Effects of sources and levels of liquor distiller’s grains with solubles on the growth performance, carcass characteristics, and serum parameters of Cherry Valley ducks

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ABSTRACT Liquor distiller’s grains with solubles (LDGS) is high in yield and rich in crude fiber and crude protein, which suggests that LDGS might be developed and used as unconventional feedstuff for ducks. The aim of this study was to investigate the effects of sources and levels of LDGS on growth performance, carcass characteristics, serum parameters, and intestinal morphology of Cherry Valley ducks from 15 to 42 D of age. A total of 3,300 15-day-old male ducks were randomly assigned into a 1 plus 2 factorial design including 2 different sources of LDGS (unfermented LDGS [ULDGS] and fermented LDGS [FLDGS]) at 5 levels (4, 8, 12, 16, and 20%) for 4 wk. Each treatment group included 6 pens with 50 ducks per pen. Levels of dietary LDGS and the interaction between sources and levels of LDGS had no effect on final body weight, average daily feed intake (ADFI), average daily gain, or feed-to-gain ratio (F:G) of ducks from day 15 to 42 (P > 0.05). Compared with dietary ULDGS, dietary FLDGS increased final body weight (P < 0.05) and ADFI (P < 0.05) and decreased the F:G (P = 0.03). The levels of LDGS and interaction effect between levels and sources of LDGS had no effect on carcass characteristics (P > 0.05). Regardless of the inclusion level, ducks fed with diets containing FLDGS had a higher percentage of thigh muscle (P < 0.01) than birds fed with diets containing ULDGS. Sources of dietary LDGS, levels of dietary LDGS, and their interaction had no effect on serum biochemistry parameters (P > 0.05) and intestinal morphology, including villus height, crypt depth, and villus height-to-crypt depth ratio (P > 0.05). In conclusion, the inclusion of LDGS in the diet at levels up to 20% had no negative effect on the growth performance, carcass characteristics, serum parameters, and intestinal morphology of ducks. Compared with ULDGS, FLDGS increased final body weight, ADFI, and thigh muscle yield and decreased the F:G of ducks. Therefore, LDGS, especially with fermentation, could be developed as an unconventional feedstuff resource for ducks from 15 to 42 D of age.

Key words: LDGS, fermentation, duck, growth performance, intestinal morphology

INTRODUCTION

Along with the rapid development of poultry husbandry, the shortage of conventional feed and rapidly increasing prices of raw feed material have become important problems. Therefore, developing unconventional feedstuff resources for poultry feed formulation could not only reduce feed costs but also prevent environmental pollution (Khatun and Khan, 2015). Liquor distiller’s grains with solubles (LDGS) is the residue of liquor extracted from sorghum, wheat, corn, and grain by fermentation and distillation. In China, approximately 18 million tons of LDGS are produced as by-products of liquor from the cumulative output of liquor-making industrial enterprises, which yielded 802.22 million kiloliters in 2018 (Jiang, 2019). Compared with corn distiller’s dried grains with solubles (DDGS), LDGS has lower nutrient values with high crude fiber
et al., 2011; Abd El-Hack et al., 2018), broilers (Ruan et al., 2018). To date, the use of DDGS as poultry feedstuff has been well studied in laying hens (Masa et al., 2018). Compared with broilers, ducks may make better use of high fiber feed materials because the gizzard weight and cecum cellulase activity of ducks are higher than those of broilers (Chen, 2005). However, limited information on LDGS utilization is available for ducks. Liquor distiller’s grains with solubles is brewed from multiple cereals, such as sorghum, maize, wheat, barley, and tubers, and contains tannins, CF, nonstarch polysaccharides (NSP), and other antinutritional factors. Owing to the high neutral detergent fiber (55.19%) and acid detergent fiber (47.13%) contents (Xu et al., 2012), it is presumed that LDGS can be developed as a poultry feed formulation by fermentation. A series of studies have indicated that fermentation could reduce antinutritional factor levels and improve nutrient efficiency. Our previous study reported that fermentation could reduce the content of tannins in banana leaves and improve the CP efficiency of geese (Wang et al., 2017). Fermentation could also reduce hydrocyanic acid content and increase flaxseed cake nutritional value and usage in ducklings (Zhai et al., 2019). As reported previously, the fermentation of DDGS decreased the CF component; increased the apparent ileal digestibility of NSP and the total tract digestibility of dry matter (DM), CP, and P (Jakobsen et al., 2015); and increased average daily gain (ADG) and decreased the feed-to-gain ratio (F:G) in pigs (Wiseman et al., 2017).

Therefore, it is hypothesized that LDGS could be developed as a good unconventional feedstuff for duck feed formulation. The present study evaluated the effects of different sources and levels of dietary LDGS on growth performance, carcass characteristics, serum parameters, and intestinal morphology of Cherry Valley ducks from 15 to 42 D of age.

### MATERIALS AND METHODS

#### Preparation of Fermented LDGS

Liquor distiller’s grains with solubles was kindly provided by Jiangsu Yanghe Daqu Winery (HuBei Gosign Bio-feed Co., Ltd., Wuhan, China). Based on our analysis, the LDGS contained 85.63% of DM, 18.99 MJ/kg of gross energy, 18.43% of CP, 4.64% of ether extract, 24.15% of CF, 0.36% of calcium, 0.21% of total phosphorus, and 1.49% of ash. The apparent metabolic energy (10.42 MJ/kg) and true metabolic energy (11.29 MJ/kg) of Cherry Valley ducks were measured by the emptying-force-feeding method mainly as per the method of Sibbald, 1976. Liquor distiller’s grains with solubles was fermented as described in the study by Tian et al., 2017. In brief, LDGS was inoculated with 0.3% *Saccharomyces cerevisiae* and fermented in a bed-packed incubator for 48 h. Fresh fermented samples were dried in a

| Table 1. Composition and nutrient levels of experimental diet supplementation with liquor distiller’s grains with solubles for 15- to 42-day-old ducks (% as feed). |
|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Ingredient     | 0              | 4              | 8              | 12             | 16             | 20             |
|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Corn           | 46.40          | 46.90          | 47.00          | 47.30          | 46.36          | 44.00          |
| Soybean meal   | 20.86          | 20.54          | 19.53          | 18.38          | 17.90          | 18.40          |
| LDGS           | 0.00           | 4.00           | 8.00           | 12.00          | 16.00          | 20.00          |
| Wheat flour    | 9.00           | 9.00           | 9.00           | 9.00           | 9.00           | 11.00          |
| Rapeseed meal  | 4.00           | 3.00           | 3.00           | 3.00           | 2.00           | 0.20           |
| Soybean oil    | 4.00           | 3.35           | 2.93           | 2.34           | 1.83           | 1.49           |
| Rice bran      | 4.00           | 3.00           | 2.00           | 1.00           | 1.50           | 0.50           |
| Chaff          | 7.89           | 6.35           | 4.64           | 2.93           | 1.27           | 0.00           |
| Dicalcium phosphate | 1.28        | 1.30           | 1.30           | 1.31           | 1.32           | 1.33           |
| Limestone powder | 1.27          | 1.24           | 1.22           | 1.19           | 1.17           | 1.15           |
| Sodium chloride | 0.40           | 0.40           | 0.40           | 0.40           | 0.40           | 0.40           |
| L-Lysine HCl (70%) | 0.20          | 0.22           | 0.25           | 0.29           | 0.31           | 0.31           |
| DL-Methionine (98.5%) | 0.16          | 0.16           | 0.17           | 0.17           | 0.18           | 0.18           |
| DL-Threonine (98.5%) | 0.04          | 0.04           | 0.05           | 0.05           | 0.06           | 0.06           |
| Premix1        | 0.50           | 0.50           | 0.50           | 0.50           | 0.50           | 0.50           |
| Zeolite powder | 0.00           | 0.00           | 0.01           | 0.14           | 0.20           | 0.48           |
| Total          | 100            | 100            | 100            | 100            | 100            | 100            |
| Calculated values |                |                |                |                |                |                |
| Metabolic energy (MJ/kg) | 12.00          | 12.00          | 12.00          | 12.00          | 12.00          | 12.00          |
| Crude protein (%) | 17.00          | 17.00          | 17.00          | 17.00          | 17.00          | 17.00          |
| Crude fiber (%) | 5.15           | 5.15           | 5.15           | 5.15           | 5.15           | 5.15           |
| Calcium (%)    | 0.95           | 0.95           | 0.95           | 0.95           | 0.95           | 0.95           |
| Nonphytate phosphorus (%) | 0.43          | 0.43           | 0.43           | 0.43           | 0.43           | 0.43           |
| Lysine (%)     | 0.90           | 0.90           | 0.90           | 0.90           | 0.90           | 0.90           |
| Methionine + cystine (%) | 0.40          | 0.40           | 0.40           | 0.40           | 0.40           | 0.40           |
| Threonine (%)  | 0.58           | 0.58           | 0.58           | 0.58           | 0.58           | 0.58           |

Abbreviation: LDGS, liquor distiller’s grains with solubles.
1Provided per kilogram of diet: vitamin A, 12,000 IU; vitamin D₃, 3,000 IU; vitamin E (all-rac-tocopherol acetate), 30 IU; vitamin B₁, 3 mg; vitamin B₂, 9 mg; vitamin B₆, 6 mg; vitamin B₁₂, 0.03 mg; folate, 1.5 mg; Fe (FeSO₄·7H₂O), 40 mg; Cu (CuSO₄·5H₂O), 8 mg; Zn (ZnO), 70 mg; Mn (MnSO₄·H₂O), 70 mg; Co, (CoSO₄·7H₂O), 0.2 mg; Se (Na₂SeO₃), 0.24 mg; I (KI), 0.35 mg.
hot air oven at 80°C for 3 D. The fermented LDGS (FLDGS) had the following nutrient composition: 89.15% of DM, 19.51 MJ/kg of gross energy, 24.75% of CP, 3.61% of ether extract, 15.50% of CF, 0.38% of calcium, 0.38% of total phosphorus, 2.37% of ash, and apparent metabolic energy (10.66 MJ/kg) and true metabolic energy (11.53 MJ/kg) were analyzed in Cherry Valley ducks. The analyzed values of ME, CP, CF, and other nutrient contents of unfermented LDGS (ULDGS) and FLDGS were used to formula the experimental diets.

Animals and Experimental Design

All practices and procedures for this experiment were reviewed and approved by the Animal Care and Use Committee of South China Agricultural University (SCAU-10564).

Before the experiment, a total of 4,000 male Cherry Valley ducklings were purchased and fed with the same commercial starter diet from day 1 to 14. The ducklings were raised in a temperature-controlled environment at an initial temperature of 33°C with 24 h of artificial light per day. The temperature was gradually reduced based on the birds’ age, as recommended by Cherry Valley duck management guidelines. On day 15, a total of 3,300 male Cherry Valley ducklings (initial weight = 680 ± 10 g) were selected and randomly assigned into a 1 (control group without LDGS) plus 5 × 2 factorial design including 2 different sources of LDGS (ULDGS and FLDGS) at 5 levels (4, 8, 12, 16, or 20%) from day 15 to 42. Each treatment included 6 pens with 50 ducks per pen. The experimental diets were formulated to be isocaloric and isonitrogenous, meeting or exceeding the nutrient requirements of ducks as per the NRC (1994) (Council, 1994). The composition of the experimental diets is listed in Table 1 and 2. The birds were housed by net rearing with 7 ducks per square meter. Plastic meshes were used to keep ducks 50 cm above the ground. The room environment was controlled at 20°C with a daily lighting schedule of 16 h of light and 8 h of dark during the experimental period. Ducks were allowed ad libitum access to the experimental diets and water. All diets were given in pellet form. Feed consumption and mortality were recorded for each replicate pen. At 42 D of age, after 12 h of fasting, the birds were weighed, and the ADG, average daily feed intake (ADFI), and F:G were calculated and corrected for mortality. Based on the average body weight (BW) of the birds in each replicate pen, one bird in each pen underwent blood sampling.

Sampling

After 12 h of feed withdrawal, approximately 10 mL of blood was collected via the jugular vein from one selected duck based on the average weight of each replicate at 42 D of age. Serum was prepared by centrifuging the blood at 3,000 rpm for 10 min and then stored at −20°C.

Table 1. Composition and nutrient levels of experimental diet supplementation with fermented liquor distiller’s grains with solubles for 15- to 42-day-old ducks (% as feed).

| Ingredient | 0% | 4% | 8% | 12% | 16% | 20% |
|------------|----|----|----|-----|-----|-----|
| Corn       | 46.40 | 47.83 | 48.00 | 48.00 | 47.65 | 44.75 |
| Soybean meal | 20.86 | 20.00 | 18.45 | 17.82 | 16.70 | 16.02 |
| FLDGS      | 0.00 | 4.90 | 8.00 | 12.00 | 16.00 | 20.00 |
| Wheat flour | 9.00 | 9.00 | 9.00 | 9.00  | 10.00 | 9.00  |
| Rapeseed meal | 4.00 | 3.00 | 2.80 | 1.50  | 0.50  | 0.20  |
| Soybean oil | 4.00 | 3.20 | 2.68 | 2.10  | 1.24  | 2.14  |
| Rice bran  | 4.00 | 2.50 | 2.00 | 1.50  | 1.00  | 1.00  |
| Chaff      | 7.89 | 6.60 | 5.08 | 3.77  | 2.43  | 0.89  |
| Dicalcium phosphate | 1.28 | 1.29 | 1.30 | 1.31  | 1.31  | 1.33  |
| Limestone powder | 1.27 | 1.25 | 1.23 | 1.21  | 1.20  | 1.16  |
| Sodium chloride | 0.40 | 0.40 | 0.40 | 0.40  | 0.40  | 0.40  |
| L-Lysine HCL (70%) | 0.20 | 0.23 | 0.27 | 0.30  | 0.33  | 0.35  |
| DL-Methionine (98.5%) | 0.16 | 0.16 | 0.17 | 0.17  | 0.18  | 0.19  |
| DL-Threonine (98.5%) | 0.04 | 0.04 | 0.05 | 0.05  | 0.06  | 0.07  |
| Premix      | 0.50 | 0.50 | 0.50 | 0.50  | 0.50  | 0.50  |
| Chaff       | 0.00 | 0.00 | 0.07 | 0.37  | 0.50  | 2.00  |
| Total      | 100 | 100 | 100 | 100  | 100  | 100  |

Calculated composition:
- Metabolic energy (MJ/kg): 12.00
- Crude protein (%): 17.00
- Crude fiber (%): 5.15
- Calcium (%): 0.95
- Nonphytate phosphorus (%): 0.43
- Lysine (%): 0.90
- Methionine + cystine (%): 0.40
- Threonine (%): 0.58

Abbreviation: FLDGS, fermented liquor distiller’s grains with solubles.

1Provided per kilogram of diet: vitamin A, 12,000 IU; vitamin D3, 3,000 IU; vitamin E (all-rac-tocopherol acetate), 30 IU; vitamin B1, 3 mg; vitamin B2, 9 mg; vitamin B6, 6 mg; vitamin B12, 0.03 mg; folate, 1.5 mg; Fe (FeSO4·7H2O), 40 mg; Cu (CuSO4·5H2O), 8 mg; Zn (ZnO), 70 mg; Mn (MnSO4·H2O), 70 mg; Co, (CoSO4·7H2O), 0.2 mg; Se (Na2SeO3), 0.24 mg; I (KI), 0.35 mg.
Slaughtering Procedures

After blood collection, the birds were executed by bloodletting of the jugular vein, and then, the carcasses of ducks without giblets were weighed and expressed as a percentage of their live BW to determine the carcass yield. The birds were then eviscerated, and the carcass weight (calculated by subtracting the weight of feathers and blood from the live weight), half-eviscerated weight (calculated by subtracting the weight of the trachea, esophagus, intestines, spleen, pancreas, and reproductive organs from the carcass weight), and eviscerated weight (calculated by subtracting the weight of the glandular stomach, gizzard, liver, lung, heart, and abdominal fat from the half-eviscerated weight) were recorded. The breast muscle and thigh muscle were removed from the carcass, trimmed of adipose tissue, and weighed. The carcass weight, the percentage of half-eviscerated yield, and the percentage of eviscerated yield were then expressed as a percentage of the live BW. The percentage of breast, thigh muscle, and abdominal fat was expressed as a percentage of the eviscerated weight. Abdominal fat comprises fat tissues surrounding the proventriculus and gizzard lying against the inside abdominal wall and around the cloaca (Ricard et al., 1983).

Chemical Analysis

The serum samples were thawed and analyzed for the content of total protein (TP), and the activities of alanine transaminase (ALT) and aspartate aminotransferase (AST) were measured using a HITACHI 7180 automatic biochemical analyzer (Hitachi Ltd., Tokyo, Japan). Serum total cholesterol (TC), triglyceride (TG), high-density lipoprotein (HDL), and low-density lipoprotein (LDL) concentrations were analyzed using commercial kits (Nanjing Jiancheng Bioengineering Institute, Nanjing, China).

Histomorphometry

Segments were removed from the duodenum, jejunum, and ileum as described in the study by Feng et al., 2007 and Gariglio et al., 2019. The samples were flushed with physiological saline to remove all the contents and fixed in 4% paraformaldehyde. Three cross sections were prepared for each sample after staining with hematoxylin and eosin using standard paraffin-embedding procedures. The evaluated morphometric indices were as follows: villus height (Vh, from the tip of the villus to the crypt), crypt depth (Cd, from the base of the villus to the submucosa), and the villus height-to-crypt depth.
Morphological indices were measured using an image processing and analysis system (version 1; Leica Imaging System Ltd., Cambridge, UK).

Statistical Analysis

All data were analyzed by one-way ANOVA using the GLM procedure in SAS software (SAS Institute Inc., Cary, NC). Data excluding the control were further analyzed in a $2 \times 5$ (sources $\times$ levels) factorial arrangement of treatments by two-way ANOVA with a model that included the main effects of sources and levels as well as their interaction. Data are expressed as means and SEM. Significant differences were set at $P \leq 0.05$.

RESULTS

Growth Performance

Compared with the control diet, dietary supplementation with LDGS had no effect on final BW, ADFI, ADG, F:G, and mortality ($P > 0.05$) (Table 3). The levels of LDGS and the interaction between the sources and levels of LDGS had no influence on growth performance ($P > 0.05$). The sources of LDGS affected the final BW, ADFI, and F:G of ducks from 15 to 42 D of age. Compared with ULDGS, dietary FLDGS increased the final BW ($P < 0.05$) and ADFI ($P < 0.05$) and decreased the F:G ($P = 0.03$) of ducks from day 15 to 42. The maximum final weight value was observed in the 16% FLDGS group.

Slaughter Characteristics

The effects of different sources and levels of dietary LDGS on the carcass characteristics, percentage of breast muscle, and percentage of thigh muscle and abdominal fat yield are listed in Table 4. Dietary supplementation with LDGS had no effect on the aforementioned indices ($P > 0.05$). The levels of LDGS or interaction effect between the levels and sources of LDGS had no effect on carcass characteristics ($P > 0.05$). Regardless of the level of LDGS, the ducks fed with the diets containing FLDGS had a higher percentage of thigh muscle ($P < 0.01$) than the birds fed with the diets containing ULDGS.

Table 4. Effects of sources and levels of dietary liquor distiller’s grains with solubles on the carcass characteristics of 42-day-old ducks.

| Item                     | Level, % | Carcass weight, g | Carcass yield, % | Half-eviscerated carcass yield, % | Eviscerated carcass yield, % | Percentage of breast muscle, % | Percentage of thigh muscle, % | Abdominal fat yield, % |
|--------------------------|----------|-------------------|-----------------|-----------------------------------|----------------------------|-------------------------------|-------------------------------|------------------------|
| Source                   |          |                   |                 |                                   |                            |                               |                               |                        |
| Control                  | 0        | 2,968             | 90.72           | 83.62                             | 76.50                      | 14.25                         | 9.88                          | 1.38                   |
| ULDGS                    | 4        | 2,802             | 90.02           | 83.33                             | 75.97                      | 13.99                         | 9.02                          | 1.50                   |
|                          | 8        | 2,843             | 89.23           | 82.67                             | 73.84                      | 13.33                         | 8.79                          | 1.25                   |
|                          | 12       | 2,937             | 90.65           | 84.29                             | 77.86                      | 13.70                         | 7.28                          | 1.35                   |
|                          | 16       | 3,037             | 90.02           | 84.27                             | 77.67                      | 13.61                         | 8.25                          | 1.18                   |
|                          | 20       | 2,982             | 89.46           | 82.23                             | 75.31                      | 15.14                         | 8.39                          | 1.51                   |
| FLDGS                    | 4        | 2,911             | 90.29           | 83.41                             | 76.41                      | 14.33                         | 9.43                          | 1.64                   |
|                          | 8        | 2,937             | 90.35           | 84.02                             | 75.57                      | 15.09                         | 9.49                          | 1.40                   |
|                          | 12       | 2,976             | 90.39           | 83.54                             | 76.67                      | 15.46                         | 9.18                          | 1.48                   |
|                          | 16       | 2,966             | 91.25           | 83.12                             | 76.19                      | 13.96                         | 10.07                         | 1.42                   |
|                          | 20       | 2,947             | 90.85           | 84.31                             | 77.27                      | 14.62                         | 10.61                         | 1.26                   |
| SEM                      |          | 60                | 0.62            | 0.70                              | 0.66                       | 0.64                          | 0.64                          | 0.15                   |
| P value                  |          | 0.35              | 0.01            | 0.38                              | 0.61                       | 0.06                          | 0.12                          | 0.51                   |

Main effect

| Source                   |          |                   |                 |                                   |                            |                               |                               |                        |
| ULDGS                    |          | 2,920             | 89.87           | 83.35                             | 73.46                      | 14.25                         | 9.80                          | 1.36                   |
| FLDGS                    |          | 2,947             | 90.47           | 83.68                             | 76.42                      | 14.79                         | 9.80                          | 1.34                   |
| SEM                      |          | 30                | 0.29            | 0.31                              | 2.17                       | 0.22                          | 0.26                          | 0.06                   |
| Level                    |          |                   |                 |                                   |                            |                               |                               |                        |
| 4                        |          | 2,856             | 90.15           | 83.37                             | 76.19                      | 14.16                         | 9.22                          | 1.57                   |
| 8                        |          | 2,890             | 89.79           | 83.34                             | 75.70                      | 14.21                         | 9.14                          | 1.32                   |
| 12                       |          | 2,956             | 90.52           | 83.92                             | 69.58                      | 15.31                         | 8.90                          | 1.42                   |
| 16                       |          | 3,001             | 90.64           | 83.69                             | 76.93                      | 14.03                         | 9.26                          | 1.30                   |
| 20                       |          | 2,964             | 89.75           | 83.27                             | 76.29                      | 14.87                         | 9.51                          | 1.38                   |
| SEM                      |          | 40                | 0.42            | 0.48                              | 3.32                       | 0.34                          | 0.43                          | 0.10                   |
| P value                  |          | 0.43              | 0.11            | 0.35                              | 0.34                       | 0.08                          | <0.01                         | 0.37                   |
| Level                    |          | 0.18              | 0.54            | 0.82                              | 0.56                       | 0.07                          | 0.93                          | 0.39                   |
| Source * level           |          | 0.53              | 0.79            | 0.13                              | 0.52                       | 0.25                          | 0.42                          | 0.52                   |
| Contrast                 |          | 0.48              | 0.66            | 0.57                              | 0.31                       | 0.40                          | 0.06                          | 0.70                   |

$^{a-b}$Values within a column with no common letters differ significantly ($P < 0.05$).

Abbreviations: FLDGS, fermented liquor distiller’s grains with solubles; ULDGS, unfermented liquor distiller’s grains with solubles.

$^{1}$Each value represents the mean of 6 replicates.

$^{2}$Contrast: control vs. other LDGS groups.

ratio (Vh:Cd) (Laudadio et al., 2012). Morphological indices were measured using an image processing and analysis system (version 1; Leica Imaging System Ltd., Cambridge, UK).

Statistical Analysis

All data were analyzed by one-way ANOVA using the GLM procedure in SAS software (SAS Institute Inc., Cary, NC). Data excluding the control were further analyzed in a $2 \times 5$ (sources $\times$ levels) factorial arrangement of treatments by two-way ANOVA with a model that included the main effects of sources and levels as well as their interaction. Data are expressed as means and SEM. Significant differences were set at $P \leq 0.05$. The sources of LDGS affected the final BW, ADFI, and F:G of ducks from 15 to 42 D of age. Compared with ULDGS, dietary FLDGS increased the final BW ($P < 0.05$) and ADFI ($P < 0.05$) and decreased the F:G ($P = 0.03$) of ducks from day 15 to 42. The maximum final weight value was observed in the 16% FLDGS group.
Serum Biochemistry Parameters

Sources of dietary LDGS, levels of dietary LDGS, and their interaction had no effect on serum biochemistry parameters ($P > 0.05$), including serum contents of TP, TC, TG, HDL, and LDL and the serum enzyme activities of ALT and AST (Table 5).

Intestinal Morphology

Sources of dietary LDGS, levels of dietary LDGS, and their interaction had no effect on duodenum, jejunum, and ileum morphology, including Vh, Cd, and Vh:Cd ($P > 0.05$) (Table 6).

DISCUSSION

In the present study, *S. cerevisiae* was used to ferment LDGS. Microbial fermentation of LDGS increased the CP level and reduced the CF level. Similar to our findings, Sharawy et al. (2016) reported that over 12, 24, and 48 h of solid-state fermentation in soybean meal by *S. cerevisiae*, CP content was increased from 40 to 44, 48.3, and 50%, respectively. The CP content in soybean meal was increased by 6.4% by *Lactobacillus brevis* fermentation and by 12.9% by *Aspergillus oryzae* (Gao et al., 2013). Another report has shown that CP content of soybean meal increased by 5.61% on fermentation with *S. cerevisiae* (Chi and Cho, 2016). The increased CP content might be attributed to the simple protein constituents in microbes and to microbial metabolism during fermentation (Kook et al., 2014; Jazi et al., 2017). The degrading activities of enzymes, such as cellulases and phytase, which are produced by microorganisms, could be responsible for the decrease in CF content (Chi and Cho, 2016; Ashayerizadeh et al., 2017).

The measured CP and CF contents of the sample of LDGS used in the present study were 18.43 and 24.15%, respectively. Compared with DDGS, LDGS has a lower CP level and a higher CF level. There are many studies about DDGS in poultry feed. It was reported that 20% DDGS derived from ethanol production can be fed to laying hens, resulting in lower emissions of NH$_3$ and H$_2$S, with no apparent adverse effects on hen performance (Wu-Haan et al., 2010). Broiler dietary supplementation with 20% DDGS from day 15 to 35 had no effect on growth performance and feed intake (Kim et al., 2018). Consistent with these studies, the results of the present study did not show any significant negative effects on the performance of ducks when LDGS was included in the diet. The final BW of ducks fed with 20% LDGS were numerically lower than those of the other groups, but this difference was not significant, indicating that 20% LDGS might be a threshold

### Table 5. Effects of sources and levels of dietary liquor distiller’s grains with solubles on serum biochemical traits of ducks at 42 D of age.

| Item | Level, % | TP, mg/mL | ALT, mU/mL | AST, mU/mL | TC, μmol/mL | TG, μmol/mL | HDL, μmol/mL | LDL, μmol/mL |
|------|----------|-----------|------------|------------|-------------|-------------|--------------|--------------|
| Source | Control | 0 | 36.22 | 36.60 | 48.00 | 4.77 | 0.76 | 3.52 | 1.30 |
| | ULDGS | 4 | 37.73 | 34.00 | 38.50 | 4.56 | 0.76 | 3.44 | 1.18 |
| | | 8 | 37.03 | 37.00 | 46.17 | 4.41 | 0.71 | 3.03 | 1.31 |
| | | 12 | 35.22 | 40.17 | 46.50 | 4.54 | 0.77 | 3.46 | 1.09 |
| | | 16 | 36.38 | 32.17 | 39.33 | 4.62 | 0.72 | 3.49 | 1.20 |
| | | 20 | 35.62 | 34.00 | 31.00 | 4.34 | 0.65 | 3.21 | 1.13 |
| FLDGS | 4 | 36.68 | 41.40 | 29.40 | 4.47 | 0.71 | 3.03 | 1.22 |
| | 8 | 39.96 | 42.80 | 36.20 | 4.66 | 0.70 | 3.33 | 1.32 |
| | 12 | 36.90 | 43.67 | 52.33 | 4.77 | 0.73 | 3.44 | 1.28 |
| | 16 | 34.05 | 37.17 | 52.35 | 4.33 | 0.77 | 3.05 | 1.23 |
| | 20 | 37.73 | 35.33 | 40.00 | 5.07 | 0.63 | 3.68 | 1.40 |
| SEM | | | 1.73 | 4.63 | 7.29 | 0.81 | 0.89 | 0.26 | 0.61 |

**Main effect**

| Source | ULDGS | 36.39 | 35.47 | 40.30 | 4.49 | 0.72 | 3.31 | 1.18 |
| | FLDGS | 36.46 | 40.07 | 42.12 | 4.66 | 0.71 | 3.03 | 1.29 |
| SEM | | 0.79 | 2.01 | 3.26 | 0.13 | 0.03 | 0.89 | 0.05 |

| Level | 4 | 37.21 | 37.70 | 33.65 | 4.51 | 0.74 | 3.17 | 1.20 |
| | 8 | 36.40 | 39.90 | 41.18 | 4.53 | 0.70 | 3.18 | 1.32 |
| | 12 | 36.06 | 41.92 | 49.42 | 4.66 | 0.75 | 3.45 | 1.26 |
| | 16 | 35.22 | 34.67 | 46.29 | 4.47 | 0.75 | 3.27 | 1.21 |
| | 20 | 36.67 | 34.67 | 35.50 | 4.70 | 0.64 | 3.44 | 1.26 |
| SEM | | 1.27 | 3.18 | 5.40 | 0.21 | 0.05 | 0.14 | 0.07 |

**P value**

| Source | 0.95 | 0.12 | 0.71 | 0.38 | 0.78 | 0.98 | 0.11 |
| Level | 0.81 | 0.41 | 0.48 | 0.92 | 0.49 | 0.46 | 0.72 |
| Source * level | 0.70 | 0.97 | 0.41 | 0.67 | 0.48 | 0.96 | 0.12 |
| Contrast | 0.94 | 0.77 | 0.42 | 0.85 | 0.91 | 0.35 | 0.68 |

**Abbreviations:** ALT, alanine transaminase; AST, aspartate aminotransferase; FLDGS, fermented liquor distiller’s grains with solubles; HDL, high-density lipoprotein; LDL, low-density lipoprotein; TC, total cholesterol; TG, triglyceride; TP, total protein; ULDGS, unfermented liquor distiller’s grains with solubles.

1 Each value represents the mean of 6 replicates.

2 Contrast: control vs. other LDGS groups.
amount and higher levels may show significant negative effects on growth performance. These results indicated that LDGS could be used as an unconventional feedstuff in duck feed formulation. Many studies have shown that fermentation could improve poultry growth performance. Feeding trials with 10% rapeseed meal, fermented with *Lactobacillus fermentum* and *Bacillus subtilis*, showed improved weight gain and feed conversion ratio in broiler chickens from day 1 to 42 (Chiang et al., 2010). In a study on Japanese quail fed with soybean meal from day 1 to 35, the birds fed with fermented soybean meal gained more weight than the control birds (Jazi et al., 2018). In the present study, dietary supplementation with FLDGS increased final BW and ADG and decreased F:G. This may be due to the fermented feed producing protease, amylase, and lipase (Chen et al., 2009) or increasing the activity of intestinal digestive enzymes, such as trypsin, lipase, and protease (Feng et al., 2007), thus increasing nutrient availability and improving ADG. In addition, fermentation could increase palatability (Liu et al., 2014), which may contribute to the increased ADFI of ducks fed with FLDGS. The aforementioned results suggested that dietary supplementation with FLDGS got better growth performance than dietary supplementation with ULDGS.

Carcass characteristics are one of the important indicators of the economic benefits of meat poultry. In the present study, dietary LDGS supplementation had no effect on the carcass characteristics of ducks. The results were in accordance with a previous report in which feeding China Micro duck drakes with 15% sorghum DDGS from 4 to 8 wk of age had no effect on carcass yield (Xie et al., 2016). Feeding 0, 6, 12, or 18% DDGS to broiler chicks had no effect on carcass yield when observing the selected carcass yield, wings, and breasts (Lumpkins et al., 2004). Feeding broilers with properly balanced feeds containing up to 24% DDGS had no effect on carcass characteristics, including chill carcass, breast, legs, and wings (Shim et al., 2011). Inclusion of maize DDGS at levels up to 25% in the diet of ducks from day 22 of rearing had no adverse effect on the carcass characteristics, regardless of age at slaughter (Kowalczyk et al., 2012). In contrast, another study evaluated the effects of feeding 0 vs 8% DDGS during the starter and grower phases (0–14 D and 14–28 D) and subsequently feeding a finisher diet (28–42 D) with either 0, 7, 14, 21, or 28% DDGS on broilers. The results showed that dressing percentage and breast meat yield declined linearly with increasing inclusion levels of DDGS (Loar et al., 2012). The reason for this disagreement may be the different sources of DDGS, such as corn, wheat, and barley. In the present study,

### Table 6. Effects of sources and levels of dietary liquor distiller’s grains with solubles on intestinal morphology of ducks at 42 D of age.1

| Item | Level, % | Villus height, μm | Crypt depth, μm | Vh:Cd | Villus height, μm | Crypt depth, μm | Vh:Cd | Villus height, μm | Crypt depth, μm | Vh:Cd |
|------|----------|-------------------|----------------|-------|-------------------|----------------|-------|-------------------|----------------|-------|
| Source | Control 0 | 987 | 230 | 4.31 | 997 | 198 | 5.04 | 971 | 228 | 4.28 |
| ULDGS 4 | 1,035 | 215 | 4.80 | 1,017 | 211 | 4.83 | 996 | 212 | 4.70 |
| 8 | 1,067 | 214 | 5.02 | 1,017 | 212 | 4.65 | 1,033 | 234 | 4.43 |
| 12 | 1,026 | 204 | 5.03 | 1,024 | 217 | 4.75 | 979 | 205 | 4.76 |
| 16 | 1,008 | 216 | 4.69 | 1,000 | 227 | 4.48 | 971 | 222 | 4.36 |
| 20 | 998 | 215 | 4.39 | 990 | 216 | 4.41 | 995 | 223 | 4.47 |
| FLDGS 4 | 989 | 232 | 4.34 | 990 | 209 | 4.74 | 1,039 | 218 | 4.68 |
| 8 | 1,023 | 218 | 4.74 | 991 | 206 | 4.80 | 1,006 | 225 | 4.53 |
| 12 | 1,017 | 215 | 4.73 | 1,009 | 205 | 4.83 | 992 | 214 | 4.64 |
| 16 | 1,010 | 212 | 4.79 | 1,039 | 203 | 5.11 | 994 | 211 | 4.81 |
| 20 | 997 | 226 | 4.57 | 1,033 | 212 | 4.99 | 986 | 206 | 4.47 |
| SEM | 36.12 | 9.51 | 0.22 | 44.94 | 8.46 | 0.28 | 32.33 | 8.35 | 0.19 |
| P value | 0.52 | 0.79 | 0.39 | 0.99 | 0.80 | 0.99 | 0.90 | 0.30 | 0.83 |

1Each value represents the mean of 6 replicates.

2Contrast: control vs. other LDGS groups.

Abbreviations: FLDGS, fermented liquor distiller’s grains with solubles; ULDGS, unfermented liquor distiller’s grains with solubles; Vh:Cd, villus height-to-crypt depth ratio.
FLDGS had no effect on carcass characteristics except thigh muscle. These findings agreed with a previous study on broilers in which feeding them with fermented feed had no effect on breast muscle (Choi et al., 2014; Yeh et al., 2017). Our study showed that compared with ULDGS, FLDGS increased thigh muscle yield. The higher final BW in the FLDGS group may partially contribute to this result. Moreover, thigh muscle and breast muscle are red or dark meat and white meat, respectively (Lumpkins et al., 2004). These muscles may deposit in different ways, and FLDGS may facilitate red meat deposition. This needs to be further studied. These results indicated that dietary supplementation with up to 20% LDGS had no negative effect on carcass characteristics and that FLDGS could increase the percentage of thigh muscle.

In the present study, the sources and levels of LDGS had no effect on the TP content, the activities of AST and ALT, and the serum concentrations of TC, TG, HDL, and LDL. This may suggest that ducks could make good use of the protein in LDGS and FLDGS. These results in our study indicated that LDGS with or without fermentation had no negative effect on the physiological state of the animal, especially liver function, and the ability to transport cholesterol from peripheral tissues to the liver was unaffected by supplemental LDGS up to 20% in ducks’ diet.

Liquor distiller’s grains with solubles contains antinutritional factors, such as tannins and NSP. A previous study has shown that NSP could lead to a decrease in ileum Vh and surface of broiler chickens at day 15 (Kermanshahi et al., 2018). Studies have suggested that fermented feed could improve intestinal morphology. Dietary supplementation with fermented Ginkgo leaves could increase duodenal and jejunal Vh, but decrease jejunal Cd in broiler chicks (Zhang et al., 2015). Pigs fed with citrus juice waste fermentation biomass had greater Vh and Vh:Cd in the duodenum, jejunum, and ileum than pigs fed with a control diet (Lee et al., 2014). In the present study, diets containing FLDGS or ULDGS had no effect on Vh and Cd in the duodenum, jejunum, and ileum of ducks. This may be because LDGS could be effectively used by ducks and had no negative effect on intestinal morphology. These results are in agreement with those of a study demonstrating that feeding broilers with 10% DDGS had no effect on Vh and Cd of the duodenum, jejunum, and ileum (Alizadeh et al., 2016). These results indicated that dietary supplementation with up to 20% FLDGS or ULDGS had no effect on the digestive and absorptive function of the intestine because there was no negative effect on the intestinal morphology with LDGS supplementation.

CONCLUSIONS

In conclusion, dietary supplementation with up to 20% FLDGS or ULDGS had no negative effect on growth performance, carcass characteristics, serum parameters, and intestinal morphology of ducks from day 15 to 42. Compared with LDGS, FLDGS could increase final BW, ADFI, and thigh muscle yield and decrease F:G in ducks. Therefore, LDGS, especially with fermentation, could be developed as an unconventional feed-stuff resource for ducks from 15 to 42 D of age.

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