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 (FAQ, 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 lipoxygenase of rice are increased (Chrastil, 1990a; Dhaliwal et al., 1991); thus the solubility and digestibility of protein in rice are
reduced during the storage process (Chrastil, 1990a,b). In addition, during storage, lipid oxidation and free fatty acid content in whole meal 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 for 2, 3, 4, or 5 yr (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. 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 ow ventilator was used to aerate the facility. 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 high-performance liquid chromatography (HPLC) (Agilent 1200, Santa Clara, CA, USA) as described by Ravindran et al. (2009). The fatty acid content was determined using gas chromatography GC-17A (Shimadzu, Kyoto, Japan) according to Sukhija and Almqvist (1988). Catalase and POD activities were determined according the method described by Cakmak et al. (1993).

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 acid content was determined using gas chromatography GC-17A (Shimadzu, Kyoto, Japan) according to Sukhija and Almqvist (1988). Catalase and POD activities were determined according the method described by Cakmak et al. (1993).

Table 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 | 3.04 | 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 |
| Peroxidase activity, U/g per min | 151.1 | 151.6 | 183.8 | 6.8 |
| O2/g | 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.

At d 42, 1 bird from each of the 6 pens, were selected randomly, and feed conversion ratio (FCR) was calculated as the weight lost from the initial weight and expressed as a percentage.
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 body weight from each treatment were selected and transferred to metabolic cages with 6 replicates per treatment. They received 23 h

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 premix¹ | 0.20 |
| Vitamin premix² | 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 (CaIO₃·H₂O).
² Provides per kilogram of diet: vitamin A, 12,500 IU; vitamin D₃, 2,500 IU; vitamin E, 18.75 IU; vitamin K, 2.40 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.

3. Results

3.1. Chemical composition

The chemical analyses of corn stored for different durations are shown in Table 3. 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 (P < 0.10), and quadratically decrease it from 4 to 6 wk (P < 0.05) and from 0 to 6 wk (P < 0.05).
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 Amino acids. The digestibility of histidine and arginine quadratically increased FCR from 4 to 6 wk (P < 0.05), whereas FI from 0 to 6 wk was positively correlated with body weight at 6 wk (0.05 < P < 0.10). 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 storage (Galliard, 1986; Chrustil, 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 could have increased lipid oxidation and free fatty acid content (P < 0.001; Table 5). Corn stored for 5 yr signification 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. (2009), who showed that the acyl-glycerides were 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 amylase 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 AMEn 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 fat 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 personal interest of any nature or kind in any product, service, and (or) organization that could be construed as influencing the present article.

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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References

Abera S, Rakshit SK. Effect of dry cassava chip storage on yield and functional properties of extracted starch. Starch 2004;56:232–40.

AOAC. Official methods of analysis. 16th ed. Washington, DC: Assoc. Off. Anal. Chem.; 1995.

Bailly C, Bogatek-Leszcynska R, Côme D, Corbione F. Changes in activities of antioxidant enzymes and lipoygenase during growth of sunflower seedlings from seeds of different vigour. Seed Sci Res 2002;12:47–55.

Bartov I. Effect of storage duration on the nutritional value of corn kernels for broiler chicks. Poul Sci 1996;75:1524–7.

Cabell CA, Ellis NR. Feeding value of stored corn. J Anim Sci 1955;14:1167–73.

Calmik I, Strbac D, Marschner H. Activities of hydrogen peroxide-scavenging enzymes in germinating wheat seeds. J Exp Bot 1993;44:127–32.

Choc M, Hughes RJ. The new season grain phenomenon: the role of endogenous glycans in the nutritive value of cereal grains in broiler chickens. Published by the “Rural Industries R&D Corporation” of Australia; 2000. https://rirdc.infoservices.com.au/downloads/00-143.

Chrastil J. Protein-starch interaction in rice grains. Influence of storage on oryzin and starch. J Agric Food Chem 1990a;38:1804–9.

Chrastil J. Chemical and physicochemical changes of rice during storage at different temperatures. J Cereal Sci 1990b;11:71–85.

Chrastil J. Correlations between the physicochemical and functional properties of rice. J Agric Food Chem 1992:40:1683–6.

Chrastil J, Zarins ZM. Influence of storage on peptide subunit composition of rice oryzin. J Agric Food Chem 1992;40:927–30.

DhalIW YS, Sekhon OS, Ngi HS. Enzymatic activities and rheological properties of stored rice. Cereal Chem 1991;68:18–21.

FAOSTAT (Online database. FAO). United Nations Food and Agriculture Organisation. 2017. http://faostat.fao.org.

Galliard T. Hydrolytic and oxidative degradation of lipids during storage of whole meal flour: effects of bran and germ components. J Cereal Sci 1986;4:179–92.

García-Rosas M, Bello-Pérez A, Yee-Madeira H, Ramos G, Flores-Morales A, Mora-Escobedo R. Resistant starch content and structural changes in corn (Zea mays) tortillas during storage. Starch 2009;61:414–21.

Hasjim J, Srichuwong S, Scott MP, Jane J. Kernel composition, starch structure, and enzyme digestibility of opaque-2 corn and quality protein corn. J Agric Food Chem 2009;57:2040–55.

Ministry of Agriculture. Feeding standard of chicken (NY/T 33-2004). Beijing, China: Agricultural Standard Council, Ministry of Agriculture; 2004.

Nishiba Y, Sato T, Suda. Convenient method to determine free fatty acid of rice using thin-layer chromatography and flame-ionization detection system. Cereal Chem 2000;77:223–9.
Pomeranz Y. Biochemical, functional, and nutritive changes during storage. In: Christensen CM, editor. Storage of cereal grains and their products. St. Paul, MN, US: Am. Assoc. Cereal Chem.; 1974. p. 56–144.

Ravindran V, Morel PCH, Rutherfurd SM, Thomas DV. Endogenous flow of amino acids in the avian ileum is increased by increasing dietary peptide concentrations. Br J Nutr 2009;101:822–8.

Salman H, Copeland L. Effect of storage on fat acidity and pasting characteristics of wheat flour. Cereal Chem 2007;84:600–6.

SPSS. Command syntax reference, 15.0. Chicago, IL, US: SPSS Inc.; 2006.

Sukhija PS, Almquist DL. Rapid method for determination of total fatty acid content and composition of the feedstuffs and feces. J Agric Food Chem 1988;36:1202–6.

Tavárez MA, Boler DD, Bess KN, Zhao J, Yan F, Dilger AC, et al. Effect of antioxidant inclusion and oil quality on broiler performance, meat quality, and lipid oxidation. Poult Sci 2011;90:922–30.

Zhang Y, Zhou X, Zhang Y. Research on membrane lipid peroxidation and physiological parameters of storage corn. Sci Agric Sin 2008;41:3410–4.

Zhou X, Zhang Y, Zhang Y. Studies on membrane lipid peroxidative indexes of stored-corn. J Corn Sci 2007;15:80–3.