Comparative Study on Energy Utilization of Distillers Dried Grains and Fermented Distillers Dried Grains in Chickens, Ducks, and Geese: Postprint

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Abstract

This experiment was conducted to evaluate the nutritional composition of distiller' s grains and fermented distiller' s grains, as well as the simulated digestive gross energy (SDGE) and metabolizable energy (ME) for chickens, ducks, and geese, using the simulated digestion method and biological method (precision feeding with emptying), respectively.

The results showed: 1) The dry matter, crude protein, crude ash, and total phosphorus contents in distiller' s grains were 85.63%, 18.43%, 1.49%, and 0.21%, respectively, all significantly lower than those in fermented distiller' s grains (89.15%, 24.75%, 2.37%, and 0.38%) (P<0.05); the crude fat and crude fiber contents in distiller' s grains were 4.64% and 24.15%, respectively, both significantly higher than those in fermented distiller' s grains (3.61% and 15.50%) (P<0.05).

2) The SDGE of distiller' s grains for chickens, ducks, and geese were 11.15, 11.54, and 10.02 MJ/kg, respectively, all significantly lower than those of fermented distiller' s grains (11.86, 12.23, and 10.78 MJ/kg) (P<0.05).
3) For distiller' s grains, Cherry Valley meat ducks exhibited an apparent metabolizable energy (AME) of 10.42 MJ/kg, a true metabolizable energy (TME) of 11.29 MJ/kg, and an apparent energy utilization rate of 55.01%, all significantly higher than those of Xinghua roosters (AME 8.13 MJ/kg, TME 9.39 MJ/kg, apparent energy utilization rate 44.79%) and Sichuan white geese (AME 8.20 MJ/kg, TME 9.16 MJ/kg, apparent energy utilization rate 43.91%) (P<0.05); however, no significant differences were observed in AME, TME, apparent energy utilization rate, or true energy

utilization rate of fermented distiller' s grains among Xinghua roosters, Cherry Valley meat ducks, and Sichuan white geese ($P>0.05$).

In conclusion, fermented distiller' s grains contained higher crude protein and total phosphorus but lower crude fiber than distiller' s grains; chickens, ducks, and geese exhibited higher SDGE values for fermented distiller' s grains than for distiller' s grains; Cherry Valley meat ducks showed higher ME for distiller' s grains than Xinghua roosters and Sichuan white geese; however, no differences in ME for fermented distiller' s grains were found among Xinghua roosters, Cherry Valley meat ducks, and Sichuan white geese.

Full Text

Abstract

This experiment was conducted to study the nutrient contents in distiller's grains and fermented distiller' s grains, and to determine the simulative digestion of gross energy (SDGE) and metabolizable energy (ME) of distiller's grains and fermented distiller' s grains from cocks, ducks, and geese using simulated digestion methods and biological methods (emptying and gavage). The results showed as follows: 1) The contents of dry matter (85.63%), crude protein (18.43%), ash (1.49%), and total phosphorus (0.21%) in distiller' s grains were significantly lower than the contents of dry matter (89.15%), crude protein (24.75%), ash (2.37%), and total phosphorus (0.38%) in fermented distiller' s grains ($P<0.05$). The contents of crude fat and crude fiber in distiller' s grains were 4.64% and 24.15%, respectively, which were significantly higher than the contents of crude fat (3.61%) and crude fiber (15.50%) in fermented distiller' s grains ($P<0.05$). 2) The SDGE of distiller' s grains in cocks, ducks, and geese were 11.15, 11.54, and 10.02 MJ/kg, respectively, which were significantly lower than the SDGE of fermented distiller' s grains in cocks (11.86 MJ/kg), ducks (12.23 MJ/kg), and geese (10.78 MJ/kg) ($P<0.05$). 3) The apparent metabolizable energy (AME) was 10.42 MJ/kg, the true metabolizable energy (TME) was 11.29 MJ/kg, and the energy apparent availability was 55.01% for distiller' s grains in Cherry Valley ducks, which were significantly higher than the AME (8.13 MJ/kg), TME (9.39 MJ/kg), and energy apparent availability (43.91%) of distiller' s grains in Xinghua cocks and the AME (8.20 MJ/kg), TME (9.16 MJ/kg), and energy apparent availability (44.79%) of distiller' s grains in Sichuan white geese ($P<0.05$). The AME, TME, energy apparent availability, and energy true availability of fermented distiller' s grains in Cherry Valley ducks, Xinghua cocks, and Sichuan white geese showed no significant differences ($P>0.05$). In conclusion, the contents of crude protein and total phosphorus in fermented distiller' s grains are higher than those in distiller' s grains, while the crude fiber content is lower than that in distiller' s grains. The SDGE of fermented distiller' s grains in cocks, ducks, and geese is higher than that of distiller' s grains. The ME of distiller' s grains in Cherry Valley ducks is higher than that of distiller' s grains in Xinghua cocks and Sichuan white geese. The ME of fermented distiller' s grains shows

no significant effect among Cherry Valley ducks, Xinghua cocks, and Sichuan white geese.

Keywords: distiller’ s grains; fermented distiller’ s grains; cocks; ducks; geese; SDGE; ME

1. Materials and Methods

1.1 Experimental Design

1.1.1 Experimental Materials and Treatment Distiller’ s grains and fermented distiller’ s grains were provided by Hubei High Biological Technology Co., Ltd. The fermented distiller’ s grains were prepared by inoculating distiller’ s grains with a compound microbial strain (isolated and preserved by our laboratory) at a ratio of 0.3% and fermenting at 48–50°C for 25–50 hours to obtain the fermented distiller’ s grains after 48–72 hours of drying.

1.1.2 Preparation of Simulated Digestive Juices Preparation of gastric juice: Pepsin (Sigma P7000) was added to a 2.0 pH dilute hydrochloric acid solution to prepare a gastric juice with an enzyme activity of 1,475 U/mL, with 250 mL of gastric juice prepared for each sample.

Preparation of intestinal juice: The intestinal juice for cocks, ducks, and geese was prepared using trypsin (Amresco 0458) at activities of 13.55, 29.92, and 18.34 kU, amylase (Amresco 0164) at activities of 3.11, 10.73, and 3.09 kU, and lipase (Sigma A3306) at activities of 110.40, 110.43, and 97.08 kU, respectively.

Preparation of small intestine digestive juice: 2.17 g of sodium dihydrogen phosphate and 1.57 g of sodium hydrogen phosphate were dissolved in 2,000 mL of distilled water, adjusted to pH 6.5, and then 250 mL of intestinal juice was added. The mixture was adjusted to pH 2.0 with dilute hydrochloric acid (cocks at 40.5°C, ducks at 41.0°C, geese at 41.5°C) and then diluted to 2,000 mL with distilled water.

Preparation of large intestine digestive juice: 11.13, 11.04, and 2.79 g of sodium dihydrogen phosphate and 3.09, 2.44, and 5.33 g of sodium hydrogen phosphate were dissolved in 2,000 mL of distilled water for cocks, ducks, and geese, respectively. Then 40.09, 39.78, and 41.69 g of sodium chloride and 9.35, 9.71, and 7.47 g of potassium chloride were added. The mixture was homogenized at 160 r/min, adjusted to pH 6.50, 6.52, and 6.38, respectively, with a 10% sodium hydroxide solution using an IKA homogenizer, and then diluted to 2,000 mL with distilled water.

Preparation of cecal digestive juice: 10.03 and 9.94 g of sodium dihydrogen phosphate and 2.79 and 2.20 g of sodium hydrogen phosphate were dissolved in 2,000 mL of distilled water for cocks and ducks, respectively. Then 6.77 and 7.91 g of sodium chloride and 48.77 and 47.42 g of potassium chloride were added. The mixture was homogenized at 160 r/min, adjusted to pH 7.99 and 7.91, respectively, with a 10% sodium hydroxide solution using an IKA homogenizer, and then diluted to 2,000 mL with distilled water.

1.1.3 Simulated Digestion Procedure **Sample preparation and weighing:** Approximately 1 g of sample was accurately weighed and placed in a 25 cm dialysis bag containing 2 L of phosphate buffer solution (2% pepsin and 1 mmol/L sodium dihydrogen phosphate, pH 8.0). The bag was incubated for 10 minutes, then rinsed with 1 mmol/L sodium dihydrogen phosphate buffer (pH 8.0) for another 10 minutes. The buffer solution was then removed and the sample was stored at 4°C for later use.

Gastric digestion: The sample in the dialysis bag was added to 20 mL of gastric juice and incubated at the corresponding temperature with shaking. After incubation, the bag was removed and rinsed with distilled water to terminate pepsin digestion.

Intestinal digestion: The gastric-digested sample was immediately transferred to a conical flask for intestinal digestion (cocks for 6 hours, ducks for 6 hours, geese for 6 hours). The intestinal juice was added, followed by the addition of small intestine digestive juice containing trypsin, amylase, and lipase. The intestinal digestion procedure lasted for 19.5 hours for cocks, 19.5 hours for ducks, and 14 hours for geese. The digested sample was then transferred to a pre-weighed beaker, dried at 65°C for 24 hours, cooled, and weighed. The residue was ashed at 105°C to determine dry matter content. The dried residue was used to determine energy content, and the difference between sample energy and residue energy was used to calculate energy digestibility.

1.2 Biological Method

1.2.1 Experimental Animal Groups Xinghua cocks, Cherry Valley ducks, and Sichuan white geese were divided into 4 groups with 6 replicates each. Group 1 served as the control group receiving a basal diet; Group 2 received a diet with 30% distiller' s grains; Group 3 received a diet with 30% fermented distiller' s grains; and Group 4 was the fasting group.

1.2.2 Experimental Animal Management Twenty-four healthy adult male Xinghua cocks, Cherry Valley ducks, and Sichuan white geese were selected and randomly divided into 4 groups with 6 replicates per group and 1 bird per replicate. Each bird was housed individually in a metabolic cage.

1.2.3 Biological Method Procedure Following the procedures of Sibbald [13] for cocks, the TME method of Aube et al. [14] for ducks, and the method of Zhang et al. [15] for geese, the birds were fasted and then force-fed. After fasting for 10 days on a basal diet, the birds were fasted again (cocks for 5 days, ducks and geese for 3 days) before being fed the experimental diets. The fasting period lasted 48 hours for cocks, 36 hours for ducks, and 24 hours for geese (to ensure complete emptying of the gastrointestinal tract). The birds were then fed the experimental diets, with cocks receiving 40 g and ducks and geese receiving 60 g of feed (approximately 80% of their normal intake). Excreta were collected quantitatively during the fasting period and for 48 hours (cocks), 36 hours (ducks), or 24 hours (geese) after feeding. The fasting group served as a control to correct for endogenous losses.

1.2.4 Excreta Collection and Processing Excreta were collected daily, stored at 4°C, and then dried at 65°C for 24 hours. After drying, samples were ground, weighed, and stored for analysis.

1.3 Sample Collection and Measurement

Dry matter, crude protein, crude fat, ash, calcium, total phosphorus, crude fiber, and gross energy contents of distiller' s grains and fermented distiller' s grains were measured. The gross energy of samples from the biological method was measured using an HWR-15C oxygen bomb calorimeter, and the gross energy of residues from simulated digestion was also measured using an HWR-15C oxygen bomb calorimeter.

1.4 Calculation Methods

Apparent metabolizable energy (AME, MJ/kg) = {[Gross energy of feed (J) - Gross energy of excreta (J)] / Gross weight of feed (g)} × 10^3

True metabolizable energy (TME, MJ/kg) = {[Gross energy of feed (J) - Gross energy of excreta (J) + Gross energy of endogenous excreta (J)] / Gross weight of feed (g)} × 10^3

Energy value of ingredients (AME, MJ/kg) = [AME of experimental diet (MJ/kg) - AME of basal diet (MJ/kg) × proportion of basal diet] / proportion of ingredient

Energy value of ingredients (TME, MJ/kg) = [TME of experimental diet (MJ/kg) - TME of basal diet (MJ/kg) × proportion of basal diet] / proportion of ingredient

Simulative digestion of gross energy (SDGE, MJ/kg) = [Gross energy of feed (MJ) - Gross energy of residue (MJ)] / Weight of feed (kg)

Simulative digestibility of gross energy (SYGE, %) = [Gross energy of feed (MJ) - Gross energy of residue (MJ)] / [Weight of feed (kg) × Gross energy of feed (MJ)] × 100

1.5 Statistical Analysis

Data were processed using Excel 2007 and analyzed using SPSS 19.0 software. One-way ANOVA was used for statistical analysis among the three groups (cocks, ducks, and geese), and Duncan' s multiple comparison test was used for pairwise comparisons. Independent samples t-test was used for statistical analysis between distiller' s grains and fermented distiller' s grains. Significance was set at P<0.05, and results are expressed as mean ± standard deviation.

2. Results

2.1 Nutrient Contents of Distiller' s Grains and Fermented Distiller' s Grains

As shown in Table 1, the dry matter, crude protein, ash, and total phosphorus contents in fermented distiller' s grains were significantly higher than those in distiller' s grains (P<0.05), while the crude fat and crude fiber contents in distiller' s grains were significantly higher than those in fermented distiller' s grains (P<0.05).

Table 1 Nutrient contents of distiller' s grains and fermented distiller' s grains (DM basis)

Items	Distiller' s grains	Fermented distiller' s grains
DM/%	85.63±0.09a	89.15±0.13b
GE/(MJ/kg)	18.99±0.03	19.51±0.13
CP/%	18.43±0.19a	24.75±0.34b
EE/%	4.64±0.11b	3.61±0.11a
Ash/%	1.49±0.11a	2.37±0.18b
Ca/%	0.36±0.01	0.38±0.01
TP/%	0.21±0.01a	0.38±0.01b
CF/%	24.15±0.26b	15.50±0.49a

In the same row, values with different small letter superscripts mean significant difference (P<0.05).

2.2 Comparison of SDGE and SYGE of Distiller' s Grains and Fermented Distiller' s Grains

As shown in Table 2, the SDGE of distiller' s grains in cocks, ducks, and geese were significantly different (P<0.05), with fermented distiller' s grains being 5.98%, 5.64%, and 7.05% higher than distiller' s grains, respectively. The SDGE and SYGE of distiller' s grains and fermented distiller' s grains in cocks and ducks were significantly higher than those in geese (P<0.05).

Table 2 Comparison of SDGE and SYGE of distiller' s grains and fermented distiller' s grains of cocks, ducks and geese

Items	Material	Cocks	Ducks	Geese
SDGE/(MJ/kg)	Distiller' s grains	11.15±0.15Ab	11.54±0.10Ab	10.02±0.22Bb

Items	Material	Cocks	Ducks	Geese
	Fermented distiller’ s grains	11.86±0.15Aa	12.23±0.10Aa	10.78±0.11Ba
SYGE/%	Distiller’ s grains	58.72±0.77A	60.79±0.51Ab	52.78±1.18B
	Fermented distiller’ s grains	60.82±0.76A	62.69±0.52Aa	55.25±0.54B

In the same row, values with different capital letter superscripts mean significant difference (P<0.05), while values with the same capital letter superscripts mean no significant difference (P>0.05). In the same column, values with different small letter superscripts mean significant difference (P<0.05), while values with the same small letter superscripts mean no significant difference (P>0.05). The same as below.

2.3 Comparison of ME and Energy Availability of Distiller’ s Grains and Fermented Distiller’ s Grains

As shown in Table 3, the AME, TME, energy apparent availability, and energy true availability of distiller’ s grains in Xinghua cocks were significantly different (P<0.05), with fermented distiller’ s grains being 20.29%, 18.06%, 16.63%, and 14.70% higher than distiller’ s grains, respectively. However, there were no significant differences in these parameters between distiller’ s grains and fermented distiller’s grains for Cherry Valley ducks and Sichuan white geese (P>0.05). The AME, TME, and energy apparent availability of distiller’ s grains in Cherry Valley ducks were significantly higher than those in Xinghua cocks and Sichuan white geese (P<0.05). There were no significant differences in AME, TME, energy apparent availability, and energy true availability of fermented distiller’ s grains among the three bird species (P>0.05).

Table 3 Comparison of ME, energy available of distiller’ s grains and fermented distiller’ s grains of Xinghua cocks, Cherry Valley ducks and Sichuan white geese

Items	Material	Xinghua cocks	Cherry Valley ducks	Sichuan white geese
AME/(MJ/kg)	Distiller’ s grains	8.13±0.35Bb	10.42±0.65A	8.20±0.86B
	Fermented distiller’ s grains	10.20±0.18a	10.66±0.40	10.10±0.59
TME/(MJ/kg)	Distiller’ s grains	9.39±0.35Bb	11.29±0.65A	9.16±0.86B
	Fermented distiller’ s grains	11.46±0.18a	11.53±0.40	11.06±0.59

Items	Material	Xinghua cocks	Cherry Valley ducks	Sichuan white geese
Energy apparent available/%	Distiller' s grains	44.79±1.88Bb	55.01±3.46A	43.91±4.68B
	Fermented distiller' s grains	53.73±1.20a	53.72±2.08	51.38±3.13
Energy true available/%	Distiller' s grains	51.60±1.88b	59.64±3.46	49.08±4.68
	Fermented distiller' s grains	60.49±1.20a	58.16±2.08	56.33±3.13

3. Discussion

3.1 Nutrient Contents of Distiller' s Grains and Fermented Distiller' s Grains

Previous studies have shown that fermentation can increase the crude protein content and reduce the crude fiber content in distiller' s grains [16-19]. The present study found that the crude protein and total phosphorus contents in fermented distiller' s grains were significantly higher than those in distiller' s grains, while the crude fiber content was significantly lower. This is consistent with previous research results [20-21]. The increase in crude protein content may be due to the proliferation of microorganisms during fermentation, which adds microbial protein to the substrate [22]. The reduction in crude fiber content may result from the degradation of cellulose and hemicellulose by microbial enzymes [23-24]. These changes in nutrient composition improve the nutritional value of distiller' s grains.

3.2 Simulated Digestion of Gross Energy

SDGE reflects the energy digestibility of feed ingredients under simulated physiological conditions. Previous studies have shown that SDGE is significantly correlated with the TME measured in vivo [25-26]. In this study, the SDGE of fermented distiller' s grains was significantly higher than that of distiller' s grains, indicating that fermentation improves the energy digestibility of distiller' s grains. The SDGE values for cocks and ducks were significantly higher than those for geese, which may be related to differences in digestive physiology among the species. The higher SDGE values for fermented distiller' s grains suggest that fermentation breaks down complex carbohydrates, making them more accessible to digestive enzymes [27]. Previous studies have also shown that adding enzymes to diets containing DDGS can improve ME values [28-30].

3.3 Metabolizable Energy

ME is an important indicator of feed energy value. The present study found that the ME of distiller' s grains in Cherry Valley ducks was significantly higher than that in Xinghua cocks and Sichuan white geese, which may be due to differences in digestive capacity among species. Previous studies have shown that ducks have better utilization of high-fiber feeds than chickens [31-32]. The lack of significant differences in ME of fermented distiller' s grains among the three species suggests that fermentation improves feed digestibility and reduces species differences. The higher ME values for fermented distiller' s grains compared to non-fermented distiller' s grains in cocks indicate that fermentation effectively improves energy utilization. The absence of significant differences in ME between distiller's grains and fermented distiller's grains in ducks and geese may be due to their inherently better ability to utilize fiber, making them less responsive to the effects of fermentation [33-34]. Previous studies have reported that the TME of duck feeds is generally higher than that of chicken feeds [35-36], which is consistent with our findings.

4. Conclusions

1. Fermented distiller's grains have higher crude protein and total phosphorus contents and lower crude fiber content compared to distiller' s grains.
2. The SDGE of fermented distiller' s grains in cocks, ducks, and geese is higher than that of distiller' s grains.
3. The ME of distiller' s grains in Cherry Valley ducks is higher than that in Xinghua cocks and Sichuan white geese.
4. There are no significant differences in ME of fermented distiller' s grains among Cherry Valley ducks, Xinghua cocks, and Sichuan white geese.

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Note: Figure translations are in progress. See original paper for figures.