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Effect of yeast culture supplementation on blood characteristics, body development, intestinal morphology, and enzyme activities in geese

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Abstract

The objective of this experiment is to evaluate the effects of yeast culture (YC) supplementation on blood characteristics, body size, carcass characteristics, organ weights, intestinal morphology, and enzyme activities. Five groups of geese were randomly assigned to five dietary treatments: the basal diet (control) and basal diets plus 0.5%, 1.0%, 2.0%, or 4.0% YC. Compared with the controls, YC supplementation at 0.5% and 1.0% increased the serum total protein (TP), albumin (ALB), and globulin (GLO) and decreased the uric acid and creatine kinase (CK) contents ($p < 0.05$). YC supplementation at 2.0% and 4.0% increased the CK, growth hormone, catalase and glutathione reductase contents, and relative proventriculus weights, and decreased the TP, ALB, and GLO contents, relative liver, gizzard, jejunum, ileum, and thymus weights ($p < 0.05$). YC supplementation at 2.0% improved fossil bone length, breast muscle percentage, jejunal villus height, ileal and jejunal villus height/crypt depth ratios, pepsin, lipase, amylase and pancreatic trypsin activities, and decreased abdominal fat percentage ($p < 0.05$). Furthermore, YC inclusion increased the body slope length (linear, $p = 0.002$; quadratic, $p = 0.02$), breast width (quadratic, $p = 0.02$), ileal (linear, $p = 0.04$; quadratic, $p = 0.01$) and duodenal villus height (cubic, $p = 0.04$), and decreased the relative gizzard (quadratic, $p = 0.04$) and thymus (linear, $p = 0.002$; quadratic, $p = 0.02$; cubic, $p = 0.02$) weights, liver (linear, $p = 0.002$; quadratic, $p = 0.02$), and serum (linear, $p = 0.006$; quadratic, $p = 0.03$) malondialdehyde contents, and jejunal crypt depth (quadratic, $p = 0.03$). The findings indicated that the YC supplementation had a positive effect on the growth and development of geese, with 2% YC being the most effective.

KEYWORDS

blood characteristics, body development, enzyme activity, geese, intestinal morphology, yeast culture

Jie Zhang and Yancong Yuan contributed equally to this study.

1 | INTRODUCTION

Yeast cultures (YCs) are micro-ecological products formed by yeast after sufficient anaerobic fermentation on specific media and are mainly composed of yeast metabolites, fermented medium, and a few yeast cells (van der Peet-Schwering et al., 2007; Shen et al., 2009). YCs are rich in vitamins, saccharides, minerals, enzymes, growth-promoting factors, and amino acids (Shen et al., 2009; Yalçin et al., 2008), which have been used to replace antibiotics to improve animal growth, metabolism, health, and maintain production efficiency (Bach, 2001; Gao et al., 2008; Smith et al., 2002). In dairy cows, supplementing diets with YCs improved lactation performance (Dias et al., 2017a, 2017b; Salvati et al., 2015) and increased feed efficiency (J. Dias et al., 2018). In sheep, adding YCs can be beneficial in the prevention and treatment of acute ruminal lactic acidosis (Reis et al., 2018). In pigs, dietary supplementation of YC improved growth performance and modulated gut immune response (van der Peet-Schwering et al., 2007; Shen et al., 2009). In aquatic animals, YC feeding benefitted the gut microbiota and promoted feed intake, weight gain, and disease prevention (Berto et al., 2016; Liu et al., 2018). Currently, studies about YC in poultry are mainly focused on chickens. For example, YC supplementation improved growth performance, immune functions, and carcass yield in broilers (Fathi et al., 2012; Gao et al., 2008). YC supplementation to laying hen diets increased egg weight and decreased egg yolk cholesterol without affecting performance and egg traits (Yalçin et al., 2008). In addition, YC also provides other benefits such as improved organ weights (Adejumo et al., 2006), enzyme activity (Jin et al., 2000; Tagang et al., 2013), meat quality, and antioxidant capacity (J. Zhang et al., 2021) in poultry. However, research on the application of dietary YC supplementation to geese is limited. Therefore, the objective of this study was to evaluate the effects of dietary YC supplementation in geese on blood characteristics, body development, intestinal morphology, and enzyme activities.

2 | MATERIALS AND METHODS

2.1 | Experimental design and goose husbandry

Three hundred 1-day-old healthy mixed-sex Sichuan white geese, with average body weights of 95.57 ± 2.42 g, were used in a completely randomised study and divided into five groups fed either 0% (control), 0.5%, 1.0%, 2.0%, or 4.0% commercial YC product (Beijing Enhalor Biotechnology). The YC was a fermented product composed of inactivated *Saccharomyces cerevisiae* grown on a medium. The ingredient analysis shows that YC contains ~15.0% crude protein, ~3.5% crude fat, ~8.7% crude fibre, ~14.2% amino acid, ~3.3% mannan, ~14.0% β-glucan, and other micro-components. The corn-soybean meal basal diets were formulated (Table 1) to meet the recommendations of the National Research Council (1994) during the starter (Days 1–28) and grower (Days 29–70) periods. Geese were housed in pens (3.5 m × 3.0 m) and net-reared in a windowed poultry house from April to June 2019. Each group consisted of 6 replicate pens with 10 geese per pen. Geese were injected with *Astragalus* polysaccharides (Yongjian Biological) and administered multidimensional electrolytes in their water on Days 1 and 7. Geese were allowed access to feed (in pellet form) and water ad libitum throughout the experimental period. Feed was provided four times daily at 7:30, 12:30, 17:00, and 21:00 h. The average house temperature during the experimental period was 21.32 ± 2.39°C, and the relative humidity was 84.03 ± 5.15%.

TABLE 1 Composition and nutrient content of starter (Days 1–28) and grower (Days 29–70) basal diets (dry basis)

Items	Starter	Grower
Ingredients (%)		
Corn	63.80	53.60
Wheat bran	2.99	14.50
Soybean meal	20.00	11.50
Rapeseed meal	4.00	–
Rice bran	–	13.40
Silkworm chrysalis	4.30	1.79
$CaHPO_4$	1.59	0.90
Limestone	0.87	0.75
L-lysine (98.5%)	0.15	0.18
DL-methionine	0.05	0.07
Salt (NaCl)	0.20	0.20
Choline chloride	0.05	0.12
Premix[a]	2.00	2.00
Sand	0	1.00
Total	100	100
Nutrient content		
Metabolisable energy (MJ kg^{-1})[b]	11.97	11.21
Crude protein (%)	20.43	14.81
Crude fibre (%)	4.12	8.04
Calcium (%)	0.87	0.80
Available P (%)[b]	0.43	0.40
Lysine (%)	1.14	0.85
Methionine (%)	0.36	0.30

[a]The premix provides the following per kilogram of diet: VA 2000 IU, VD_3 1000 IU, VE 3000 mg, VK_3 200 mg, VB_1 100 mg, VB_2 1200 mg, VB_6 200 mg, VB_{12} 2.5 mg, nicotinic acid 600 mg, pantothenic acid 1800 mg, folic acid 200 mg, biotin 20 mg, Fe 6 g, Cu 0.2 g, Mn 15 g, Zn 8 g, I 10 mg, and Se 30 mg.

[b]Calculated according to Chinese Feed Database News Web Center (2005).

2.2 | Experimental procedures

2.2.1 | Blood characteristics

Blood samples of 18 fasted geese randomly selected from each group (3 geese per pen) were collected from vena brachialis under the wing at Day 70. Samples were collected without anticoagulant, let stand for 10 min, and centrifuged at 3500 g for 10 min at room temperature, and then the resultant sera were stored at −80°C. Serum samples were analysed for total protein (TP), albumin (ALB), globulin (GLO), uric acid (UA), and creatine kinase (CK) using CL-8000 clinical chemical analyzer (Shimadzu) via standard enzymatic procedures.

2.2.2 | Body development

Body size

The body size was determined with reference to the national standard NY/T 823-2020 (MOAPRC, 2020). The body slope length, fossil bone length, breast depth, breast width, shank length, shank circumference, pelvis width, neck length, and half-diving depth were measured with a caliper or tape.

Carcass characteristics

After blood collection, the same geese were weighed individually and sacrificed by cervical dislocation and exsanguinated to evaluate the carcasses. The feathers, foot cuticle, toe shell, and beak shell were manually removed after scalding at 60°C for approximately 2 min, then the carcass was weighed. Next, the half eviscerated, eviscerated, leg muscle, breast muscle and abdominal fat were weighed, and each portion was expressed as a percentage of the live body weight.

Organ weights

The heart, liver, spleen, gizzard, proventriculus, thymus, pancreas, bursa of Fabricius, duodenal, jejunum, and ileum were removed and weighed. Organ weight was expressed as a percentage of live body weight.

2.2.3 | Intestinal morphology

Three centimeters of the duodenum, jejunum, and ileum were removed, rinsed in Tris-buffered saline, and fixed in 4% paraformaldehyde. Fixed intestinal segments were routinely processed, embedded in paraffin, sliced into 5-μm-thick sections, and stained with hematoxylin and eosin for light microscopy measurements of the villus height and crypt depth at ×22 magnification. All villi and crypts were measured in triplicate for each tissue.

2.2.4 | Enzyme activities

Immediately following organ weighing, aliquots of the liver, proventriculus, pancreas, and duodenal samples (approximately 5 g each) were removed from each goose, cryogenically frozen in liquid nitrogen, and stored in a −80°C freezer until use. The activities of glutathione (GSH), catalase (CAT), glutathione reductase (GR), malondialdehyde (MDA), growth hormone (GH), pepsin, trypsin, lipase, and amylase were measured using commercial analytical kits according to the manufacturer's instructions (Solarbio).

2.3 | Statistical analysis

Data were analysed using one-way analysis of variance of the SPSS 22.0 software package for Windows (IBM Corporation, 2014) with least significant difference multiple comparison tests. The effect of supplemental YC levels was determined using orthogonal polynomials for linear, quadratic, and cubic effects. Variability in the data is expressed as the standard error of means and a probability level of $p \leq 0.05$ was considered to be statistically significant.

3 | RESULTS AND DISCUSSION

3.1 | Blood characteristics

Dietary YC significantly affected the serum TP, ALB, GLO, UA, CK, and GH contents ($p < 0.05$; Table 2). Compared with the controls, the serum TP, ALB, and GLO contents increased at 0.5% and 1.0% YC supplementation and decreased at 2.0% and 4.0% YC supplementation; 0.5% supplementation showed a higher increase than did 1.0% supplementation ($p < 0.05$). No differences occurred at 2.0% or 4.0% supplementation. Supplemental YC at 2.0% and 4.0% increased the CK contents, whereas 0.5% and 1.0% decreased the UA and CK contents compared with those of the controls ($p < 0.05$). CK mainly exists in the cytoplasm and mitochondria and is directly related to intracellular energy operation, muscle contraction, and ATP regeneration. The increase in CK contents in the 2% and 4% may be due to accelerated muscle contraction and energy operation caused by the goose struggling vigorously during sampling, which, in turn, resulted in elevated contents in the blood. GH content did not differ among the 0.5%, 1.0% and control groups but improved at 2.0% and 4.0% ($p < 0.05$). The 2.0% level showed the best improvement, which is consistent with previous findings that 2% YC yielded the maximum growth rate. Dietary YC supplementation affected the blood metabolism because yeast products are rich in vitamins, saccharides, minerals, enzymes, growth-promoting factors, and amino acids, which improve digestibility, immune status, and growth (Gao et al., 2008; Salinaschavira et al., 2017). Abouelnour (1998), Doto et al. (2011), and Xiong et al. (2015) reported similar results. However, Stanley et al. (2004) and Chen et al. (2013) indicated that dietary YC did not affect the TP, ALB, or GLO contents. The results also showed that TP and GH varied inconsistently as the YC levels increased, suggesting that YC efficiency exerts different effects on protein absorption and utilisation (Doto et al., 2011).

TABLE 2 Effects of yeast culture supplementation in goose diets on blood biochemical parameters

Items	Yeast culture supplementation (% of diet)					SEM	*P*		
	0 (Control)	0.5	1.0	2.0	4.0		*L*	*Q*	*C*
TP (g/L)	37.60[a]	44.10[b]	39.17[c]	35.43[d]	35.33[d]	0.15	0.27	0.62	0.58
ALB (g/L)	15.30[a]	18.33[b]	16.13[c]	14.17[d]	14.10[d]	0.06	0.25	0.59	0.53
GLO (g/L)	22.30[a]	25.83[b]	23.00[c]	21.17[d]	21.23[d]	0.18	0.29	0.65	0.62
UA (μmol/L)	221.00[a]	134.00[b]	166.00[c]	227.00[a]	224.67[a]	5.43	0.42	0.75	0.40
CK (U/L)	515.00[a]	486.00[b]	399.00[c]	717.33[d]	660.67[e]	17.16	0.22	0.54	0.39
GH (ng/ml)	0.94[a]	0.93[a]	0.99[a]	1.88[c]	1.33[b]	0.05	0.42	0.39	0.53

Note: [a–e]Means within a row with no common superscripts differ significantly ($p < 0.05$).

Orthogonal contrasts: *L* = linear, *Q* = quadratic, and *C* = cubic effect of yeast culture supplementation.

Abbreviations: ALB, albumin; CK, creatine kinase; GH, growth hormone; GLO, globulin; TP, total protein; UA, uric acid.

3.2 | Body development

3.2.1 | Body size

As shown in Table 3, YC supplementation at 2.0% significantly increased the fossil bone length compared with that of the controls ($p < 0.05$). The body slope length (linear, $p = 0.002$; quadratic, $p = 0.02$) and breast width (quadratic, $p = 0.02$) increased as dietary YC increased. Body size is an important trait that directly or indirectly affects animal growth performance (Munim et al., 2013). The results of this study confirmed that the body size is consistent with the positive effect of YC supplementation on body weight (Gao et al., 2008; Yalçin et al., 2008). This may be because YC improves intestinal morphology and increases the absorption rates of Ca and P required for body size growth (Gao et al., 2008). Furthermore, it is also confirmed from the results of intestinal morphology in this article.

3.2.2 | Carcass characteristics

Compared with that of the controls, 2.0% YC supplementation significantly increased breast muscle percentages ($p < 0.05$) and decreased abdominal fat percentages ($p < 0.05$). Fathi et al. (2012) observed significantly increased breast muscle percentages in broilers fed 1.5 g/kg of YC. Similarly, broilers fed a diet containing 1% yeast extract showed significantly improved breast yields. *Lactobacillus* supplementation in broiler diets effectively reduced abdominal fat deposition after 28 days of age (Kalavathy et al., 2003). Onifade et al. (1999) also showed that broilers fed yeast (*S. cerevisiae*) had lower abdominal fat depositions. Also, Li et al. (2019) reported an increased carcass and breast yield, gizzard weight, and decreased abdominal fat by supplementing yeast up to 0.3% in diets of broiler. The higher carcass yield of geese-fed diets supplemented with YC in the present study may be attributed to better digestive function as it provides more available nutrients including vitamins and minerals, required for muscle growth (Cheng et al., 2017).

3.2.3 | Organ weights

Dietary YC did not affect the relative heart weights. YC supplementation at 2.0% and 4.0% increased the relative weights of the proventriculus, decreased those of the liver, gizzard, jejunum, ileum, and thymus (all $p < 0.05$); and did not affect those of the pancreas, spleen, and bursa of Fabricius compared with the controls. YC inclusion also decreased the relative gizzard (quadratic, $p = 0.04$) and thymus (linear, $p = 0.002$; quadratic, $p = 0.02$; cubic, $p = 0.02$) weights, and these decreases were minimal at the 2.0% and 4.0% levels. Similarly, Alcicek et al. (2004) and Bozkurt et al. (2011) reported that dietary supplementation with prebiotics and probiotics decreased the relative liver and small intestinal weights in broilers. Engberg et al. (2000) found that antimicrobial activity in the gut lumen thinned the intestinal wall and reduced the intestinal weight. However, Adejumo et al. (2006), Tagang et al. (2013), and Jin et al. (1998) reported inconsistent results for broilers, and Chen et al. (2013) reported inconsistent results for geese.

3.3 | Intestinal morphology

YC supplementation and sampling sites variably affected the intestinal villus heights and villus height/crypt depth ratios (VCRs) of the geese (Table 4). Dietary YC supplementation significantly increased the jejunal villus height ($p < 0.05$), which was significantly higher after 2.0% YC supplementation than after 0.5%, 1.0%, or 4.0% YC supplementation ($p < 0.05$). YC supplementation increased the ileal (linear, $p = 0.04$; quadratic, $p = 0.01$) and duodenal (cubic, $p = 0.04$) villus heights. Increasing the YC supplementation rate did not affect the intestinal crypt depth and decreased the jejunal crypt depth (quadratic, $p = 0.03$). Similarly, Gao et al. (2008) found that YC supplementation increased the duodenal villus height and reduced jejunal crypt depth in 42-day-old broilers. Shen et al. (2009) observed increased jejunal villus heights, while crypt depth was unaffected in pigs supplemented with YC, and van der Peet-Schwering et al. (2007) reported that dietary YC did not affect crypt

TABLE 3 Effects of yeast culture supplementation in geese diets on goose body development

Items	Yeast culture supplementation (% of diet)					SEM	*p*		
	0 (Control)	0.5	1.0	2.0	4.0		*L*	*Q*	*C*
Body size (cm)									
Body slope length	26.17[a]	26.31[a]	26.36[a]	27.17[ab]	28.33[b]	0.42	0.002	0.02	0.10
Fossil bone length	12.50[a]	14.67[b,c]	13.83[a,b,c]	15.33[c]	13.33[a,b]	0.54	0.94	0.59	0.81
Breast depth	6.54	6.69	6.48	6.64	6.27	0.13	0.17	0.28	0.61
Breast width	5.65	5.95	6.06	6.24	5.99	0.14	0.41	0.02	0.13
Shank length	7.78	8.44	7.97	8.19	8.36	0.29	0.38	0.72	0.87
Pelvis width	6.29	6.44	5.68	5.86	5.97	0.22	0.46	0.48	0.80
Half-diving depth	64.83	66.33	61.67	61.33	61.00	1.64	0.15	0.30	0.65
Carcass characteristics (%)									
Carcass	89.53	91.38	91.53	89.84	91.73	1.17	0.47	0.81	0.06
Half eviscerated	81.04	83.14	83.25	82.63	82.64	1.08	0.65	0.57	0.25
Eviscerated	72.13	75.04	74.70	74.24	73.80	1.22	0.82	0.57	0.43
Leg muscle	10.92	11.38	11.74	11.27	11.94	0.42	0.16	0.45	0.23
Breast muscle	4.45[a]	4.49[a]	4.66[a]	5.42[b]	4.27[a]	0.18	0.89	0.36	0.16
Abdominal fat	3.36[a]	2.49[b,c]	2.95[a,b]	2.18[c]	2.93[a,b]	0.16	0.74	0.37	0.72
Organ weights (%)									
Heart	0.88	0.85	0.85	0.88	0.82	0.04	0.25	0.52	0.19
Liver	2.25[a]	1.83[b]	1.82[b]	1.90[b]	1.77[b]	0.08	0.28	0.46	0.27
Gizzard	3.16[a]	2.89[b]	2.59[c]	2.50[c]	2.70[b,c]	0.08	0.33	0.04	0.16
Proventriculus	0.35[a]	0.27[c]	0.34[a]	0.39[b]	0.39[b]	0.01	0.23	0.56	0.57
Pancreas	0.35[a,b]	0.33[b,c]	0.32[b,c]	0.38[a]	0.31[c]	0.01	0.64	0.69	0.22
Duodenal	0.26[a]	0.20[c]	0.25[a,b]	0.22[b,c]	0.25[a,b]	0.01	0.84	0.77	0.94
Jejunum	0.72[a]	0.53[d]	0.66[b]	0.71[a,b]	0.59[c]	0.02	0.73	0.91	0.73
Ileum	0.60[a]	0.50[b]	0.52[b]	0.53[b]	0.51[b]	0.02	0.41	0.60	0.49
Spleen	0.07[ab]	0.06[b]	0.08[a]	0.07[a,b]	0.08[a]	0.01	0.32	0.68	0.91
Bursa of Fabricius	0.29[a,b,c]	0.26[c]	0.27[b,c]	0.32[a]	0.30[a,b]	0.01	0.36	0.68	0.12
Thymus	0.16[a]	0.14[b]	0.13[b,c]	0.12[c]	0.07[d]	0.01	0.002	0.02	0.02

Note: [a–c]Means within a row with no common superscripts differ significantly ($p < 0.05$).
Orthogonal contrasts: *L* = linear, *Q* = quadratic, and *C* = cubic effect of yeast culture supplementation.

depth. Taller villi, by providing an increased surface area, have the capability of greater absorption of available nutrients (Khalid et al., 2021).

Compared with the controls, dietary YC supplementation at 1.0%, 2.0%, and 4.0% significantly increased the ileal and jejunal VCRs ($p < 0.05$), with a maximal increase at 2.0%. Gao et al. (2008) reported increased intestinal VCRs and that broilers fed 2.5 g/kg showed enhanced performance after YC supplementation. Shen et al. (2009) also observed increased jejunal VCRs in pigs supplemented with YC. This may be due to the mannan oligosaccharides (MOS) and β-glucan in YC promoting intestinal health by enhancing intestinal immunity. VCRs reflect the development of the intestinal mucosa. The better the development and the more perfect the structure, the more the number of goblet cells, which can secrete more mucin to improve the immune protection of the mucosa, thus ensuring the smooth immunity of the intestinal mucosa (Liao, 2009). It also has been reported that MOS can bind to the receptors on the surface of intestinal mucosal immune cells of piglets to activate the intestinal mucosal immune response and promote the production of intestinal mucosal secretory immunoglobulin A (Halas & Nochta, 2012). Moreover, the improvement in intestinal health by dietary YC supplementation was related to the upregulation of intestinal barrier–related genes and antimicrobial peptides genes (J.-C. Zhang et al., 2020).

TABLE 4 Effect of dietary yeast culture supplementation on intestinal morphology of geese

Items	Yeast culture supplementation (% of diet)					SEM	*p*		
	0 (Control)	0.5	1.0	2.0	4.0		*L*	*Q*	*C*
Villus height (μm)									
Ileum	787.67^{a}	813.67^{a,b}	857.67^{b,c}	895.67^{c}	908.67^{c}	16.44	0.04	0.01	0.12
Jejunum	1363.00^{a}	1325.67^{a}	1438.00^{b}	1670.33^{c}	1555.67^{d}	22.80	0.18	0.23	0.13
Duodenum	969.00^{a}	986.33^{a}	1052.67^{b}	1194.67^{c}	1105.67^{b}	16.94	0.21	0.12	0.04
Crypt depth (μm)									
Ileum	206.00	206.33	192.67	197.67	220.00	9.38	0.32	0.12	0.43
Jejunum	236.33	228.33	214.00	208.00	214.67	8.49	0.22	0.03	0.22
Duodenum	218.33	208.67	195.67	219.33	223.67	11.24	0.40	0.61	0.42
VCR									
Ileum	3.84^{a}	3.96^{a}	4.46^{b}	4.54^{b}	4.14^{a,b}	0.15	0.57	0.11	0.41
Jejunum	5.77^{a}	5.82^{a}	6.74^{b}	8.04^{c}	7.27^{b}	0.17	0.18	0.12	0.15
Duodenum	4.46	4.74	5.43	5.46	4.97	0.24	0.54	0.10	0.37

Note: $^{a-d}$Means within a row with no common superscripts differ significantly ($p \leq 0.05$).
Orthogonal contrasts: L = linear, Q = quadratic, and C = cubic effect of yeast culture supplementation.
Abbreviation: VCR, villus-to-crypt ratio.

TABLE 5 Effects of yeast culture supplementation in goose diets on digestive enzymes

Items	Yeast culture supplementation (% of diet)					SEM	*p*		
	0 (control)	0.5	1.0	2.0	4.0		*L*	*Q*	*C*
Pepsin (U/mg)	9.96^{a}	10.32^{a}	10.18^{a}	12.06^{b}	9.85^{a}	0.50	0.93	0.34	0.32
Duodenum									
Trypsin (U/mg)	3.04	3.11	3.22	3.64	2.79	0.26	0.69	0.16	0.07
Lipase (U/g)	426.06^{c}	473.85^{b}	471.40^{b}	531.47^{a}	428.23^{c}	11.35	0.94	0.11	0.33
Amylase (U/mg)	0.96^{b,c}	0.88^{c}	1.06^{a,b}	1.12^{a}	1.04^{a,b}	0.05	0.36	0.39	0.63
Pancreas									
Trypsin (U/mg)	1128.19^{a}	1439.03^{b}	1411.82^{b}	2135.71^{c}	1747.26^{d}	63.86	0.23	0.16	0.32
Lipase (U/g)	51.17^{a}	50.90^{a}	51.43^{a}	64.77^{b}	55.19^{a}	2.45	0.44	0.41	0.19
Amylase (U/mg)	0.50^{a}	0.53^{a}	0.55^{a,b}	0.66^{b}	0.66^{b}	0.04	0.04	0.07	0.11

Note: $^{a-d}$Means within a row with no common superscripts differ significantly ($p < 0.05$).
Orthogonal contrasts: *L* = linear, Q = quadratic, and *C* = cubic effect of yeast culture supplementation.

3.4 | Enzyme activities

YC supplementation did not affect trypsin activity in the duodenum (Table 5). YC supplementation at 2.0% improved the activities of pepsin, lipase, amylase, and pancreatic trypsin compared with those of the controls ($p < 0.05$). As the dietary YC increased, the pancreatic amylase activity responded linearly ($p = 0.04$), and the duodenal trypsin activity tended to be improved (cubic, $p = 0.07$); these results were maximal at the 2.0% level. Similarly, Jin et al. (2000) reported that supplementation with *Lactobacillus* cultures increased intestinal amylase activity in chickens. Several studies on probiotics have shown increased activity among digestive enzymes such as pepsin, trypsin, lipase, and amylase (Hunt et al., ; Zacarias-Soto et al., 2011). YCs are rich in enzymes and can modulate intestinal microorganisms that modify the intestinal milieu and deliver enzymes and other beneficial substances to the intestines (Shen et al., 2009). The YC has been shown to improve nutrient digestibility (Gao et al., 2008), which supports the finding that YC increases digestive enzyme activity in the intestines.

Dietary YC supplementation at 2.0% and 4.0% increased the liver CAT and serum GR contents compared with those of the controls ($p < 0.05$; Table 6). GSH levels did not differ between the YC-treated

TABLE 6 Effects of yeast culture supplementation in goose diets on antioxidant enzymes

Items	Yeast culture supplementation (% of diet)					SEM	*p*		
	0 (Control)	0.5	1.0	2.0	4.0		*L*	*Q*	*C*
Liver									
GSH (μmol/g)	0.94^{a,b}	0.83^{a}	1.06^{b}	1.05^{b}	1.04^{b}	0.05	0.32	0.53	0.82
CAT (U/mg)	124.92^{a}	131.97^{a}	125.55^{a}	175.57^{b}	146.33^{c}	4.14	0.36	0.39	0.37
GR (U/g)	13.41^{b,c}	14.00^{b}	10.14^{d}	12.43^{c}	27.52^{a}	0.36	0.08	0.03	0.20
MDA (nmol/mg)	7.30^{a}	6.54^{b}	5.70^{c}	5.31^{c}	2.50^{d}	0.13	0.002	0.02	0.07
Serum									
GSH (μmol/g)	2.88	2.58	2.86	2.76	2.58	0.12	0.33	0.67	0.85
CAT (U/mg)	5.00^{b,c}	5.53^{a,b}	4.73^{c}	5.78^{a}	4.77^{c}	0.20	0.75	0.69	0.83
GR (U/g)	46.54^{a}	31.20^{b}	46.21^{a}	63.35^{c}	52.82^{d}	1.37	0.35	0.57	0.44
MDA (nmol/mg)	5.72^{a}	5.28^{a}	4.33^{b}	3.95^{b}	2.78^{c}	0.15	0.006	0.03	0.17

Note: $^{a-d}$Means within a row with no common superscripts differ significantly ($p < 0.05$).
Orthogonal contrasts: *L* = linear, *Q* = quadratic, and *C* = cubic effect of yeast culture supplementation.
Abbreviations: CAT, catalase; GR, glutathione reductase; GSH, glutathione; MDA, malondialdehyde.

and control groups; however, liver GSH increased slightly at 1.0%, 2.0%, and 4.0% supplementation. Inclusion of YC decreased the MDA contents in the liver (linear, $p = 0.002$; quadratic, $p = 0.02$) and serum (linear, $p = 0.006$; quadratic, $p = 0.03$). Similarly, Tagang et al. (2013) reported that yeast probiotic supplementation enhanced serum antioxidant enzyme activities in broilers, but they found no effect on MDA levels. Chen et al. (2013) showed that fermented liquid feed supplemented with *Bacillus subtilis* and *S. cerevisiae* increased the GSH-Px and superoxide dismutase activities and decreased the MDA contents in geese. Nutrition plays a vital role in maintaining the pro-oxidant/antioxidant balance (Cowey, 1986). Delles et al. (2014) demonstrated that dietary antioxidant supplementation improved oxidative stability, which was associated with enhanced cellular antioxidant enzymatic activity. This may suggest that dietary YC supplementation can significantly improve the health and oxidative statuses of geese.

4 | CONCLUSION

Dietary YC supplementation variously affected blood metabolism parameters and decreased organ weights, and improved body development, intestinal morphology, digestive and antioxidant enzyme activities of geese, with 2% YC supplementation was the most effective under the current experimental conditions.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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