



Original Research Article

Effect of storage time on the characteristics of corn and efficiency of its utilization in broiler chickens

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ABSTRACT

Corn is one of the staple food and feed ingredients in China, therefore its storage is of particular importance. Corn is typically stored for 2 or more years in national barns before it is sold as a food or feed ingredient. However, the effects of stored corn in national barns on the animal performance and nutrient utilization have not been investigated thus far. This study attempted to determine the effects of storage time on the chemical and physical characteristics of corn and its nutritional value, broiler growth performance, and meat quality. Corn grains used in the present study were stored for 4 different periods, from 2 to 5 yr, under the same conditions in a building at the Beijing National Grain Storage Facility. A total of 240 birds in Exp. 1 and 90 birds in Exp. 2 were used to compare the effects of storage time on the utilization of nutrients of corn, the performance, and meat quality of broilers. The content of starch, crude protein, amino acids, fatty acids, and test weight generally decreased with increasing storage time. Corn stored for over 4 yr showed decreased catalase (CAT) and peroxidase (POD) activities and increased fat acidity. Body weight gain (BWG) and European production index (EPI) of broilers from 0 to 3 wk tended to decrease linearly with storage time ($0.05 < P < 0.10$), and the BWG and EPI of broilers from 4 to 6 wk decreased quadratically ($P < 0.05$), whereas feed conversion ratio (FCR) increased with storage time ($P < 0.05$). The FCR, performance, and EPI of broilers positively correlated with CAT activity ($P < 0.05$), and negatively correlated with fat acidity ($P < 0.05$). Drip loss of breast muscle increased linearly with corn storage time ($P < 0.001$); however, pH decreased linearly with corn storage time. Drip loss had a strong negative correlation with POD ($P < 0.05$). There were no significant differences of the storage length on metabolizable energy (ME), digestibility of crude protein, and starch ($P > 0.05$). The digestibility of histidine and arginine, and C18:2 and C18:3 changed quadratically with storage time ($P < 0.05$). Collectively, the results suggest that the use of corn stored for 4 yr in animal feed decreased the performance and meat quality of broilers. Fat acidity, CAT, and POD activities can be used as indexes for evaluating the storage quality of corn.

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1. Introduction

Globally, over 2.58 billion tons of cereal grains such as corn, wheat, and rice (FAO, 2017) are produced annually, and these cereal grains are stored for the purpose of food security and sustainability. Unfortunately, a considerable amount of such stored grains can be lost due to interactions among various physical, chemical, and biological factors (Choct and Hughes, 2000).

Activities of alpha-amylase and beta-amylase are decreased during storage, whereas those of proteases, lipases, and lip-oxygenase of rice are increased (Chrastil, 1990a; Dhaliwal et al., 1991); thus the solubility and digestibility of protein in rice are

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reduced during the storage process (Chrastil, 1990a,b). In addition, during storage, lipid oxidation and free fatty acid content in whole meal flour are increased (Galliard, 1986), and fat acidity in wheat flour is increased whereas iodine-binding values are decreased (Salman and Copeland, 2007). Free fatty acids can be easily oxidized to produce H₂O₂, and thus affect catalase (CAT) and peroxidase (POD) activities in corn (Bailly et al., 2002). The activities of CAT and POD are also affected by cell-membrane lipid peroxidation and are used as indicators to assess the quality of stored corn (Zhou et al., 2007).

Usually, corn is stored for 2 or more years in many countries and then used as a food or feed ingredient. Cabell and Ellis (1955) found a decrease in protein efficiency in corn from 2.72 to 1.81 g after 5 yr of storage; however, no effect was observed in the growth rate of rats fed corn that was stored for as long as 6 yr (Cabell and Ellis, 1955). Bartov (1996) indicated that the chemical composition of corn stored inside a storehouse was relatively stable for at least 110 mo, and the content of metabolizable energy corrected for N (AME_n) was not affected by the storage duration. However, storage conditions likely affect the nutritional value of corn (Bartov, 1996), as indicated by changes in the lysine content. Previous studies have focused on the nutrient utilization of corn stored in good condition or the effect of stored corn on the growth of rats. Little attention has been paid to the effects of corn stored in a natural environment (room temperature in barns) on the animal performance and the utilization of nutrients in broilers.

Thus, the present study determined the effects of storing corn up to 5 yr in national barns on the performance, meat quality, and utilization of energy and nutrients in broiler chickens.

2. Materials and methods

All corn samples used in the present study were stored in brick structures, each of which could hold up to 5,000 t of corn (Yanqing, Beijing, China). The study protocol was approved by the China Agricultural University (Beijing, China) and consistent with the Chinese National Guidelines for Experimental Animals.

2.1. Corn samples

Corn samples stored at room temperature for 2, 3, 4, or 5 yr after harvest were used for the analyses (Table 1). All corn samples were yellow corn, which were sun-dried to attain a moisture content of 15% or less to prevent microbial growth. No information on the varieties of corn was available. At the storage facility, corn was treated with phosphine every year to control insects and weevils, and an axial flow ventilator was used to aerate the facility to reduce the temperature and moisture to prevent mycotoxin contamination.

2.2. Characterization of the corn

The content of dry matter, crude protein (CP), amino acids, fatty acids, and the CAT and POD activities were determined (Table 1). Dry matter was determined by drying samples at 105 °C using a forced-air drying oven (AOAC, 1995). Nitrogen content was determined by the Kjeldahl method (AOAC, 1995), and CP content was calculated as N × 6.25. The amino acid content was determined by HPLC (Agilent 1200, Santa Clara, CA, USA) as described by Ravindran et al. (2009). The fatty acids content was determined using gas chromatography GC-17A (Shimadzu, Kyoto, Japan) according to Sukhija and Almquist (1988). Catalase and POD activities were determined according the method described by Cakmak et al. (1993).

Table 1

Selected nutrient components of corn stored for different years (air dry basis).¹

Item	Corn storage time, yr			
	2	3	4	5
Moisture, %	11.42	11.50	11.10	12.40
Test weight, g/L	719.0	718.5	718.5	687.5
CP, %	6.97	7.58	7.12	7.15
Amino acid, %				
Asp	0.46	0.48	0.47	0.43
Thr	0.26	0.27	0.27	0.25
Ser	0.33	0.36	0.36	0.33
Glu	1.47	1.54	1.51	1.44
Pro	0.58	0.63	0.62	0.60
Gly	0.27	0.28	0.28	0.26
Ala	0.52	0.54	0.52	0.51
Cys	0.19	0.19	0.20	0.18
Val	0.43	0.42	0.42	0.40
Met	0.18	0.11	0.14	0.15
Ile	0.23	0.24	0.24	0.23
Leu	0.84	0.88	0.85	0.84
Tyr	0.16	0.18	0.15	0.15
Phe	0.28	0.35	0.27	0.33
Lys	0.22	0.37	0.23	0.34
His	0.23	0.31	0.24	0.27
Arg	0.27	0.28	0.27	0.25
Fatty acid, mg/g				
C16:0	3.09	3.28	3.01	2.81
C16:1	0.03	0.03	0.03	0.03
C18:0	0.34	0.38	0.33	0.30
C18:1	6.11	6.74	5.86	5.19
C18:2	11.38	12.27	10.55	9.69
C18:3	0.28	0.31	0.26	0.22
C20:1	0.07	0.04	0.07	0.07
Catalase activity, mg H ₂ O ₂ /g	151.1	151.6	183.8	6.8
Peroxidase activity, U/g per min	381.9	595.2	416.3	159.3
Acidity of fatty acids, KOH mg/100 g dry matter	56.2	48.8	54.5	108.1

¹ Analysis based on a duplicate.

2.3. Broiler chickens, management, and sample collection

In Exp. 1, a total of 192 one-day-old Cobb 500 female broiler chickens from a local hatchery were used. The broiler chickens were randomly allotted to 4 dietary treatments with 8 replicates of 6 broiler chickens per pen. The 4 dietary treatments for the starter (0 to 3 wk) and grower (4 to 6 wk) phases were established using corn stored for 2, 3, 4, or 5 yr. Thus, the only difference among the experimental diets was the corn used. The basal starter and grower diets met or exceeded the nutritional recommendations by the Chinese Ministry of Agriculture (2004) except linoleic acid (Table 2).

Boiler chickens were weighed at hatching and at 3 and 6 wk after a 6-h fasting, and feed intake (FI) was recorded from 0 to 3 wk and from 4 to 6 wk to determine body weight gain (BWG) and feed conversion ratio (FCR). Mortality and culling were recorded daily for each pen and were used to determine the European production index (EPI) = 100 × [BWG (kg) × livability (%)]/[FCR × age (d)].

At d 42, 1 bird from each of the 6 pens, were selected randomly, weighed, and sacrificed by intravenous injection of sodium pentobarbital after fasting for >10 h. The breast muscle was removed, and its pH and drip loss were measured. The pH was measured by direct insertion of an electrode (Testo 205; Testo Pty Ltd., Testo AG, Lenzkirch, Germany) into 1 cm below the left major pectoralis muscle. Drip loss of raw muscle of breast was determined by placing the sample in a plastic bag and hanging it in a refrigerator at 4 °C for 24 h; it was calculated as the weight lost from the initial weight and expressed as a percentage.

In Exp. 2, one-day-old Cobb 500 female chickens were allotted to 4 dietary treatments with 6 replicates of 18 birds per pen. The

Table 2
Composition of the basal experimental diets (Exp. 1).

Item	Starter (0 to 3 wk)	Grower (4 to 6 wk)
Ingredient, %		
Corn	62.80	72.00
Soybean meal	24.60	9.00
Corn gluten meal	8.00	12.00
Rapeseed meal	—	2.40
Dicalcium phosphate	1.80	1.60
Limestone	1.24	1.20
NaCl	0.35	0.30
Trace mineral premix ¹	0.20	0.20
Vitamin premix ²	0.02	0.02
Choline chloride (50%)	0.16	0.14
Lys-HCl (98%)	0.45	0.65
Dl-Met (98%)	0.14	0
L-Thr (98%)	0.06	0.09
L-Trp (98%)	0	0.05
L-Arg	0.18	0.35
Calculated analysis, %		
AME, kcal/kg	2,900	3,050
Crude protein	21.00	18.50
Total Lys	1.15	1.00
Total Met	0.45	0.35
Total Met + Cys	0.85	0.65
Total Thr	0.82	0.73
Total Trp	0.21	0.20
Total Arg	1.20	1.12
Ca	1.00	0.90
Available P	0.42	0.40

¹ Provided per kilogram of diet: Fe, 100 mg (FeSO₄·H₂O); Cu, 10 mg (CuSO₄·5H₂O); Zn 120 mg (ZnSO₄·H₂O); Mn 100 mg (MnSO₄·H₂O); Se 0.3 mg (Na₂SeO₃); and I, 0.7 mg (CaI₂·H₂O).

² Provides per kilogram of diet: vitamin A, 12,500 IU; vitamin D₃, 2,500 IU; vitamin E, 18.75 IU; vitamin K, 2.65 mg; niacin, 36.8 mg; pantothenic acid, 12 mg; folic acid, 1.25 mg; thiamin, 2.5 mg; riboflavin, 6.6 mg; pyridoxine, 4.9 mg; vitamin B₁₂, 0.025 mg; and biotin, 0.013 mg.

chickens were fed different diets composed of the same 4 corn samples as used in Exp. 1 (Table 3). On d 19, 18 chickens of a similar body weight from each treatment were selected and transferred to metabolic cages with 6 replicates per treatment. They received 23 h of continuous light and 1 h of darkness, and the initial temperature was set at 33 °C and then gradually reduced to 21 °C by d 21. Feed and water were provided *ad libitum*.

After 14 h of fasting, birds were fed the diets for 58 h and then fasted again for 14 h. All excreta were collected during the 72-h period, and samples collected every 24-h period were stored at -20 °C until analysis. At the end of the feeding period, feed intake was recorded.

The excreta for each cage were weighed, mixed, and sub-sampled. They were then dried at 65 °C, ground, and assayed for starch, CP, amino acids, fatty acids, and gross energy. Feed samples

Table 3
Composition of the diet for metabolism study (Exp. 2).

Ingredient, %	Content
Corn	96.40
Dicalcium phosphate	1.80
Limestone	1.23
NaCl	0.35
Trace mineral premix ¹	0.20
Vitamin premix ²	0.02

¹ Provided per kilogram of diet: Fe, 100 mg (FeSO₄·H₂O); Cu, 10 mg (CuSO₄·5H₂O); Zn 120 mg (ZnSO₄·H₂O); Mn 100 mg (MnSO₄·H₂O); Se 0.3 mg (Na₂SeO₃); and I, 0.7 mg (CaI₂·H₂O).

² Provided per kilogram of diet: vitamin A, 12,500 IU; vitamin D₃, 2,500 IU; vitamin E, 18.75 IU; vitamin K, 2.65 mg; niacin, 36.8 mg; pantothenic acid, 12 mg; folic acid, 1.25 mg; thiamin, 2.5 mg; riboflavin, 6.6 mg; pyridoxine, 4.9 mg; vitamin B₁₂, 0.025 mg; and biotin, 0.013 mg.

were also assayed for CP, amino acids, fatty acids, starch, and gross energy. Crude protein, amino acids, and fatty acids of fecal samples were analyzed in a manner similar to the corn samples. Starch content was analyzed using the α -amylase glucosidase method (AOAC, 1995). Gross energy was measured with an adiabatic bomb calorimeter (Gallenkamp Autobomb, London, UK).

2.4. Statistical analysis

Data were analyzed using SPSS (Version 15.0), and the results are presented as means and SEM. Linear and quadratic effects were assessed, and results were considered significant at $P < 0.05$, whereas the results with $0.05 < P < 0.10$ were considered as trends. The percentage values were transformed by an arcsine function before the statistical analysis was performed, and the correlation between corn characteristics and growth performance was assessed.

3. Results

3.1. Chemical composition

The chemical analyses of corn stored for different durations are shown in Table 1. The moisture content was similar among the 4 samples, and corn stored for 2, 3, or 4 yr showed no differences in test weight, whereas corn stored for 5 yr had a lower test weight than others. The content of CP, amino acids, and fatty acids generally decreased with increasing years of corn storage. There were large differences in CAT and POD activities as well as in fat acidity; moreover, corn stored for 5 yr showed a greater decrease in CAT and POD activities and an increase in fat acidity.

3.2. Broiler performance

The performance of broilers fed different stored corn is shown in Table 4. There were no significant differences in FI from 0 to 3 wk, 4 to 6 wk, or 0 to 6 wk among broilers fed different corn samples ($P > 0.05$).

Storage time had a significant effect on BWG: it tended to linearly decrease BWG from 0 to 3 wk ($0.05 < P < 0.10$), and quadratically decrease it from 4 to 6 wk ($P < 0.05$) and from 0 to

Table 4
Growth performance of broiler chickens fed corn stored for 2, 3, 4, or 5 yr (Exp. 1).¹

Item	Corn storage time, yr				SEM	P-value	
	2	3	4	5		Linear	Quadratic
Feed intake, kg							
wk 0 to 3	0.82	0.81	0.81	0.85	0.015	0.544	0.522
wk 4 to 6	2.13	2.13	2.13	2.04	0.022	0.217	0.313
wk 0 to 6	2.95	2.94	2.94	2.89	0.030	0.584	0.579
Body weight gain, kg							
wk 0 to 3	0.58 ^a	0.55 ^{ab}	0.56 ^{ab}	0.54 ^b	0.006	0.055	0.748
wk 4 to 6	1.09 ^{bc}	1.15 ^a	1.12 ^{ab}	1.07 ^{bc}	0.011	0.393	0.021
wk 0 to 6	1.67	1.70	1.68	1.61	0.009	0.091	0.062
FCR							
wk 0 to 3	1.41 ^{ab}	1.47 ^{ab}	1.31 ^b	1.57 ^a	0.028	0.085	0.547
wk 4 to 6	1.95 ^a	1.85 ^{bc}	1.91 ^b	1.91 ^b	0.012	0.339	0.045
wk 0 to 6	1.77	1.73	1.75	1.79	0.013	0.164	0.069
EPI ²							
wk 0 to 3	213 ^a	197 ^{ab}	202 ^a	178 ^b	5.3	0.041	0.699
wk 4 to 6	270 ^c	298 ^a	282 ^{bc}	269 ^c	4.1	0.541	0.010
wk 0 to 6	234 ^{bc}	242 ^a	236 ^{ab}	221 ^c	2.4	0.023	0.008

^{a-c} Means within a row lacking a common superscript differ ($P < 0.05$).

¹ Data are means of 8 replicate pens with 6 female broiler chickens per pen, and experiment lasted for 42 d.

² European production index (EPI) = $100 \times [\text{BW (kg)} \times \text{Livability (\%)}] / [\text{FCR} \times \text{Age (d)}]$.

6 wk ($0.05 < P < 0.10$). Storage time also significantly affected FCR; it quadratically increased FCR from 4 to 6 wk ($P < 0.05$), and tended to increase it from 0 to 6 wk ($0.05 < P < 0.10$). Storage time linearly decreased the EPI of broilers from 0 to 3 wk ($P < 0.05$) and quadratically decreased it from 4 to 6 wk ($P < 0.05$) and from 0 to 6 wk ($P < 0.01$). Corn stored for 5 yr significantly increased EPI of broilers from 0 to 6 wk as compared to corn stored for 3 or 4 yr ($P < 0.05$).

3.3. Meat quality

Storage time significantly affected drip loss and pH of breast muscle ($P < 0.001$; Table 5). Corn stored for 5 yr significantly increased drip loss and decreased the pH of breast muscle as compared to corn stored for 2, 3, or 4 yr ($P < 0.001$).

3.4. Digestibility measurements

Storage time on digestibility of nutrients is shown in Table 6. No significant differences in metabolizable energy (ME) were observed in both the fresh sample and on a dry matter basis, CP, or starch digestibility among the different corn storage ages ($P > 0.05$). Furthermore, there were no significant differences in the digestibility of most amino acids, except isoleucine, histidine, and arginine. The digestibility of histidine and arginine quadratically changed with storage time ($P < 0.05$), and the digestibility of isoleucine tended to be affected by storage time ($P < 0.10$).

There were no significant differences in the digestibility of C16:0, C16:1, C18:0, and C18:1 among the 4 different storage times evaluated. However, the digestibility of C18:2 and C18:3 quadratically changed with storage time ($P < 0.05$).

3.5. Correlations

Correlations of corn characteristics and bird performance are shown in Table 7. Fat acidity was negatively correlated with CAT activity ($P < 0.05$) whereas FI from 0 to 6 wk was positively correlated with the CAT activity ($P < 0.05$). There was a strong negative correlation with the fat acidity ($P < 0.05$) of corn. The body weight of birds at 6 wk showed a significant positive correlation with CAT ($P < 0.05$). However, the opposite trend was noted for fat acidity ($P < 0.05$), that is, its correlation with body weight was negative. The FCR of birds from 0 to 6 wk showed a positive correlation with CAT ($P < 0.05$) and negative correlation with fat acidity ($P < 0.001$). The EPI had a strong positive correlation with CAT ($P < 0.05$), and a strong negative correlation with fat acidity ($P < 0.01$). Drip loss showed a negative correlation with POD ($P < 0.05$).

4. Discussion

Previous studies have shown that changes in the chemical composition and nutritive value of cereal grains might occur during

Table 5
Effects of corn stored for different years on breast-muscle quality in broiler chickens at d 42 (Exp. 1).¹

Item	Corn storage time, yr				SEM	P-value	
	2	3	4	5		Linear	Quadratic
% of body weight	19.22	20.40	19.75	19.52	0.315	0.243	0.837
Drip loss, %	2.25 ^b	2.93 ^b	1.86 ^b	3.54 ^a	0.161	<0.001	0.001
pH	5.68 ^a	5.53 ^a	5.57 ^a	5.25 ^b	0.038	<0.001	0.113

^{a,b} Means within a row lacking a common superscript differ ($P < 0.05$).

¹ Data are means of 6 replicates per treatment with one randomly selected broiler chicken from each of 6 pens, which were selected randomly from 8 pens.

Table 6
Effects of corn stored for different years on energy and nutrient metabolism in female broiler chickens at 3 wk of age (Exp. 2).¹

Item	Corn storage time, yr				SEM	P-value	
	2	3	4	5		Linear	Quadratic
ME, MJ/kg as-fed	13.50	13.59	13.50	13.42	0.057	0.473	0.660
ME, MJ/kg DM	15.30	15.34	15.17	15.30	0.064	0.853	0.811
Digestibility, %							
Starch	91.64	82.62	91.40	90.02	0.023	0.726	0.136
CP	76.50	75.83	79.17	77.33	0.010	0.889	0.637
Amino acids							
Asp	79.17	81.67	77.67	76.75	0.012	0.843	0.740
Thr	73.33	75.83	71.50	70.83	0.014	0.329	0.445
Ser	80.17	82.67	80.50	80.00	0.011	0.235	0.468
Glu	88.67	89.07	87.33	88.00	0.007	0.780	0.324
Pro	85.33	87.83	84.33	85.67	0.008	0.514	0.965
Ala	85.83	88.00	85.00	86.17	0.008	0.685	0.824
Cys	83.83	84.33	83.17	82.83	0.007	0.588	0.533
Val	79.50	80.33	77.00	77.17	0.011	0.261	0.674
Met	84.50	77.80	84.83	86.17	0.019	0.129	0.866
Iso	82.17	84.50	81.17	82.33	0.010	0.172	0.057
Leu	87.33	88.17	86.50	87.50	0.006	0.764	0.755
Tyr	80.17	83.67	78.17	80.83	0.016	0.880	0.971
Phe	80.83	75.17	82.83	77.33	0.016	0.763	0.779
Lys	71.83	88.50	79.83	86.83	0.016	0.765	0.830
His	89.30 ^c	93.67 ^a	90.83 ^b	90.17 ^b	0.009	0.001	0.029
Arg	87.00	89.17	86.83	86.67	0.012	0.915	0.025
Fatty acids							
C16:0	69.11	70.80	68.78	68.78	0.022	0.590	0.498
C16:1	59.00	53.40	58.00	55.60	0.067	0.683	0.399
C18:0	37.00	38.50	30.50	35.80	0.043	0.487	0.202
C18:1	70.68	68.33	64.50	69.83	0.021	0.683	0.150
C18:2	79.67	82.83	69.00	79.00	0.037	0.068	0.028
C18:3	81.17 ^c	90.83 ^a	71.00 ^d	86.67 ^{ab}	0.026	0.004	0.001

^{a-d} Means within a row lacking a common superscript differ ($P < 0.05$).

¹ Data are means of 6 replicates per treatment and 3 broiler chickens per replicate.

Table 7
Main correlations between corn characteristics and growth performance.

Item	r	P-value
Fat acidity and CAT	-0.986	0.023
FI (wk 0 to 6) and CAT	0.973	0.045
FI (wk 0 to 6) of age and fat acidity	-0.934	0.020
BW (wk 6) and CAT	0.901	0.037
FCR (wk 0 to 6) and CAT	0.981	0.036
FCR (wk 0 to 6) and fat acidity	-0.995	<0.010
EPI (wk 0 to 6) and CAT	0.992	0.048
EPI (wk 0 to 6) and fat acidity	-0.996	<0.010
Drip water loss and POD	-0.983	0.019

CAT = activity of catalase; FI = feed intake; EPI = European production index; POD = activity of peroxidase.

storage (Galliard, 1986; Chrastil, 1990a,b; Dhaliwal et al., 1991; Abera and Rakshit, 2004). In the present study, we found that fat acidity increased significantly in corn stored for 5 yr, suggesting that stored corn could have increased lipid oxidation and free fatty acid content (Galliard, 1986). Zhou et al. (2007) showed that CAT and POD could be used as indexes for evaluating the quality of stored corn, and that corn was suitable for storage when POD vigor was greater than 400 units. However, corn was not suitable for storage at a POD value between 250 and 400 units. In the present study, corn stored for 5 yr showed significantly decreased CAT and POD activities, with the POD activity being lower than 250 units. These results confirm the finding of previous studies that CAT and POD activities gradually decreased with time (Zhang et al., 2008). Furthermore, these findings suggest that the maximum period for corn storage should be 4 yr. The present study found that fat acidity and CAT significantly correlated with broiler performance, indicating that these could be used as indexes to evaluate the quality of stored corn.

Previous studies have shown that corn storage might cause starch retrogradation and lead to resistant starch (RS) formation (García-Rosas et al., 2009). The content of lower molecular-weight peptides decrease and that of higher molecular-weight peptides increase during storage (Chrastil and Zarins, 1992). Moreover, the molecular weight of the protein in rice grains increases owing to the formation of disulfide bond during storage (Chrastil, 1992), thus reducing grain-protein solubility and digestibility (Chrastil, 1990a,b). The present study showed that storage for 5 yr did not affect the digestibility of starch and CP in corn. However, the digestibility of isoleucine, histidine, and arginine tended to change quadratically with the storage time. This result suggests that storing corn for more than 4 yr can have a negative impact on the digestibility of amino acids.

Pomeranz (1974) reported that the long-term storage of cereal grain resulted in decreased fat content and increased free fatty acid content. In the present study, we did not determine the content of free fatty acids in corn. However, the total concentrations of C16:0, C18:0, C18:1, C18:2, and C18:3 tended to decrease with storage time. This indicated that some fatty acids oxidized during storage, and this finding was consistent with the higher fat acidity in corn stored for 5 yr. This result was in accordance with those of Nishiba et al. (2000), who showed that triacyl-glycerides are degraded during storage, and the absolute amounts of both oleic and linoleic acids in the neutral lipid-fraction decrease during storage, whereas the free fatty acid fraction increases. Hasjim et al. (2009) showed that free fatty acids could form a helical complex with amylose or amylopectin, and alter the physical and nutritional properties of the grain and its final products. This might be the reason that the digestibility values for C18:2 and C18:3 and isoleucine, histidine, and arginine were lower in corn stored for 5 yr than in corn stored for 3 yr.

The present study, however, did not find any differences in ME values between the different corn samples, in sun-dried samples as well as on a dry-matter basis. This is in agreement with the results of Bartov (1996), who showed that the AME_n content was not significantly affected by the storage duration. However, this study found that the storage time tended to linearly decrease the BWG of broilers from 0 to 3 wk, and quadratically decrease it from 4 to 6 wk, which is different from the results of Cabell and Ellis (1955), who indicated that corn stored for as much as 6 yr did not affect rat growth. The current result might be related to the lower content of starch, CP, and amino acids, and the lower content and digestibility of C18:2 and C18:3, lower CAT and POD activity, and higher fat acidity in corn stored more than 4 yr. Although the performance of broilers from 4 to 6 wk was worse when they were fed corn stored for 3 and 4 yr than when fed corn stored for 2 yr, the mechanism underlying this difference needs to be further investigated. In the present study, the bodyweight of broiler chickens did not reach the standard, which might be because of the mashed diet and lower linoleic acid content in the diet. The linoleic acid content in a diet prepared using corn stored for 2, 3, 4, and 5 yr was 0.71%, 0.77%, 0.66%, and 0.61%, respectively, which was lower than the recommended requirement of 1% in the broiler chicken diet.

Drip loss can indicate quality deviations associated with the rate and extent of postmortem glycolysis in muscle tissue. The volume of drip loss is related to the lipid peroxide content in muscle (Tavárez et al., 2011). Meat pH indicates lactic acid production, and hence, the anaerobic metabolic decomposition of the glycogen reserves in the muscles. In the present study, the drip loss increased linearly with storage time, and pH decreased linearly with storage time. Corn stored for 5 yr resulted in a significantly lower pH and increased drip loss. The correlations between drip loss and corn characteristics indicated that drip loss was highly negatively correlated with POD activity in corn. The present study indicated that corn stored for 5 yr decreased the quality of breast muscle.

Moreover, it suggests that corn stored for over 4 yr lowers the meat quality of breast muscle.

5. Conclusions

The content of starch, CP, and amino acids in corn decreased with storage time. The CAT and POD activities were significantly decreased and fat acidity increased, when corn was stored for more than 4 yr in national grain storage barns. Although the digestibility of starch, CP, and AME of corn was not affected by storage for 5 yr, corn stored for over 4 yr resulted in decreased performance and meat quality in broilers. Therefore, when used as a feed ingredient, corn should be stored for no more than 4 yr if possible.

Conflict of interest

The authors certify that there is no financial and (or) personal relationships with other individuals or organizations that can affect the current research project improperly, or no professional or personal interest of any nature or kind in any product, service, and (or) organization that could be construed as influencing the present article.

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