Effects of dietary corn germ meal levels on growth performance, serum biochemical parameters, meat quality, and standardized ileal digestibility of amino acids in Pekin ducks

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ABSTRACT The study aimed to investigate the effects of dietary corn germ meal (**CGM**) levels on growth performance, carcass characteristic, serum biochemical indexes, meat physical and chemical quality, and standardized ileal digestibility of amino acids (**SIDAA**) in Pekin ducks from 10 to 42 d of age. A total of 420 ten-day-old Cherry Valley ducks were randomly allotted to 5 treatments with 6 replicate cages per treatment and 14 ducks per cages based on mean body weight. Five isonitrogenous and isocaloric experimental diets were formulated on a digestible amino acid basis to produce diets containing 0, 3, 6, 9, or 12% CGM. Results showed: 1) Compared with other groups, ducks fed 12% CGM significantly increased ($P < 0.05$) the feed to gain ratio. 2) Dietary CGM levels had no effect ($P > 0.05$) on the carcass traits and breast meat physical quality; but the content of crude protein presented a linear decrease ($P < 0.05$) in breast meat with increasing dietary CGM levels. 3) Serum biochemical indices (e.g., alanine aminotransferase, aspartate aminotransferase, glucose, high density lipoprotein cholesterol, total cholesterol, triglyceride, total protein, and urea) showed no significant differences among all groups ($P > 0.05$). 4) The levels of CGM had no significant effect on SIDAA of diets ($P > 0.05$), except for cysteine which showed a quadratic increase ($P < 0.05$). These results suggested that the optimal levels of CGM in diets for meat duck aged from 10 to 42 d should be below 9% based on feed to gain ratio and the content of crude protein in breast meat.

Key words: corn germ meal, duck, serum biochemical parameters, meat quality, standard ileal amino acid digestibility

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INTRODUCTION

Along with the rapid development of poultry husbandry, the shortage of conventional feed and rapidly increasing prices of raw feed material have become a key factor to restrict the sustainable development of poultry industry. Developing unconventional feedstuff resources for poultry feed formulation could not only reduce feed costs but also prevent environmental pollution (Khatun and Khan, 2015). It is estimated that world corn production is more than 1136.3 million metric tons (**MMT**) in 2020−2021(Sep-Aug) and about 31.7% (360.3 MMT) was produced in the United States, followed by China (260.6 MMT) and Brazil (109.0 MMT) (https://www.fas.usda.gov). Corn germ meal (**CGM**), a by-product of corn, is produced during the process of corn germ extraction to produce corn oil for human consumption (Stock et al., 1999) and is also considered a good ingredient for all livestock species (Schilling et al., 2017). It has good palatability, rich in digestible amino acids and hemicellulose, and can be used as protein feed for monogastric animals, as well as protein and energy feed for ruminants (Lakshmi et al., 2017). Corn germ meals have been widely used as a substitute for corn grain in Brazil, China, and Ethiopia. However, the high fiber content of CGM limits its utilization primarily to ruminant diets (Herold et al., 1998) and fish diets (Li et al., 2013). The use of CGM as poultry feedstuff has been studied in laying hens (Brito et al., 2009; Brunelli et al., 2010) and broilers (Brito et al., 2005a; Brunelli et al., 2006). Compared with broilers, ducks may make better use of high fiber feed materials because the gizzard weight and mechanical movement ability as well as cecum cellulase activity and the abundance of

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microbiota of ducks are higher than those of broilers (Han et al., 2017; Qin et al., 2020). However, to date, there is limited information on the amount of CGM in diets can be tolerated by growing ducks without negatively affecting growth performance and other physiological parameters.

Alhotan et al. (2016) reviewed that a dose-response study involving feeding birds increasing levels of the test ingredient had to be conducted in order to estimate the maximum safe levels of a new ingredient. In the dose-response study, one or more measurements (e.g., BW gain, feed efficiency, serum biochemical indices, meat yield, and quality) are taken for a special poultry and the maximum safe level of the test ingredient is determined for each measurement. As living standards improve, consumers pay more attention to the quality of meat than the quantity of meat Widmer et al. (2008). reported that inclusion of up to 10% corn germ in diets fed to growing-finishing pigs reduced the iodine value of belly fat, which suggested the content of saturated fatty acids in belly fat increased Harbach et al. (2007). also found that phytic acid from CGM inhibited pork meat lipid oxidation. These researches indicated that inclusion of CGM in diets could affect the meat quality in animal production. However, to the best of our knowledge, there are no reports about the effect of dietary CGM on duck's meat quality. Therefore, the experiment was conducted to determine the effects of dietary CGM levels (0 −12%) on growth performance, serum biochemical indexes, carcass characteristic, meat physical, and chemical quality as well as muscle fiber characteristic, and standardized ileal digestibility of amino acids (**SIDAA**) in Pekin ducks from 10 to 42 d of age using a dose-response study model, and then to determine the optimal or maximum safe levels of CGM in duck's diets.

MATERIALS AND METHODS

The Institutional Animal Care and Use Committee of Sichuan Agricultural University approved all procedures used in the study.

Birds, Diets, and Management

A total of 420 one-day-old Cherry Valley ducks were fed a standard starter diet containing 12.13 MJ/ kg ME, 19.5% CP, 1.15% lysine, 0.48% methionine, 0.78% threonine, and 0.22% tryptophan from 1 to 10 d of age. On day 11, ducks were randomly assigned to 5 treatments with 6 replicate cage per treatment and 14 ducks per cage (2.0 m × 0.8 m × 0.6 m) based on mean body weight. Ducks were reared in a temperature and humidity-controlled room, and had free access to water and feed to 42d of age. Five isonitrogenous and isocaloric experimental diets were formulated on a digestible amino acid basis to produce diets in which containing 0, 3, 6, 9, or 12% CGM. Diets were fortified with supplemental feed-grade lysine, methionine, threonine, and tryptophan to provide the recommended levels of AA for Pekin ducks in accordance with the NRC (1994) (Table 1). The analyzed nutrient compositions of CGM are presented in Table 2.

Table 1. Composition and nutrient contents of the experimental diets (air dry basis) %.

Items	Corn germ meal levels %				
	0	3	6	9	12
Ingredients, %					
Corn	62.96	60.45	57.94	55.43	52.92
Soybean oil	0.94	1.43	1.93	2.43	2.92
Soybean meal	13.34	12.47	11.61	10.75	9.89
Corn germ meal	0.00	3.00	6.00	9.00	12.00
Rapeseed meal	6.00	5.80	5.60	5.40	5.20
Wheat middling	4.60	4.64	4.68	4.72	4.76
DDGS	8.00	8.00	8.00	8.00	8.00
L-Lysine. HCL	0.39	0.40	0.42	0.43	0.44
Threonine	0.05	0.05	0.05	0.05	0.06
Tryptophan	0.03	0.03	0.03	0.03	0.03
DL-Methionine	0.21	0.21	0.21	0.21	0.22
Calcium carbonate	1.00	1.01	1.02	1.02	1.03
Dicalcium phosphate	1.32	1.32	1.32	1.32	1.33
Sodium chloride	0.35	0.35	0.35	0.35	0.35
Choline chloride (50%)	0.15	0.15	0.15	0.15	0.15
Vitamin premix[1]	0.03	0.03	0.03	0.03	0.03
Mineral premix[2]	0.50	0.50	0.50	0.50	0.50
Total	100.00	100.00	100.00	100.00	100.00
Calculated nutrients levels, %					
ME, MJ/kg	12.13	12.13	12.13	12.13	12.13
Crude protein	16.5	16.5	16.5	16.5	16.5
Crude fiber	3.47	3.66	3.75	3.85	3.95
Calcium	0.75	0.75	0.75	0.75	0.75
Available phosphorus	0.38	0.38	0.38	0.38	0.38
Lysine	0.90	0.90	0.90	0.90	0.90
Methionine	0.43	0.43	0.43	0.43	0.43
Threonine	0.68	0.68	0.68	0.68	0.68
Tryptophan	0.19	0.19	0.19	0.19	0.19

[1]Vitamin premix provides the following per kg of final diet: vitamin A 8,000 IU; vitamin D_3 2,000 IU; vitamin E 5 mg; vitamin K_2 1 mg; vitamin B_1 0.6 mg; vitamin B_2 4.8 mg; vitamin B_6 1.8 mg; vitamin B_{12} 0.009 mg; niacin 10.5 mg; DL-calcium pantothenate 7.5 mg; folic acid 0.15 mg.

[2]Mineral premix provides the following per kg of final diet: Fe ($FeSO_4$•H_2O) 80 mg; Cu ($CuSO_4$•$5H_2O$) 8 mg; Mn ($MnSO_4$•H_2O) 70 mg; Zn ($ZnSO_4$•H_2O) 90 mg; I (KI) 0.4 mg; Se (Na_2SeO_3) 0.3 mg.

Table 2. Analyzed nutrient composition of corn germ meal (as-fed basis).

Items	Corn germ meal
Gross energy, MJ/kg	16.54
Dry matter, %	78.99
Crude protein, %	25.12
Crude fat, %	2.73
Nonessential amino acids, g/kg	
Aspartic acid	1.10
Alanine	0.68
Cysteine	0.05
Glutamic acid	2.86
Glycine	0.70
Proline	1.27
Serine	0.97
Tyrosine	0.83
Essential amino acid, g/kg	
Arginine	0.93
Histidine	0.45
Isoleucine	0.51
Leucine	1.31
Lysine	0.66
Methionine	0.21
Phenylalanine	0.59
Threonine	0.72
Valine	0.79

Data Collection and Measurements

On d 42, after 12 h of feed withdrawal, ducks were weighed, and feed consumption was obtained for each pen. Feed intake (**FI**), BW gain (**BWG**), and feed-to-gain (**F:G**) ratio were determined. Mortality was recorded, and the weights of dead birds were used to adjust the F:G ratio.

Then, one bird with weight that was closest to the average of the pen was selected and euthanized by exsanguination. After slaughtering, feathers were plucked, followed by evisceration to obtain dressed breast and leg meats. Carcass yield was determined as the carcass weight in relation to BW expressed as percentage of BW (%), whereas breast and leg muscle weights were expressed as percentages of the carcass weight.

Determination of Serum Biochemical Parameters

The 5 mL of the whole blood samples were centrifuged at 3,000 g for 15 min at 4°C to collect serum, and then stored at −20°C until further biochemical parameters were analyzed. Serum aspartate aminotransferase (**AST**), alanine aminotransferase (**ALT**) activities, glucose, high density lipoprotein cholesterol (**HDL**), low density lipoprotein cholesterol (**LDL**), total cholesterol (**TC**), triglyceride (**TG**), total protein (**TP**), and uric acid (**UA**) were analyzed using automatic biochemical analyzer (HATICHI 7180, Japan).

Determination of Meat Physical and Chemical Parameters

Meat physical parameters include drip loss, pH value, and color at 45 min and 24 h. The pH of breast meat samples was measured from the same place on the right upper third of all samples using a pH meter (pH-2004; Selecta, Barcelona, Spain) as per previous study of Liao et al. (2018). Each meat sample was measured 3 times, and the average pH value of meat samples was calculated. The color profile (lightness[L*], redness [a*], and yellowness [b*]) of breast meat was measured using a colorimeter (Minolta CR-400; Konica, Chiyoda-ku, Japan) at 3 points on the dorsal surface of each breast sample after 30 min of exposure to ambient air (Van Laack et al., 2000). Drip loss was determined from 2 samples per plot, in accordance with the methodology previously described by Silva et al. (2019). Samples were cut into 2.5 cm^3 cubes, placed in hermetically sealed containers, and kept in a refrigerator at 4°C for 24 h. Subsequently, samples were removed from the refrigerator and weighed to calculate percentage drip loss.

Meat Chemical parameters include moister, crude protein (**CP**), and ether extract. The left breast was collected for determination of chemical composition. Moister was detected by the freeze-drying method. Crude protein was detected by the Kjeldahl method (using a factor of 6.25), and ether extract was obtained by the Soxhlet method (AOAC, 1995).

Determination of Density and Diameter of Muscle Fibers

In brief, muscle samples were fixed in 4% paraformaldehyde for 24 h at room temperature, embedded in paraffin, cut at thicknesses of 5 microns by a microtome (RM 2235, Leica, Germany), and stained with H&E. Representative areas were photographed under an optical microscope (CX22, OLMPUS, Japan) at a magnification of 200 ×. An image analysis system (DM1000; Leica, Germany) was used to examine the stained sections. For each muscle, 3 different points on 3 images containing a total of about 300 muscle fibers without signs of tissue disruption and freeze damage were estimate. Fiber density (number/mm^2) and fiber diameter (mm) were calculated.

Assay of Standardized Ileal Amino Acids Digestibility of Diets

On d 22, two birds per pen were randomly selected (12 ducks per treatment, 72 ducks in total) and transferred to metabolic cages (2 ducks per cage) and fed with the original diets mixed with titanium dioxide (TiO2; 0.5%). An additional 12 ducks from the 0% CGM group were randomly selected based on BW, assigned to 6 cages of 2 ducks, and fed with a N-free diet mixed with TiO2 (0.5%) to determine basal endogenous amino acid (**AA**) losses according to the method of Han et al. (2017). On d 28, ducks were fed for 4 h and then were euthanized by cervical dislocation. The ileal digesta was gently rinsed with distilled water into plastic containers (Qin et al., 2017). The collected ileal samples from 2 birds within a cage were pooled and stored at −20°C for subsequent analyses of DM, TiO2, and AA. These data were used to calculate SIDAA based on our previous studies of Han et al. (2017) and Qin et al. (2017).

Statistical Analysis

Data were analyzed using One-way ANOVA of SPSS22.0 (SPSS software for Windows, release 22.0, SPSS Inc., Chicago, IL). Duncan's test was used for multiple comparisons, and orthogonal polynomials were used to test linear and quadratic for increasing levels of CGM in the diet. Significance was declared at $P < 0.05$.

RESULTS

Growth Performance

The effects of dietary CGM levels supplementation on BW, BWG, FI, and F:G ratio are presented in Table 3. Dietary CGM levels had no effect ($P > 0.05$) on the BW, ADG, ADFI, and mortality in meat ducks during the experimental period. However, compared with other

Table 3. Effects of dietary corn germ meal levels on growth performance of ducks from 10 to 42 d of age.

Items	Corn germ meal levels %					SEM	*P*-value		
	0	3	6	9	12		ANOVA	Linear	Quadratic
10 d BW, g	363.2[1]	363.6	363.1	362.2	363.3	2.15	0.97	0.92	0.82
42 d BW, g	3149	3142	3175	3159	3098	44.80	0.51	0.98	0.98
10−42 d ADG, g	87.06	86.81	87.87	87.40	85.45	1.38	0.49	0.99	0.99
10−42 d ADFI, g	180.6	178.6	185.9	174.6	207.5	12.56	0.11	0.09	0.07
F: G, g/g	2.07[b]	2.06[b]	2.12[b]	2.00[b]	2.43[a]	0.14	0.05	0.10	0.08
Mortality, %	2.38	4.76	7.14	4.76	10.72	5.44	0.62	0.07	0.16

[a−b]Values within a column with no common superscripts differ significantly ($P < 0.05$).
Abbreviations: BW, body wight; BWG, BW gain; F:G, feed-to-gain ratio.
[1]Values are the means of 6 replicates of 14 ducks each (n = 6).

groups, ducks fed 12% CGM significantly increased ($P < 0.05$) the F: G ratio.

Carcass Traits

There were no linear or quadratic effects ($P > 0.05$; Table 4) of including graded levels of CGM in diets on the weight and the percentage of carcass, eviscerated with giblet, eviscerated, leg muscle, and abdominal fat during the entire experimental period. However, the weight and the percentage of breast meat had a numerical decrease ($P > 0.05$; Table 4) with increasing of dietary CGM levels.

Meat Physical and Chemical Quality as Well as Muscle Fibers Characters

The effects of dietary CGM levels on meat physical and chemical quality are displayed in Table 5. There was no significant difference ($P > 0.05$) on drip loss, pH,

Table 4. Effects of dietary corn germ meal levels on carcass traits of ducks from 10 to 42 d of age.

Item	Corn germ meal levels %					SEM	*P*-value		
	0	3	6	9	12		ANOVA	Linear	Quadratic
Carcass traits (g)									
Carcass	2,658[1]	2,712	2,710	2,713	2,720	79.24	0.94	0.24	0.50
Eviscerated with giblet	2,594	2,528	2,550	2,553	2,567	66.51	0.89	0.78	0.22
Eviscerated	2,351	2,290	2,299	2,300	2,280	59.84	0.79	0.68	0.37
Breast muscle	351.3	339.2	332.5	317.5	300.0	26.64	0.38	0.15	0.30
Leg muscle	252.0	245.8	250.7	257.3	270.8	16.08	0.62	0.46	0.25
Abdominal fat	26.58	22.77	25.21	26.99	27.99	4.97	0.84	0.37	0.55
Carcass traits (%)									
Carcass	83.23	86.11	85.25	85.23	86.77	1.91	0.51	0.21	0.46
Eviscerated with giblet	81.11	80.29	80.21	80.19	81.87	0.96	0.33	0.56	0.06
Eviscerated	73.53	72.72	72.31	72.27	72.70	0.94	0.72	0.50	0.28
Breast muscle	10.98	10.78	10.45	9.95	9.53	0.75	0.29	0.11	0.25
Leg muscle	7.87	7.81	7.89	8.09	8.63	0.48	0.56	0.41	0.26
Abdominal fat	0.83	0.72	0.79	0.86	0.90	0.16	0.84	0.64	0.54

[1]Values are the means of 6 ducks per dietary treatment.

Table 5. Effects of dietary corn germ meal levels on meat quality of ducks from 10 to 42 d of age.

Items	Corn germ meal levels %					SEM	*P*-value		
	0	3	6	9	12		ANOVA	Linear	Quadratic
Breast meat physical quality									
Drip loss, %	2.79[1]	3.47	3.70	6.23	2.72	1.40	0.24	0.11	0.11
45 min pH value	6.27	6.40	6.29	6.49	6.56	0.14	0.20	0.31	0.35
24 h pH value	6.11	6.16	6.12	6.25	6.47	0.18	0.25	0.24	0.24
45 min color									
L*	46.94	42.81	45.97	48.38	45.19	2.25	0.20	0.61	0.88
a*	12.52	11.64	12.12	10.90	11.67	1.15	0.71	0.14	0.34
b*	4.81	5.12	5.15	4.53	6.28	1.26	0.64	0.77	0.72
24 h color									
L*	44.76	44.40	45.79	44.35	45.44	2.95	0.98	0.84	0.93
a*	17.07	16.29	16.22	16.35	14.70	1.36	0.45	0.27	0.44
b*	10.67	9.26	9.94	9.98	9.02	1.14	0.67	0.46	0.76
Breast meat chemical quality									
Moisture, %	78.97	79.11	78.98	78.76	79.71	0.69	0.67	0.29	0.45
Protein, %	19.56[a]	19.65[a]	18.43abc	17.07[c]	17.88[bc]	0.68	0.00	0.01	0.02
Fat, %	6.20	5.68	6.60	7.49	5.81	1.08	0.46	0.36	0.63

[a−c]Values within a column with no common superscripts differ significantly ($P < 0.05$).
[1]Values are the means of 6 ducks per dietary treatment (n = 6). L*, Lightness; a*, Redness; b*, Yellowness.

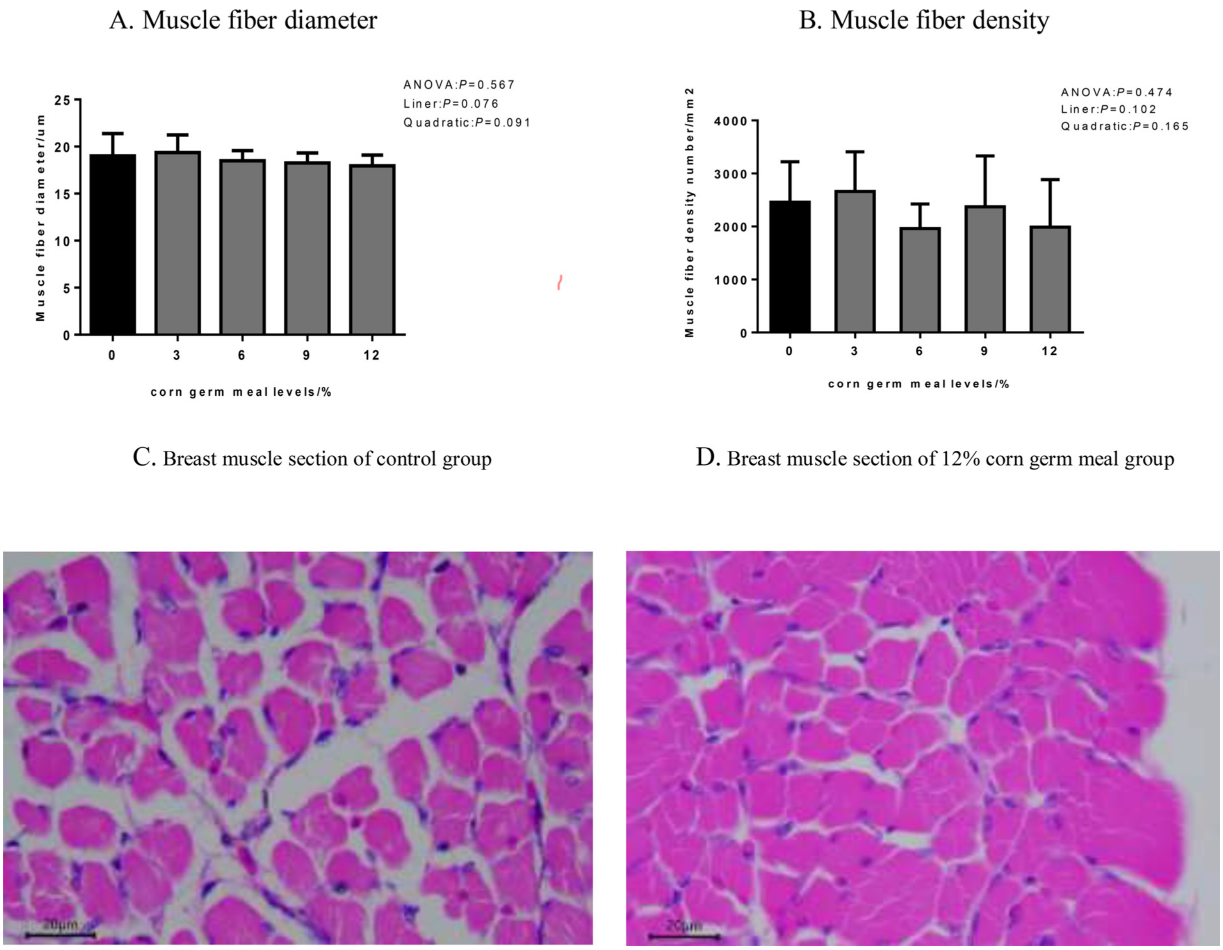

Figure 1. Effect of corn germ meal (CGM) levels on muscle fiber diameter and density of duck. Means are the means of 6 ducks per dietary treatment (n = 6). The error bars represent SEM. Scale bars: 20μm.

color, and the content of moisture and fat in breast meat among all treatments. But the content of crude protein in breast meat presented a linear decrease ($P < 0.05$) with increasing dietary CGM levels.

As shown as Figure 1, the inclusion levels of CGM had no significant effect ($P > 0.05$) on muscle fiber density and diameter.

Serum Biochemical Indices

Serum biochemical indices (ALT, AST, glucose, HDL-C, LDL-C, TC, TG, TP, and UERA) showed no significant differences ($P > 0.05$; Table 6) among all groups.

Standardized Ileal Digestibility of Amino Acid

The effect of dietary CGM levels on SIDAA is shown in Table 7. There was no significant difference ($P > 0.05$) on SIDAA among diets containing different CGM levels. There was a tendency ($P = 0.099$) for an increase in the SID of arginine and the SID of cysteine presented a quadratic increase ($P < 0.05$) with increasing dietary CGM levels. The SID of EAA was from 80.82 to 86.17%, the SID of NEAA was from 75.46 to 79.97%, and the SID of total AA was from 78.11 to 83.03% among 5 experimental diets.

DISCUSSION

A major objective of this experiment was to determine the optimal level or the maximum safe levels of CGM in growing duck's diet based on growth performance, serum biochemical indexes, carcass characteristic, meat physical, and chemical quality as well as muscle fiber characteristics and SIDAA when 5 experimental diets kept are isonitrogenous and isocaloric. The results showed that dietary inclusion of graded levels of CGM had no effect of growth rate, carcass traits, and serum biochemical indices of ducks. Our findings are in agreement with a recent study (Lakshmi et al., 2017) in which dietary CGM, when fed up to 25% of the diet, had no effect on carcass performance of colored broilers Harbach et al. (2007). found that diets containing 40% CGM had no deleterious effect on pig's growth rate when the diets were formulated to be isocaloric.

However, in the current study, ducks fed diets containing 12% CGM had a significant higher F: G than ducks fed other four diets Brunelli et al. (2010). also found that the increasing level of defatted CGM inclusion had a negative linear effect on FI and a quadratic effect on F: G without significantly altering the other parameters in broiler chickens Weber et al. (2010). found that dietary CGM levels (0−38.69%) linearly depressed the ADFI and ADG of pigs during the first

Table 6. Effects of dietary corn germ meal levels on serum biochemical indices of ducks from 10 to 42 d of age.

Items	Corn germ meal levels %					SEM	P-value		
	0	3	6	9	12		ANOVA	Linear	Quadratic
ALT, U/L	36.97[1]	34.91	36.77	36.41	31.97	6.19	0.94	0.59	0.39
AST, U/L	25.93	23.76	32.16	32.55	19.47	11.65	0.78	0.82	0.55
Glucose, mmol/L	7.08	7.57	8.00	7.03	7.20	0.67	0.51	0.67	0.68
HDL-C, mmol/L	2.70	2.63	3.20	2.75	2.77	0.27	0.31	0.97	0.48
LDL-C, mmol/L	0.88	0.78	0.86	1.02	0.92	0.11	0.39	0.28	0.24
TC, mmol/L	5.98	5.99	6.29	6.13	5.78	0.35	0.70	0.49	0.35
TG, mmol/L	1.42	1.55	1.23	1.32	1.08	0.26	0.46	0.26	0.48
TP, g/L	32.23	30.73	32.9	31.82	31.72	1.08	0.46	0.49	0.80
UREA, mmol/L	0.53	0.50	0.52	0.60	0.45	0.09	0.56	0.70	0.82

Abbreviations: ALT, alanine aminotransferase; AST, aspartate aminotransferase; HDL-C, high density lipoprotein cholesterol; LDL-C, low density lipoprotein cholesterol; TC, total cholesterol; TG, triglyceride; TP, total protein; UREA, uric acid.

[1]Values are the means of 6 ducks per dietary treatment (n = 6).

week of the study Jaworski et al. (2015). suggested that CGM had 2 primary fiber components, the cellulose and arabinoxylans, could limit the application of CGM in poultry diets. In our previous study of Han et al. (2017), however, which found that diets containing 7.52% crude fiber had no negative effect on the growth performance of ducks aged 1 to 21 d of age. Thus, the main reason may be due to the lower nutrient utilization of CGM when compared with nutrient utilization of corn or soybean meal. The content of corn or soybean meal in control group was 10 or 3.4% higher than those in 12% CGM group. Correspondingly, we also found that the yield and the protein content of breast meat linearly decreased with increasing dietary CGM levels in the present study. This result further suggested that inclusion of CGM to replace corn or soybean meal in diets decreased the availability of dietary crude protein or amino acids.

Almeida et al. (2011) evaluated the SID of CP and AA in CGM by using growing pigs and found that SID of CP was 69.5%, SID of all indispensable AA was 78.9%, and SID of all dispensable AA was 76.3%, however, the corresponding value in corn was, 89.1, 84.9, and 103.3%, respectively. In contrast, we observed that there was no difference of SIDAA among 5 experimental diets and the SID of EAA was above 80%. However, the lysine concentration in CGM was 0.66% in the present study which was lower than 0.94% in the study of Almeida et al. (2011). This may be a main reason why 12% CGM groups presented a significant increase of F:G. Furthermore, Bovera et al. (2007) showed that blood urea improves with increasing dietary CP content. Although there was no significant difference of serum urea among 5 dietary treatment, serum urea concentration was lower (0.45 mmol/L) in 12% CGM groups than 0.53 mmol/L in control groups. This further verified that 12% CGM diets had lower protein availability when all experimental diets were formulated to be isonitrogenous. Apparently, the variation in nutritional value of corn by-products is a major concern when it is

Table 7. Effects of dietary corn germ meal levels on standardized ileal digestibility of amino acids of ducks from 10 to 42 d of age.

Items	Corn germ meal levels %					SEM	P-value		
	0	3	6	9	12		ANOVA	Linear	Quadratic
Essential amino acid (EAA)									
Arg	82.09[1]	82.15	78.72	84.59	85.56	2.54	0.10	0.46	0.13
His	83.77	83.59	82.87	87.87	85.42	2.31	0.23	0.77	0.81
Ile	80.20	79.35	77.42	84.35	81.59	3.46	0.40	0.87	0.73
Lys	81.20	79.29	78.70	84.90	82.13	3.39	0.40	0.99	0.69
Leu	84.91	84.36	83.2	87.85	86.69	2.47	0.36	0.95	0.67
Met	88.64	89.73	89.49	92.61	91.69	2.66	0.55	0.89	0.93
Phe	84.36	83.88	82.42	87.45	85.5	2.61	0.39	0.94	0.75
Val	80.11	79.15	77.83	83.62	81.79	3.30	0.46	0.90	0.71
Thr	81.43	80.54	80.06	84.90	83.58	3.15	0.50	0.94	0.74
Total EAA	82.78	82.14	80.82	86.17	84.68	2.81	0.37	0.92	0.66
Nonessential amino acids (NEAA)									
Ala	82.91	81.27	80.84	85.17	84.72	2.89	0.47	0.97	0.52
Asp	78.94	77.06	76.03	79.94	79.14	2.98	0.67	0.46	0.51
Cys	67.09	65.02	67.36	69.37	77.28	4.32	0.07	0.20	0.02
Gly	72.04	70.34	69.27	74.75	73.47	3.67	0.57	0.837	0.62
Glu	83.00	82.25	80.85	84.72	84.21	2.30	0.47	0.81	0.56
Pro	84.37	82.65	82.66	85.99	85.34	2.08	0.39	0.99	0.49
Tyr	77.16	78.19	75.33	81.11	80.71	3.64	0.48	0.99	0.80
Ser	82.53	80.96	80.85	83.94	85.67	2.58	0.31	0.64	0.20
Total NEAA	77.95	76.68	75.46	79.97	79.84	3.07	0.52	0.88	0.52
Total AA	80.32	79.36	78.11	83.03	82.24	2.93	0.45	0.98	0.59

Abbreviations: Ala, Alanine; Arg, Arginine; Asp, Aspartic acid; Cys, Cysteine; Gly, Glycine; Glu, Glutamic acid; His, Histidine; Ile, Isoleucine; Lys, Lysine; Leu, Leucine; Met, Methionine; Phe, Phenylalanine; Pro, Proline; Ser, Serine; Val, Valine; Thr, Threonine; Tyr, Tyrosine.

[1]Values are the means of 6 replicates of 2 ducks per each treatment (n = 6).

marketed to livestock farmers (Nuez-Ortín and Yu, 2009; Azarfar et al., 2012) Xin et al. (2020). found there were significant differences of CP concentration among 3 batches of CGM. It is necessary to analyze the chemical composition and consider the nutrients availability of CGM before using CGM to poultry diets.

In recent years, low-cost production of high-quality meat has become a major goal of the poultry industry. Meat color and intramuscular fat content are 2 of the most important quality attributes of poultry meat for consumer acceptance (Tang et al., 2007) and are mostly influenced by diet. In the commercial evaluation of meat quality, color is used as an indicator of its freshness and suitability for specific culinary purposes (Gornowicz et al., 2009). Increasing the intramuscular fat content to improve the meat quality is the most important part of the breeding work (Chen et al., 2017). In the present study, dietary CGM inclusion had no effect on the meat color and intramuscular fat content. A previous study has shown that DDGS addition at up to 30% to Pekin duck from 22 d of age did not have a negative effect on meat quality of birds slaughtered at 49 d of rearing (Adamski et al., 2011) Widmer et al. (2008). reported that in conclusion of up to 10% corn germ in diets fed to growing-finishing pigs has no detrimental effects on carcass quality and pork palatability.

However, as the pattern change of the protein content in breast meat, we found that the muscle fiber diameter in breast meat tended to reduce with increasing of dietary CGM levels. This agreed with the study of Huo et al. (2021), which showed that the diameter of muscle fibers had a moderate or significant correlation with pH, shear force value, moisture content, and protein content of meat in fast growing ducks (Pekin duck). And then the authors determined the correlation coefficients was 0.525 between muscle fiber diameter and protein content and was 0.469 between muscle fiber density and protein content Lee et al. (2012). also showed that the variation in muscle fiber characteristics can partially explain the variation in meat quality, because the size of muscle fibers affects muscle growth potential and the size of the fiber bundle, resulting in the visible coarseness of transverse sections of meats (Kokoszynski et al., 2019).

CONCLUSIONS

In conclusion, dietary inclusion of 3, 6, 9, and 12% CGM had no detrimental effect on growth rate, carcass characteristics, serum biochemical parameters, meat physical quality, and dietary SIDAA, but ducks fed diets containing 12% CGM had a higher F: G and lower meat protein content. Therefore, these results suggested that the optimal or the maximum safe levels of CGM in diets for meat duck aged from 10 to 42 d of age should be below 9%.

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DISCLOSURES

No conflict of interest exits in the submission of this manuscript, and manuscript is approved by all authors for publication.

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