content. There was an indication as β-glucan levels decreased in grains stored for a long time (Jacob and Pescatore, 2012). The levels of β-glucan found in the current study is in agreement with those of several studies in the literature, for example, 25 to 113 g kg^{-1} by Izydorczyk and Dextor (2008) and 54.7 g kg^{-1} of β-glucan by Sharma *et al.* (2011).

3.2. Chemical Composition of Experimental Diets

The chemical compositions of experimental diets are presented in Table 3. The DM, CP, CF and ash values of the starters and finishers diets showed a slight increase as the inclusion level of barley grain increased. Conversely, the ME, EE and NFE contents slightly decreased with increasing levels of barley.

Table 3. Chemical composition (g kg^{-1}) of experimental diets (DM basis).

Chemical composition	Starter diets				Finisher diets			
	T_1	T_2	T_3	T_4	T_1	T_2	T_3	T_4
Dry matter	925.6	927.2	928.9	930.5	922.5	924.7	926.8	929
Crude protein	231	233	234	236	201	203	205	208
Ether extract	65.8	64.7	63.6	62.5	58.2	56.8	55.3	53.9
Crude fiber	83.1	85.8	88.4	91.0	77.5	81.0	84.5	87.9
Ash	53.0	53.7	54.3	55.0	48.5	49.4	50.3	51.1
NFE	493	491	488	486	538	535	532	529
ME (kcal kg^{-1} DM)	3252	3220	3187	3155	3278	3235	3193	3151

Note: *T_1 = 100% maize; T_2 = 33.3% of maize replaced with dry roasted barley (DRB); T_3 = 66.7% of maize replaced with DRB; T_4 = 100% of maize replaced with DRB; NFE = Nitrogen free extract; and ME = Metabolizable energy (kcal kg^{-1} DM).*

The crude protein (a mean of 231 g kg^{-1} in starters and 201 g kg^{-1} in finishers of the control) of the treatments diets was within the recommended range of 230 g kg^{-1} for a 1-21 day old chicks and 200 g kg^{-1} for 21-42 days standard requirements of crude protein in a ration of broilers chickens (NRC, 1994). The crude fiber content of the experimental diets varied between 775 and 910 g kg^{-1}, as maize and barley were interchanged weight for weight (w/w) without consideration of their chemical composition. The CF value in the present study is slightly above the maximum CF (700 g kg^{-1}) requirement of broiler diets (Varastegani and Dahlan, 2014). According to Saki *et al.* (2010), fiber can be included in broiler diets to reduce fat deposits and produce lean meat. It was clear that roasted barley has reasonable crude fiber helps to make it moderate energy, mark able protein feed resource rich in fiber.

The trend of ether extract reduction and ash increment across the treatment diets, with increment of barley grain in the diets, could be attributed to low oil content and higher ash content of barley grain than maize. This, together with the higher crude fiber content seems to have contributed to the differences in metabolizable energy content of the treatment diets. The metabolizable energy of treatment diets showed a linear decrease with increasing levels of barley grain in the diet, slightly above the recommended energy level (3200 kcal ME/kg DM) for broilers outlined by NRC (1994). The high energy value of the treatment diets could be explained by the fact that the adopted equation from Wiseman (1987) might have overestimated the ME values. Other scholars in the previous studies have also noted similar overestimations (Yibrehu Emshaw *et al.,* 2012; Cheru Tesfaye *et al.,* 2018).

3.3. Feed Consumption

The inclusion of roasted barley in the diet had significant effect (P < 0.01) on daily feed intake of broilers during the starter and finisher phase as well as for the entire growth period (Table 4). The daily feed intake of broilers in T_4 (100% roasted barley) was lower than those broilers in T_3, T_2, and the control diet.

Table 4. Daily feed intake (DFI, g/day) of Cobb 500 broilers fed diets with different levels of dry roasted barley (as fed basis).

Variables	Stage	Treatments				SEM	P-value
		T_1	T_2	T_3	T_4		
DFI	Starter	38.82[a]	38.84[a]	38.47[b]	37.25[c]	0.20	<0.0001
	Finisher	142.33[a]	141.84[ab]	141.41[b]	137.12[c]	0.63	<0.0001
	Overall	103.51[a]	103.21[a]	102.81[b]	99.67[c]	0.47	<0.0001

Note: *T_1 = 100% maize; T_2 = 33.3% of maize replaced with dry roasted barley (DRB); T_3 = 66.7% of maize replaced with DRB; T_4 = 100% of maize replaced with DRB; and SEM = Standard error of the mean. Means in the same row without common letters are significantly different at P < 0.01.*

Broilers fed high barley diet (T_4) had depressed feed intake than broiler fed T_3, T_2 and T_1 at all stages of this study. The relatively lower feed intake of broilers, especially starter chicks, fed high barley diet might be associated with the higher dusty fraction of barley diets. It had been reported elsewhere that roasted barley will grind easier (25% faster than raw) as roasting ruptures the kernel. Despite the advantages of reducing grinding costs and time saving, roasting increases the incidence of dusty material in the feed which is suggested to negatively affect the consumption rate. Mathison (1996) reported that dry-rolled and ground barley contains substantial dust that may reduce intake and adversely affect the performance of animals. The depression in voluntary feed intake with the addition of roasted barley grains could also be explained by the high fiber content of diets when it has a high inclusion level. It was reported that the presence of high levels of dietary fiber fraction in the grains might have depressed the appetizing and digestive process of digestions in chickens (Teguia and Beynen, 2005). Furthermore, dietary factors including energy density, deficiency, or excesses of the nutrient also influence feed intake in poultry. On the contrary, Veldkamp *et al.* (2005) reported that birds satisfy their energy needs by decreasing feed intake as dietary energy level increases.

Feeding high barley diet was not effective in restoring feed intake of broilers possibly due to the levels of anti-nutritional factors that may have persisted, which, in turn, may have increased residual effects. The retained β-glucans (i.e., 18.5 g kg^{-1}) from roasting action are not broken down because of limited enzyme production and the rapid rate of passage in poultry (Leeson *et al.,* 2000), as well as slow gastrointestinal transit of digesta may reduce feed intake of broilers (Gracia *et al.,* 2003). Differences in feed consumption responses might also be due to the energy content of the diets (Onderci *et al.,* 2008). In general, the high barley diet at the inclusion rate of 330 g kg^{-1} starter diet and 435 g kg^{-1} grower-finisher diet negatively affected the feed intake of broilers.

3.4. Growth Performance and Feed Conversion Ratio

The final body weights of broilers at the end of the starter phase (day 21) were significantly different (P < 0.01), whereas body weight at day 1 and at the end of the entire experimental (day 56) were similar in the treatment diets (Table 5). The average daily gain (ADG) of broilers on diet containing 100% roasted barley was significantly lower (P < 0.01) than the rest during the finisher phase. However, broilers in all treatments had similar ADG for the starter phase as well as the entire experimental period. Dietary treatments generally did not affect feed conversion ratio at all stages of growth ($P > 0.01$).

The substitution of maize with dry roasted barley had no significant ($P > 0.01$) effect on broilers performance indices in terms of body weight gain and feed conversion ratio at all stages of growth. This consistency in body weight gain among treatment groups might indicate the optimum balance of available nutrients in maize and barley diets. Rates of average weight gain were reduced by 6.5%, 9.4%, and 8.9% when maize was totally replaced with dry roasted barley at the starter, finisher phase, and overall period, respectively, but not significantly different.

Table 5. Body weight (BW), average daily gain (ADG), and feed conversion ratio (FCR) of Cobb 500 broilers fed diets with different levels of dry roasted barley.

Parameter	Stage	Treatments				SEM	P-value
		T_1	T_2	T_3	T_4		
BW (g)	1 d	40.27	40.13	39.60	39.93	0.17	0.5877
	21 d	402.50^a	399.93^a	398.47^a	378.57^b	3.07	0.0006
	56 d	2213.47	2200.77	2116.30	2019.17	31.28	0.1124
ADG (g)	Starter	17.25^a	17.13^a	17.09^a	16.13^b	0.15	0.0007
	Finisher	51.74	51.45	49.08	46.87	0.84	0.1124
	Overall	38.81	38.58	37.08	35.34	0.56	0.0746
FCR	Starter	2.25	2.27	2.25	2.31	0.01	0.1269
	Finisher	2.76	2.76	2.88	2.93	0.04	0.3626
	Overall	2.67	2.68	2.77	2.82	0.03	0.3335
Mortality (%)	Starter	7.14	7.14	4.76	7.14	1.38	0.9300
	Finisher	2.56	0.00	0.00	0.00	0.64	0.4411
	Overall	9.70	7.14	4.76	7.14	1.24	0.6722

Note: *T_1 = 100% maize; T_2 = 33.3% of maize replaced with dry roasted barley (DRB); T_3 = 66.7% of maize replaced with DRB; T_4 = 100% of maize replaced with DRB; and SEM = Standard error of the mean. Means in the same row without common letters are significantly different at $P < 0.01$; *$P<0.01$.*

Under the conditions of this experiment, the weight gains of the chickens did not depend greatly on the energy content of the diets as well as the low feed intake observed. While it seems logical that dry roasting of barley grain in the present study may have a significant increase in the digestibility or bioavailability of nutrients, even though the process had a negligible effect on its proximate composition and feed intake. Different authors reported that the heat action increases digestibility by breaking down the cell structure within the grain - in the same manner as natural digestive enzymes - so it will be readily available in the small intestine of animals (Gurbuz, 2017). Gracia *et al.* (2003) reported that heat treatment of barley improves the accessibility of enzymes to nutrients facilitating its digestibility and resulting in improved body weight gain of broilers. Emiola and Ologhobo (2006) also reported that heat treatment of grains contributed increased carbohydrate digestibility and improved starch digestion as well as protein quality by making them more susceptible to attack by digestive enzymes. In addition, heat processing solubilized fiber components of barley grain, an effect that might enhance the activity of exogenous enzymes in broilers (Svihus *et al.,* 2000). A decreased demand for endogenous digestive enzyme production could explain some of the efficiencies observed with the heating process (Gracia *et al.*, 2003).

However, this observed response in broilers body weight gain to dietary barley grain addition, especially at the starter stage, was inconsistent with results of other studies. Gracia *et al.* (2003) stated that steam flaking of barley improved feed intake and daily gain only for the first 8 days of life. The disparities most likely stem from differences in the feeding period, the levels of inclusion and methods of heat treatment employed. Meanwhile, the reduction of live weight changes of broilers fed high barley diet was consistent with previous reports. It has been reported that feeding high barley diets could impair body weight gain (Mansoori *et al.,* 2011; Ribeiro *et al.,* 2012), which is shown to be related to the altered intestinal morphology, endogenous enzyme activity and gut microflora (Shakouri *et al.,* 2009), as well as due to shortening, thickening, and atrophy of the villi and increases in the number and size of goblet cells (Onderci *et al.,* 2008). In this study, no unusual ill health effects related to dry roasted barley utilization were observed.

However, personal observation affirmed the incidence of sticky droppings along with increased pasted vents in chicks fed high barley diet (T_4). Although intestinal viscosity was not scoped in the present study, it tended to decrease linearly with increasing age of the birds, which may be a consequence of acclimatization to diet including an alteration in the gut microflora as previously suggested by Gracia *et al.* (2003).

Broilers in all treatments recorded similar feed conversion ratio in the starter and finisher phase as well as in the entire experimental period. The computed feed conversion ratio (ranging from 2.67 to 2.8) are better than the values of 2.66–3.14 reported for Cobb 500 broilers fed raw barley as a substitute for maize (Seid Ali *et al.,* 2020). Similar confirmation of the suitability of barley was established by the work of Mansoori *et al.* (2011), which showed that the feeding efficiency of the broiler was unaffected by 300 g kg^{-1} barley inclusion. Differently from the present finding, Ribeiro *et al.* (2012) found that feeding high barley diets reduced feed conversion ratio. In this study, the feed conversion ratio has decreased numerically across the dietary treatment with an increase in the rate of barley. An unaffected but decreasing trend of FCR has also been reported in broiler chickens fed diets with increasing levels of barley (Onderci *et al.,* 2008; Shirzadi *et al.,* 2009; Sadeghi and Habibian, 2016). Teguia and Beynen (2005) stated that an increase in dietary fiber may depress the efficiency of feed utilization, which could be the possible explanation for the observed response.

Under the conditions of this experiment, the replacement of maize with dry roasted barley has been more effective in grower-finisher diets of broilers than in the starter phase. This implies that dry roasted barley is better reserved for older broilers as these are more resistant to anti-nutritional factors as well as higher dietary fiber levels, as observed in this trial. For young broiler chicks, thus, lower levels of barley may be preferable whereas older broilers can better tolerate high levels of dry roasted barley. It seems that the presence of a more developed digestive system in mature, compared with immature birds, presumably enables the broilers to utilize more efficiently diets rich in viscous polysaccharides (Nahas and Lefrancois, 2001). The beneficial effects of dry roasting on nutrient digestibility and absorption during the growing-finishing phase were reflected in a better performance of the chicks during their older age.

3.5. Carcass Yield and Organ Weight of Broilers

The carcass yield analysis showed no significant difference for carcass trait parameters across all the treatment groups ($P > 0.01$). Broilers fed roasted barley based diet (T_4, T_3, and T_2) recorded lower ($P < 0.01$) back weight than broilers fed the control diet (T_1). The weight of skin was significantly lower only for T_2 as shown in Table 6.

Table 6. Effect of dietary treatments on carcass components of Cobb 500 broilers (g).

Parameter	Treatments				SEM	P-value
	T_1	T_2	T_3	T_4		
Slaughter weight	2258.67	2147.0	2187.0	2125.0	22.89	0.1756
Dressed carcass weight	1603.78	1525.80	1568.57	1501.85	19.36	0.2598
Dressing percentage	71.01	71.06	71.72	70.68	0.34	0.6940
Breast	617.98	598.53	609.50	582.10	6.21	0.1997
Drumsticks	216.62	216.93	227.45	216.55	3.50	0.6497
Thighs	245.57	245.87	249.32	234.55	3.00	0.3483
Neck	62.37^{ab}	69.50^{ab}	75.70^{a}	59.12^{b}	2.14	0.0175
Wings	80.67	82.72	82.53	82.42	1.42	0.9594
Back	150.0^{a}	117.52^{b}	108.17^{b}	110.97^{b}	4.65	0.0007
Liver	50.25	50.18	47.60	49.17	0.71	0.5426
Gizzard	50.32	50.58	47.17	45.63	0.76	0.0425
Skin	130.02^{a}	93.97^{b}	121.13^{a}	121.35^{a}	4.01	0.0028
Abdominal fat	11.68^{ab}	4.50^{b}	19.83^{a}	16.92^{a}	1.55	0.0002
Total edible offal	230.58^{a}	194.73^{b}	215.90^{ab}	216.15^{ab}	4.07	0.0096
Total non-edible offal	580.42	527.80	548.45	530.32	8.19	0.0337

Note: *T_1 = 100% maize; T_2 = 33.3% of maize replaced with dry roasted barley (DRB); T_3 = 66.7% of maize replaced with DRB; T_4 = 100% of maize replaced with DRB; and SEM = Standard error of the mean. Means in the same row without common letters are significantly different at $P<0.01$.*

In the present study, the weight of primal carcass parts was similar across the treatment groups irrespective of differences in dietary ME level as well as intake. It had been reported by several authors that carcass weight was unresponsive to dietary ME levels (Melkamu Bezabih, 2013; Seid Ali *et al.,* 2020). Contrary to the present findings, Sadeghi and Habibian (2016) observed reduced carcass weight with increasing levels of barley in the diets. The maximum levels of roasted barley in treatment diets herein were 330 g kg^{-1} for starting period while 435 g kg^{-1} during the growing/ finishing period of 22 to 56 days. In this trial, the level of barley inclusion in broilers diet had no effect on carcass and breast weight. Unaffected carcass yield and breast part have also been reported in broilers-fed diets containing 350 g kg^{-1} barley compared with maize diet as a control (Moharrery, 2006).

Dressing percentage did not differ amongst treatments while numerically higher for T_2 and T_3, owing to their higher dry matter and crude protein intake. The comparable TNEOs (e.g., intestine, spleen and pancreas) and gizzard weight of broilers fed maize diet and broilers fed barley diets indicates that broilers got adequate energy from those dietary treatments, irrespective of the difference in dietary fiber values. This finding contrasts the findings of earlier research which advocated feeding high fiber diets amplified the relative weight of intestine, gizzard and sizes of various digestive components which, in turn, resulted in a lower dressing percentage (Gracia *et al.,* 2003; Sadeghi and Habibian, 2016). The reason is unknown but it seems probable that the dry roasting of barley grains here resulted in negligible alteration of metabolic as well as the secretory function of these organs. It was stated that autoclaving of barley at 100°C for 5 min solubilizes fiber components of barley grain, as already explained by Svihus *et al.* (2000).

The results of this experiment indicated that a higher weight of abdominal fat was observed in broilers fed optimum/higher levels of roasted barley diets (T_3 and T_4) than in low barley diet (T_2). On the contrary, Sadeghi and Habibian (2016) observed that abdominal fat weight reduced with increasing levels of barley in the diet (i.e., energy level decreased). The abdominal fat in broilers is reported to be affected greatly by genotype, sex, age, and the plane of nutrition (Nikolova *et al.,* 2007). The disparities among studies might be related to the nutritional value of diets, environmental factors, management as well as sex composition of birds in treatment groups, and also the growing period in which the chickens were fed.

4. Conclusions

From this study it has been demonstrated that the dry roasting technique reduced β-glucans present in barley grains. The weight gain and feed conversion efficiency of broilers at all stages were not affected up to 100% substitution of maize with dry roasted barley. Broilers in all treatments attained comparable slaughter weight. The weight of primal carcass cuts (e.g., breast muscles, thighs, and drumsticks) was not affected by up to 100% substitutions. It was therefore concluded that substituting maize with dry roasted barley by up to 100% would not adversely affect broiler performance and carcass components. Accordingly, small scale poultry producers can narrow down the overdependence on maize as the sole source of dietary energy in poultry diets. However, future studies should analyze the effect on product quality and economic feasibility of substituting maize with different levels of roasted barley in poultry diets.

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