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Performance of broilers fed raw or fermented and redried wheat, barley, and oat grains

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Abstract: The efficacy of diets containing 40%–50% wheat, barley, or oat grains, fermented by a solid-state fermentation process, on bird performance, carcass yield, digestive organ development, and intestinal viscosity was tested. Compared with broiler chicks fed unfermented grains, those fed fermented oats had increased feed intake, and treatment with fermented wheat and barley improved the feed conversion ratio at days 21 and 42. Treatment with fermented barley and oats resulted in increased body weight at day 42. Treatment with fermented wheat and oats increased the percentage of carcass yield. Birds fed unfermented grains had highly viscous digesta, not seen among birds fed fermented grains. Compared with those fed unfermented grains, birds fed fermented grains had reduced ($P < 0.05$) size and weight of the digestive tract, but increased liver weight. In conclusion, feeding broiler chicks diets of fermented grains, particularly wheat and barley, yielded certain performance and carcass benefits, promising a growth-stimulating effect.

Key words: Broiler chickens, functional feeds, cereals, solid-state fermentation, whey, citrus pomace

1. Introduction

Appreciable amounts of nonstarch polysaccharides (NSPs) are found in wheat, barley, and oat grains. Young birds do not secrete sufficient amounts of enzymes to degrade certain NSPs (beta-glucans, xylan, and arabinoxylan). Thus, feeding young birds diets rich in NSP content reduces feed intake (FI), depresses growth rate, and worsens the feed conversion ratio (FCR) due to the high viscosity of the digestive tract contents limiting nutrient uptake by the intestinal epithelium (1).

In past studies, wetting (1) and fermentation (2–5) of cereal grains have improved the nutritional value of cereal grains. Due to the high risk of contamination of wet diets with pathogenic microorganisms, the use of wet mash diets is not practical on a commercial scale. An appropriate fermentation method combined with a suitable drying process could produce functional feeds from cereal grains. A simple solid-state fermentation (SSF) method that does not require aseptic conditions was tested previously and found to improve the nutritional value of cereal grains in meat-type Japanese quails (6). Some modern SSF methods are well-defined, controlled systems that require aseptic conditions and are employed in the production of commercial exogenous enzymes (e.g., pectinase, cellulase, glucanase, phytase, and xylanase) by *Aspergillus, Neurospora, Rhizopus*, and *Trichoderma* spp. (7,8).

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To date, many researchers have mimicked both aseptic and nonaseptic conditions of an SSF process with or without microbial inoculants to ferment various feed materials for increasing the DL-lactic acid content (9,10) and lactic acid bacteria counts (3,7–9,11–13), for the elimination of antinutritional factors (7,14), for the fortification of major nutrients and enzymes (7,8,15–20), and for the destruction of grain viscous constituents (6). Successful fermentation depends on the control of many factors. The above studies controlled the fermentation temperature (10 to 40 °C), pH (3.5 to 6.0), incubation time (2 to 72 h), and the amount of water (0.8 to 3.5 parts per 1.0 kg of air-dried substrate). We extracted a set of optimum conditions from these studies. For example, Carlson and Poulsen (16) found 80% degradation of phytic acid from cereal grains after 8 h of fermentation at temperatures from 10 to 20 °C. However, when the temperature was increased to 35 °C, the maximal degradation of phytic acid occurred in 2 h. The criteria for the selection of our optimal levels were based mainly on maximum enzymatic, microbial, and nutritional enrichments of the substrates. Thus, the amount of added liquid (water or whey) was fixed at 1.1 or 1.2 parts per part of cereal grain (w/w), a substrate pH of 4 to 5, a substrate temperature of 35 °C, and a fermentation period of 8 h.

For the use of bacteria (9,10,14), yeast (7), and fungi (8) inoculants, the SSF process requires aseptic conditions. Asepsis inevitably raises the cost of the final product. However, the SSF in our study, designed as a means of natural fermentation, does not require additional microbial inoculants and aseptic conditions. Keeping the pH of the fermenting substrate under 5.0 and its water content not less than 60% suffices to initiate an SSF treatment for cereal grains. This method's success was demonstrated in previous studies (6,15,16,20). Controlling the pH of the fermenting substrate at desirable levels is absolutely critical for natural microbial fermentation. The fermentation can be initiated spontaneously with an immediate increase in lactic acid by adding copper to the medium (6,21). The reduction in pH to a desirable level (usually under 5.0) to prevent the growth of pathogenic microorganisms (6,22) can be managed by adding diluted acids or a natural source of citric acid. Fruit pomace (6,8,12,17,20) and other industrial or agricultural wastes (8,19) can also be added to increase the fortification of the final product with biomolecules. The use of whey for fermenting cereal grains also improved weight gain (WG) (6,11) and increased total N and P availability (15). In our study, fresh whey was used instead of water to provide suitable moisture content (60%), and citrus pomace was added for acidification of the fermentation medium.

The objective of the present study was to measure the efficacy of growth of broiler chickens fed diets containing unfermented (UF) grains or fermented (F) grains using a natural SSF process (at 35 °C, for 8 h, at pH below 5.0, with 60% moisture, and no microbial inoculant).

2. Materials and methods

2.1. Fermentation process

Grain fermentation was carried out in an in-house developed SSF system (90L) described elsewhere (6). Samples of wheat, barley, and oat grains, purchased locally, were ground through a 3.5 mm screen prior to fermentation. Citrus pomace was freshly prepared from an entire lemon after physically extracting its juice and grinding it through a 3.5 mm screen. Whey was obtained fresh from a dairy plant. The samples of wheat, barley, and oat grains were soaked in 1.1, 1.1, and 1.2 parts of whey per 1.0 part of grain (w/w), respectively, to provide a medium of 60% moisture. Copper sulfate (250 mg per 1.0 kg grain) was added. Diets of UF grains were also prepared with the same quantity of copper sulfate during diet formulation. All these ingredients were mixed thoroughly for 5 min after pouring into the fermentation system preheated for 1 h at 40 °C. When the substrates were added, the temperature dropped to 33 °C due to the exchange of heat between the chamber wall and the substrate. The substrate temperature was thereafter maintained at 35 ± 2 °C by heating the water circulated within the chamber wall. At 0 h of fermentation, the substrates were mixed vertically by a rotating mixer installed in the center of the chamber at 7 rpm for 5 min. Mixing combined with a constant rate of aeration with preheated air continued during pH measurements. Initial pH values for the raw grains were 5.3 for wheat, 5.1 for barley, and 5.2 for oats. At 2 h of fermentation citrus pomace (preheated at 35 °C) was added to reduce the pH below 5.0. The amounts of citrus pomace needed for pH reduction were 1% for wheat, 1% for barley, and 2.3% for oats. The final pH readings at the end of the 8-h fermentation were 4.2 for wheat, 4.5 for barley, and 4.5 for oats.

After the completion of the 8-h fermentation, the final product was unloaded and spread on 5-cm-thick trays to allow sufficient air circulation. Small portions were frequently turned, leading to efficient drying at room temperature. The entire drying process lasted 2 days to obtain a final product with 12% moisture. Dried portions of the fermented dried products were ground thorough a 5 mm screen before including in the broiler diets.

2.2. Diet formulation

All dietary ingredients including F cereal grains (except citrus pomace and whey) were analyzed chemically according to the official methods for nutrient contents (23) (Table 1).

Isocaloric and isonitrogenous diets containing 45% to 50% of F or UF grains were formulated to meet the nutrient requirements of broiler chickens according to recommendations of the National Research Council (NRC) (24). The diet formulations and nutrient compositions of the 6 starter diets (0–21 days) and 6 grower diets (22–42 days) are shown in Table 2.

2.3. Bird efficacy trial

The experimental protocol for animal treatment was approved by the Animal Welfare and Ethics Committee of Süleyman Demirel University. A total of 378 one-day-old Ross 308 chicks (of both sexes), purchased from a commercial breeder hatchery, were distributed randomly to 18 floor pens, each with 21 birds. Each of the 6 experimental diets (Table 2) was allocated randomly to 3 floor pens. The experimental design was a factorial model ((3 grains: wheat, barley, or oats) × (2 forms: F or UF)) with 3 replicates. Room temperature was 34 ± 1 °C on the first day and decreased gradually to 24 °C by the end of the third week. The lighting schedule was 21 h of light and 3 h of darkness per day throughout the trial. The birds had free access to feed and water during the experimental period.

The FI of the birds was recorded daily. Every morning, the feed remaining in each feeder was weighed, discarded, and the feeder was reloaded with fresh feed. In the first 2 days the amount of feed spilled was calculated and subtracted from the daily FI. Feed spillage was collected

Table 1. Dry matter (DM, %), fat (F, %), crude protein (CP, %), crude fiber (CF, %), crude ash (CA, %), total starch (%), nitrogen free extract (NFE, %) and metabolizable energy (ME, kcal/kg) of fermented (F) and unfermented (UF) grains and other feed ingredients used to formulate the diets.

Ingredients	DM	F	CP	CF	CA	Starch	NFE	ME*
Corn	89.4	3.2	8.1	2.4	1.6	64.6	74.1	3328.0
Soya meal, 45% CP**	91.8	4.0	46.0	4.7	4.0	--	33.1	2403.8
Fish meal, 64 % CP**	92.3	5.0	66.0	--	17.3	--	4.0	2895.6
UF wheat	90.1	2.2	11.9	3.5	1.8	57.5	70.7	3130.0
UF barley	90.3	2.1	12.8	6.3	3.0	49.3	66.0	2816.3
UF oats	91.2	3.9	11.3	12.2	4.0	47.0	59.8	2453.2
F wheat	90.0	2.2	13.4	3.0	3.0	56.0	68.9	3118.1
F barley	90.0	2.4	12.0	6.8	4.0	48.0	64.8	2765.4
F oats	90.8	3.8	12.0	12.0	5.8	46.0	57.2	2402.1

*Calculated according to the formula of Janssen, 1989. ** Declared values from the manufacturers.

rigorously on plastic sheets placed under each chick tray feeder. The body weight (BW) of each bird in all pens was recorded individually every 7 days. WG and FCR (the amount of feed consumed per kg weight gain in a given period) were calculated. The number of birds with sticky droppings and the number of dead birds were recorded regularly. The FI for each pen was corrected for dead birds. Three birds from each pen were killed on day 21 and all the remaining birds were killed on day 42 to collect data on digestive organ development, digesta viscosity, and carcass quality. The entire digestive tract was removed, weighed, and divided into the following sections: crop (from pharynx to proventriculus), proventriculus, gizzard, small intestine, ceca, and colon. The small intestine was divided into 3 segments: duodenum (from the gizzard outlet to the end of the pancreatic loop), jejunum (from the pancreatic loop to Meckel's diverticulum), and ileum (from Meckel's diverticulum to the cecal junction). The length of each segment was measured. Carcasses were reweighed to estimate carcass yield. The collected ileum contents were centrifuged and the viscosities of the supernatant fluids were measured at 25 °C using a digital cone-plate viscometer (model LVTD-CP-40, Brookfield Engineering Laboratories, Middleboro, MA, USA); pH was measured with a digital laboratory pH meter.

2.4. Statistical analysis

All the data were statistically analyzed according to a factorial model of ANOVA, 3 (grain) × 2 (form), based on the means for each floor pen (3 per diet). Significant differences between treatment means were determined by the least significant difference (25). The treatment means for the 3 groups of cages per treatment are presented with the number of observations used for statistical analysis of each treatment replicate.

3. Results

3.1. Performance parameters and carcass yield

The main effects and interactions of dietary treatments (grain and form) on performance parameters are presented in Table 3.

The FI from day 0 to day 21 was affected by the type of grain fed ($P < 0.05$). The mean FI values were 1306, 1273, and 1123 g/b (SEM = 18.5) for the wheat, barley, and oat diets, respectively, and were significantly different from each other. The FI of birds fed F grains (1260 ± 15 g/b, mean with SEM) was higher ($P < 0.05$) than that of birds fed UF grains (1209). The interaction effect between the grain and the form was not significant ($P > 0.05$). On day 42, FI was still affected ($P < 0.05$) by the type of grain. Birds fed wheat and barley consumed similar amounts of feed during the 42 days (4590 and 4483 g/b, means ± 53.0 SEM, respectively), but their FI was greater ($P < 0.05$) than that of birds fed oats (3998 g/b). FI was not affected significantly by form on day 42 ($P > 0.05$); all birds fed UF grains and F grains consumed similar amounts of feed (4351 vs. 4364 g/b, SEM = 43.3). However, the interaction between form and grain was significant for FI ($P < 0.05$). Birds consumed less ($P < 0.05$) F wheat than UF wheat (4446.2 vs. 4715.5 g/b, respectively). In contrast, birds consumed less UF oats than F oats (3856 vs. 4140 g/b, respectively). Birds that were fed F barley and those fed UF barley consumed similar amounts of feed (4485 vs. 4482 g/b).

Table 2. Ingredients and nutrient compositions of the diets with fermented (F) and unfermented (UF) wheat, barley, and oat grains.

Ingredients (%)	Starter diets from 0 to 21 days					
Diets	Wheat		Barley		Oats	
Fermentation	F	UF	F	UF	F	UF
Corn	16.00	17.00	16.00	19.00	16.00	15.75
Cereal grain	45.00	45.00	40.00	40.00	40.00	40.00
Soybean meal	26.50	23.00	27.50	24.00	21.00	21.50
Fish meal	4.50	7.50	5.50	7.00	10.00	10.00
Oil	4.75	4.25	7.75	6.75	9.75	9.50
Other*	3.25					
Nutrient composition (%)						
DM (analyzed)	88.0	88.0	88.4	88.4	88.9	89.0
CP (analyzed)	22,5	22.4	22.4	22.3	22.4	22.3
ME (kcal/kg)	3030.1	3030.4	3031.1	3029.9	3031.0	3028.8
Ca	1,00	1.03	1.00	1.03	1.05	1.04
Available phosphorus	0.47	0.47	0.47	0.49	0.49	0.49
Methionine + cystine	0.90	0.90	0.92	0.92	0.94	0.94
Ingredient (%)	Grower diets from 22 to 42 days					
Corn	19.00	18.25	18.75	20.75	16.25	16.50
Cereal grain	50.00	50.00	45.00	45.00	45.00	45.00
Soybean meal	22.00	21.50	22.50	21.50	19.50	19.75
Fish meal	3.00	4.50	4.50	4.25	7.00	7.00
Oil	2.75	2.50	6.00	5.25	9.00	8.50
Other*	3.25					
Nutrient composition (%)						
DM (analyzed)	87.7	87.8	88.1	88.1	88.8	88.9
CP (analyzed)	20.3	20.3	20.2	20.2	20.3	20.1
ME (kcal/kg)	3093.0	3093	3094.0	3092.0	3090.0	3090.0
Ca	0.96	0.97	0.96	0.96	0.98	0.98
Available phosphorus	0.43	0.42	0.44	0.44	0.43	0.44
Methionine + cystine	0.84	0.84	0.86	0.85	0.86	0.86

* All the diets were supplemented with 1.25% dicalcium phosphate, 1.0% calcium carbonate, 0.40% salt, 0.20% methionine, and 0.40% vitamin & mineral premix, which supplied per kg of diet: 5,000,000 IU Vitamin A, 750,000 IU Vitamin D_3, 25,000 mg of vitamin E, 2000 mg of vitamin K_3, 2500 mg of vitamin B_1, 5000 mg of vitamin B_2, 2500 mg of vitamin B_6, 30,000 mg of niacin, 10,000 mg of calcium D-pantothenate, 1000 mg of folic acid, 100 mg of biotin, 37,500 mg of Mn, 50,000 mg of Fe, 40,000 mg of Zn, 7500 mg of Cu, 250 mg of iodine, 100 mg of cobalt, and 100 mg of selenium.

Table 3. Effects of fermentation (form) and type of cereals (grain) on FI (g/b/period), BW (g/b/period), FCR (FI divided by the WG calculated by subtracting the final BW from the BW at day 1) and the percentage of carcass yield (carcass weight divided by BW and multiplied by 100) of broiler chickens.

Treatments	UF			F			SEM	Significance (P ≤)		
	Wheat	Barley	Oats	Wheat	Barley	Oats		Grains	Form	Form × Grain
$^{*}n_{1d}$	63	63	63	63	63	63				
BW_{1d}	56.0	55.9	55.6	55.9	56.6	55.2	0.50	0.776	0.344	0.614
$n_{dead\ 1\text{-}21d}$	-	-	-	-	-	-				
BW_{21d}	1010.4^{a}	972.3^{c}	827.3^{d}	1065.4^{b}	1045.8^{b}	832.7^{d}	15.4	0.000	0.004	0.119
FI_{21d}	1289.6^{ab}	1260.0^{a}	1075.3^{c}	1322.0^{b}	1286.0^{ab}	1171.6^{d}	26.1	0.000	0.033	0.358
FCR_{21d}	1.35^{a}	1.38^{ac}	1.40^{c}	1.31^{b}	1.30^{b}	1.51^{d}	0.02	0.000	0.983	0.001
$n_{killed\ 21d}$	9	9	9	9	9	9				
Carcass $yield_{21d}$	61.6^{a}	59.3^{ab}	56.0^{b}	61.7^{a}	61.0^{a}	56.5^{b}	1.5	0.002	0.527	0.842
n_{22d}	54	54	54	54	54	54				
$n_{dead\ 22\text{-}42d}$	1	1	1	4**	1	2				
n_{42d}	53	53	53	50	53	52				
BW_{42d}	2856.0^{a}	2675.0^{b}	2274.5^{c}	2884.0^{a}	2916.6^{a}	2435.0^{d}	52.0	0.000	0.006	0.154
FI_{42d}	4715.5^{a}	4481.9^{b}	3856.2^{c}	4446.2^{b}	4485.3^{b}	4140.4^{d}	75.0	0.000	0.838	0.013
FCR_{42d}	1.68^{a}	1.71^{a}	1.74^{a}	1.58^{b}	1.57^{b}	1.74^{a}	0.03	0.006	0.005	0.070
Carcass $yield_{42d}$	70.1^{a}	70.3^{a}	66.0^{c}	72.5^{b}	69.6^{ad}	68.5^{d}	0.5	0.006	0.001	0.034

^{a,b,c} different superscript letters within the rows show significant differences (P < 0.05) among the column treatment means (± standard error of the means, SEM).

*n, n_{dead}, and n_{killed} are the number of live, dead, and killed observations, respectively, per all pen replicates over the particular period of the experiment within each treatment group.

**2 birds died by accident in one of the pens.

The BWs at 0, 21, and 42 days of birds fed SSF treated and untreated grains are presented in Figure 1. The WG of broiler chickens at 21 and 42 days was calculated by subtracting the initial BW at day 0 from the BW of the bird at 21 and 42 days (Table 3). The WG at 21 days was affected significantly (P < 0.05) by the grain. The WG of birds fed wheat, barley, and oats differed from each other, with 981.6, 952.8, and 774.6 g/b (SEM = 10.6), respectively. The effect of the form on WG was also significant (P < 0.05). The WG of birds fed F grains was higher (P < 0.05) than that of birds fed UF grains (881 vs. 925 g/b, SEM = 8.2). WG was not significantly influenced by the interaction between grain and form (P > 0.05). At 42 days, WG was significantly affected by the type of cereal (P < 0.05). The WG of birds fed wheat and barley were similar to each other (2814 and 2740 g/b, SEM = 36.6), but greater than the WG of birds fed oats (2299.3 g/b). The effect of form on WG was significant (P < 0.05). Birds fed F grains had higher WG than those fed UF grains (2689 vs. 2546 g/b, SEM = 29.9). The interaction effect between form and grain was not significant for WG.

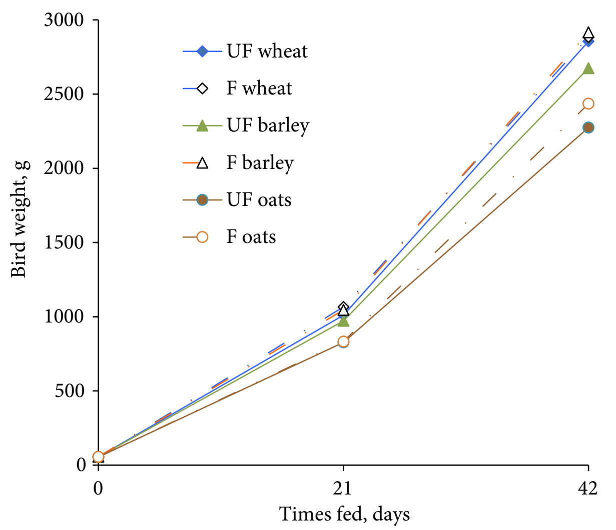

Figure 1. Changes in bird weights (g) at the times fed (days) by SSF treated and untreated grains (SEM of 0.50, 15.40, and 52.0 at 0, 21, and 42 days, respectively).

FCR values at 21 days were significant (P < 0.05) for cereal type. The FCR values were similar for birds fed wheat and barley (1.33 and 1.33; SEM = 0.01), but less than the FCR values of birds fed oats (1.45). The effect of form on FCR values was not significant (P > 0.05). The FCR values of birds fed UF and F grains were 1.37 and 1.37 (SEM = 0.01). An interaction between form and grain on FCR was detected (P < 0.05). FCR was worse for F oats than it was for UF oats (1.51 vs. 1.40, SEM = 0.02), whereas it was better for F barley than that for UF barley (1.30 vs. 1.38). No significant differences in FCR for F wheat or UF wheat were detected (1.31 vs. 1.35). At 42 days, the effect of type of grain on FCR was significant (P < 0.05). Similar FCR values were obtained from diets of wheat and barley (1.63 and 1.64, respectively, SEM = 0.02), which were better than the FCR for diets of oats (1.74). The effect of form on FCR was also significant (P < 0.05). Birds fed F grains had better FCR values than those fed UF grains (1.63 vs. 1.71, SEM = 0.01). The interaction of grain and form on FCR was not significant.

The percentage of carcass (carcass yield) of the birds at 21 days was significantly affected by the cereal type (P < 0.05), but not by the form and not by the interaction form × grain (P > 0.05). The carcass yields of birds fed wheat, barley, and oats were 61.7%, 60.1%, and 56.2%, respectively (SEM = 1.0). The values for birds fed F and UF grains were 59.0% and 59.7% (SEM = 0.9), respectively. At 42 days, the carcass yield was influenced by both the type and the form of grains (P < 0.05). No differences were observed between birds fed wheat and barley (71.3% and 70%, SEM = 0.6), but these values were higher than those of birds fed oats (67.3%). The birds fed F cereals produced higher carcass yields than those fed UF cereals (70.2% vs. 68.8%, SEM of 0.5).

3.2. Viscosities and pH of ileal contents

The effects of grain, form, and the interaction between grain and form (Table 4) were significant for ileal viscosities and for the number of birds with sticky droppings on day 21 (P < 0.05). The highest viscosity of the ileal contents was with the UF barley diet, followed by the UF oats and the UF wheat diets. However, when the diets contained F grains, the lowest viscosity was obtained from the F oats diet, followed by the F barley and F wheat diets. The responses to fermentation in ileal viscosity differed among cereal grains (Figure 2).

At 42 days, the effects of grain and form on ileal viscosity were significant (P < 0.05), but no significant interactions between grain and form were observed. The effect of grain fermentation was less pronounced at 42 than at 21 days (Figure 2). Ileal pH values were not significantly

Table 4. Influence of dietary treatments on viscosity and pH of ileal contents and sticky dropping problems (the number of birds with a heavy case) at days 21 and 42.

Grain	Viscosity (cPs)		Sticky droppings		pH	
	21 days	42 days	21 days	*42 days	21 days	42 days
Wheat	4.3^{x}	2.7^{x}	2.3^{x}	--	6.48^{x}	6.19^{x}
Barley	5.9^{y}	4.5^{y}	5.8^{y}	--	6.43^{x}	6.55^{y}
Oats	3.9^{x}	3.5^{z}	1.5^{x}	--	6.68^{y}	6.36^{xy}
SEM	0.4	0.2	0.4	--	0.04	0.09
Form						
N	6.4^{x}	3.9^{x}	4.3^{x}	--	6.49	6.41
F	3.0^{y}	3.2^{y}	2.1^{y}	--	6.56	6.32
SEM	0.3	0.1	0.3	--	0.03	0.07
Significance (P ≤ 5)						
Grain	0.001	0.000	0.000	--	0.000	0.032
Form	0.000	0.000	0.001	--	0.169	0.348
Grain × Form	0.000	0.434	0.001	--	0.089	0.996

^{x,y,z} Means within a column and measurements with different superscripts differ (P < 0.05).
*The feathers of the birds at 42 days were too dirty to visually differentiate the normal birds from those with sticky droppings; therefore no scores were obtained.

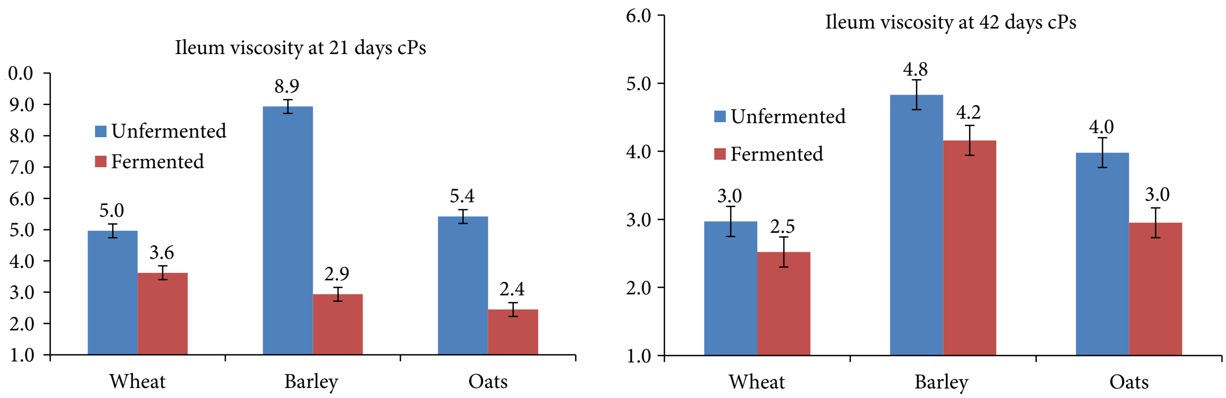

Figure 2. Changes in viscosity (cPs) of ileal contents in broilers at 21 days (SEM = 0.54) and 42 days (SEM = 0.22).

affected by the form of grain or by the interaction effect, but the effects of grain on ileal pH were significant at both 21 and 42 days.

3.3. Development of digestive organs

In the present study, the weights of the digestive tract were expressed as relative weight of the digestive tract (RW) per 100 g of BW. The results in Table 5 show that the RWs of birds at 21 and 42 days were affected by both grain and form ($P < 0.05$), but not by a grain × form interaction ($P > 0.05$). In general, the birds fed oats had significantly higher digestive tract weights than those fed wheat or barley. Diets containing F grains had decreased weights for the total digestive tract at both 21 and 42 days. No effects of dietary treatments on heart weight in broiler chickens were observed in the present study. The liver weight was influenced by grain, form, and the interaction of grain × form at 21 days ($P < 0.05$) but not at 42 days ($P > 0.05$).

The liver weight increased with the F as compared with the UF grains (3.3 vs. 3.1 g/100 g BW, SEM of 0.05). This increase was due mainly to the fermentation of the oat grains (3.8 g/100 g of BW for F oats vs. 3.1 g/100 g of BW for UF oats, SEM of 0.09) as no differences were found between F and UF diets of wheat (2.9 g/100 g of BW for F vs. 3.2 g/100 g of BW for UF) or barley (3.2 g/100 g of BW for F vs. 3.1 g/100 g of BW for UF).

The total length of the digestive tract was not influenced significantly by cereal grain type or the interaction between grain and form ($P > 0.05$), but the effect of form at both 21 and 42 days was significant ($P < 0.05$). Fermentation reduced the length of the digestive tract in all birds fed F grains ($P < 0.05$). This decrease was due mainly to the decrease in the length of the duodenum and the total small intestinal (jejunum + ileum). The lengths of the foregut (from the crop to the end of the gizzard), cecum, and colon remained unchanged by fermentation of the grains.

4. Discussion

The birds in the current study were fed diets high in grain content, the primary source of NSPs, which have antinutritional effects on young birds. The performance of birds fed with wheat and barley did not significantly differ. Birds fed with oats had poorer performance. These results agree with previously reported results (6). They reflect a reduced nutrient uptake by the intestines due to insoluble and/or soluble NSPs (dietary fiber) introduced into the digestive tract at appreciable levels by the feeding of oat-based diets. This, in turn, limits the intake of metabolizable energy by birds (26). This mechanism has been extensively discussed previously (1).

Feeding wetted grain-based diets, which had fermented for an average of 12 h in a previous trial (1), resulted in large increases in FI and WG with better FCR values for broiler chickens when compared with diets containing dry grain. In our study no significant differences were observed in FI in diets containing UF and F and redried grains (4351 vs. 4364 g/b). Moreover, no differences in FI of broiler chickens fed on the diets containing wheat grain supplemented with various types of functional feed additives were detected previously (27). Birds fed on SSF grains exhibited increased WG and FCR by 5.6% and 4.7%, respectively, as compared with birds fed UF grains in our study. Similar results were reported previously for Japanese quails (6). The improvements in WG and FCR values by the SSF are not simply the result of an increase in the voluntary FI by broiler chickens. The mechanism by which WG and FCR were improved appears to be modulated by the functional properties of redried F feed, causing favorable changes at the sites of digestion and absorption from the digestive tract. Birds responded differently to the different types of F grains. This clearly indicates that the effect of SSF on FI depends on the type of cereal grain. In fact, our study detected significant interactions between the grain type and grain form. As a result, the SSF effects on the performance of birds differed among grains. This

Table 5. Parameters of weight and length of digestive organs by fermentation (form) and type of cereals (grain).

	UF			F			SEM	P (Significance)		
	Wheat	Barley	Oats	Wheat	Barley	Oats		Grain	Form	Interaction
Relative weight of digestive tract (g/100 g of body weight)										
21 days	15.0^{a}	16.7^{a}	20.1^{c}	13.0^{a}	13.7^{a}	19.2^{b}	0.6	0.001	0.001	0.321
42 days	6.9^{a}	7.6^{a}	9.3^{b}	6.7^{a}	7.0^{ab}	7.7^{b}	0.3	0.001	0.008	0.111
Relative weight of the heart (g/100 g of body weight)										
21 days	0.71	0.65	0.60	0.69	0.60	0.68	0.04	0.149	0.989	0.273
42 days	0.60	0.56	0.50	0.56	0.50	0.54	0.03	0.074	0.419	0.149
Relative weight of the liver (g/100 g of body weight)										
21 days	3.2^{a}	3.1^{a}	3.1^{a}	3.0^{a}	3.1^{a}	3.8^{b}	0.09	0.001	0.025	0.001
42 days	2.2	2.1	2.2	2.1	2.2	2.1	0.10	0.960	0.623	0.489
Length of digestive tract (cm/b)										
21 days	161.0^{a}	166.8^{a}	156.3^{a}	154.0^{a}	152.4^{a}	156.8^{a}	4.3	0.765	0.057	0.252
42 days	191.7^{a}	211.1^{a}	198.4^{a}	188.4^{a}	194.3^{a}	178.1^{a}	8.2	0.152	0.044	0.532
Length of foregut (cm/b)										
21 days	14.6^{a}	16.4^{b}	16.2^{b}	15.0^{a}	15.8^{a}	15.7^{a}	0.5	0.051	0.576	0.645
42 days	25.1^{a}	25.2^{a}	23.6^{a}	24.7^{a}	23.5^{a}	22.4^{a}	0.8	0.055	0.100	0.720
Duodenal length (cm/b)										
21 days	22.2	22.4	22.1	22.8	20.9	22.1	1.0	0.700	0.680	0.556
42 days	21.5^{a}	23.1^{a}	20.4^{a}	17.2^{a}	18.9^{a}	18.1^{a}	1.0	0.204	0.001	0.576
Intestinal length (cm/b)										
21 days	117.1^{ab}	121.0^{b}	111.9^{a}	109.3^{a}	108.5^{a}	112.0^{a}	3.7	0.753	0.031	0.243
42 days	136.6^{a}	154.2^{a}	146.5^{a}	137.0^{a}	143.0^{a}	130.6^{a}	6.7	0.172	0.106	0.459
Cecal length (cm/b)										
21 days	12.8	11.8	11.9	12.7	11.7	11.8	0.6	0.207	0.823	0.100
42 days	18.0^{a}	17.5^{a}	16.2^{a}	15.6^{ab}	18.7^{b}	14.0^{a}	0.9	0.007	0.231	0.106
Colon length (cm/b)										
21 days	7.0^{a}	7.0^{a}	6.0^{b}	6.8^{a}	7.3^{a}	6.9^{a}	0.3	0.152	0.297	0.260
42 days	8.4^{a}	8.5^{a}	7.8^{a}	9.5^{a}	8.9^{a}	7.0^{b}	0.5	0.020	0.661	0.234

[ab] Means within a row within a form (UF or F) with different superscripts differ ($P < 0.05$).

could be due to different functional properties among untreated grains or other factors induced by the SSF.

On day 21 of the study, the SSF of wheat increased WG and FCR. This may reflect a decreased intestinal viscosity (Figure 1) due to the degradation of some wheat pentosans by SSF. Similar results were reported previously (1,6). Interestingly, on day 42 of the trial the birds fed F wheat had reduced FI although the efficiency of feed utilization was better than that of the birds fed UF wheat. SSF presumably degraded wheat NSPs; the reduced ileal viscosity (Figure 2) is an indirect indication of this degradation. Thus, the birds fed F wheat ate and grew more than the birds fed

UF wheat during the first 21 days. However, from 21 to 42 days, the birds apparently overcame the detrimental effects of the NSPs in wheat and the significant differences in ileal viscosity between F and UF wheat disappeared. The birds fed UF wheat and those fed F wheat grew optimally and at an equal rate. The birds fed F wheat had significantly improved FCR because they ate less feed. Higher carcass yields with F wheat may reflect the reduced weight of the digestive organs of birds fed SSF treated grains.

The performance responses to SSF were different for the birds fed barley-based diets. The FI was not changed by SSF treatment despite responses in growth rate (about a 9% increase) and FCR (about an 8.2% improvement). The degree of reduction in ileal viscosity by SSF treatment was more pronounced for the barley grain than for the other grains, particularly on day 21 (Figure 2). These results match those reported by Kianfar et al. (28), where no significant increase in FI was observed, but increases in FCR and WG were observed in birds on diets containing 40% F barley. Japanese quails also had increased FI, WG, and FCR with a diet of F barley when compared with a control diet based on corn grain (6). The barley grain is a primary source for beta-glucans in broiler chickens and SSF had been shown to reduce the amount of beta-glucans in barley (14), suggesting that fermentation should have increased nutrient or energy bioavailability. This is supported by the large decrease in ileal viscosity (Figure 2). Although digestive tract weights across grains were decreased by SSF treatment (see Table 5), carcass yield was not increased by the SSF treatment of barley.

The SSF of oats did not induce similar performance changes as compared with the SSF of wheat and barley in broiler chickens. Although FI was consistently greater for birds fed F oats, BW only increased at 42 days of treatment and FCR was worse at 21 days of treatment. On day 42, FCR was not different for birds fed F or UF oats. The oat grain contains high amounts of dietary fiber. This probably slows the passage rate of digesta, allowing a sufficient time for nutrient digestion and intestinal uptakes for broiler chickens with relatively low FI. Although carcass yield was improved, the SSF conditions tested do not appear suitable for improving the nutritional value of oat grains for broilers.

When averaged across the grains tested, SSF treatment reduced the viscosity of the ileal contents as well as the RWs of the digestive organs. Zarghi et al. (29) similarly found that enzyme supplementation of cereal grain reduced digesta viscosity and the RWs of the small intestine and pancreas, presumably reflecting more rapid or complete digestion due to reductions in NSP content of cereal grains. These, in turn, improved broiler performance particularly with wheat and barley.

The texture, odor, and smell of the grains at the end of the 8-h fermentation with whey and citrus pomace differed markedly from those of untreated grains. A heavy lactic acid odor was prominent with all F grains. Compared with an average pH value of 5.6 at the start of fermentation, F grains had an average pH of 4.5 immediately after fermentation, and pH remained constant after drying even after 6 months of storage. Samples of SSF treated and untreated grains were stored at room temperature for 6 months after the completion of the animal trail. It was observed that the UF feed developed a musty or oily scent and insect populations after 6 months of storage, but the F grains remained fresh and intact. In previous reports of similar SSF conditions (16), SSF induced favorable physicochemical changes in grains that included a marked reduction in the pH of F feed, degradation of phytic acid, an increase in endogenous phytase activity of the grain, and increased amounts of lactic acid and lactic acid bacteria. Similar changes presumably occurred with SSF treatment of grains in the present study and led to beneficial changes in bird performance.

The nutritional value may be enhanced further by the addition of nutrients from whey and citrus pomace used in the present study. The value of whey and citrus pomace in the SSF treatment of cereal grains has been reported previously (6,8,12,17,20). The SSF process may have produced additional beneficial functional molecules from such products. In addition, the drying process used in the present study may have increased the viability of the microbes present, which may have been beneficial to birds.

In summary, cereal grains (wheat, barley, and oats) were subjected to an SSF process (35 °C of substrate temperature, a pH between 4.0 and 5.0, with the use of whey and citrus pomace and no microbial inoculants for 8 h) and the treated grains were dried at room temperature. Compared with untreated grains, the SSF treated grains fed to growing broilers resulted in reduced digesta viscosity and improved FCR and WG in broilers fed barley, and improved FCR and carcass yield in broilers fed wheat-based diets. No performance benefits from the SSF treatment of oats were detected in the present study. An SSF process could be easily installed in a feed production line.

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