Effect of supplemental yeast cell walls on growth performance, gut mucosal glutathione pathway, proteolytic enzymes and transporters in growing broiler chickens

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ABSTRACT: This study aimed to investigate the effect of supplemental yeast cell walls (YCW) on growth performance, gut mucosal glutathione pathway, proteolytic enzymes, and transporters in broiler chickens from 1 to 21 d of age. One-day-old broiler chickens ($n = 480$) were randomly allocated to 4 treatments with 6 replicates of 20 chicks each for diets containing YCW at 0, 0.5, 1.0, and 1.5 g/kg. The results showed that YCW supplementation increased ($P < 0.05$) ADFI and ADG by 15.3% and 16.0%, respectively, and the 2 higher doses of YCW had greater effects ($P < 0.05$) than the lower dose. For the glutathione pathway in the duodenal mucosa, the levels of reduced glutathione and glutathione reductase in the YCW treatments were increased ($P < 0.05$) by 15.6% and 17.4%, respectively, but glutathione S-transferases

was not affected. Similarly, the YCW increased ($P < 0.05$) the mucosal activities of trypsin, dipeptidyl, and leucine aminopeptidase by 12.4%, 5.5%, and 17.3%, respectively, and the mRNA profiles of neutral, cationic, and oligopeptide transporters by 62.5%, 69.1%, and 11.5%, respectively. The YCW also increased ($P < 0.05$) the concentrations of Thr, Met, Ile, Leu, Lys, Arg, and Tyr in the blood by 8.8% to 39.2%. Additionally, the ADFI, ADG, reduced glutathione, trypsin, dipeptidyl aminopeptidase, leucine aminopeptidase, and cationic amino acid transporter increased linearly and quadratically ($P < 0.05$) with YCW supplementation. The results suggest that YCW supplementation can beneficially modulate intestinal glutathione pathway, proteolytic enzyme activity, and nutrient transport in growing animals.

Key words: broiler chickens, glutathione pathway, proteolytic enzymes, transporters, yeast cell walls

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INTRODUCTION

The radical development in fuel alcohol has created vast quantities of commercial-scale source of yeast cell walls (YCW). The YCW comprises 2 major constituents: glucans (glucose polysaccharides) and mannans (mannose polysaccharides). Its largest commercial application is as a nutritional supplement in animal feed (Moran, 2004). Recent studies have shown that YCW or its components can be used as a natural growth promoter

for growing animals (Santin et al., 2001; Kogan and Kocher, 2007; Huyghebaert et al., 2011; Ghosh et al., 2012; Xue et al., 2017). This function of YCW is an integrative effect, including as prebiotics modulating gut microbiota, reducing enterotoxin, adsorbing exogenous toxins, blocking pathogenic bacterial adhesion to the gut mucous, and improving immunity (Vinogradov et al., 1998; Mansour and Levitz, 2003; Yannikouris et al., 2004; Wellens et al., 2008; Krizkova et al., 2006).

Intestinal mucosal oxidative stress caused by various toxins from dietary ingredients or gut harmful bacteria is a primary factor that damages the gut health and growth of animals. In the meanwhile, antioxidative reaction is mainly from

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glutathione pathway. Literature showed that interference of YCW with toxins and pathogenic bacteria decreased the oxidative stress of animals by beneficially modulating malondialdehyde, catalase, glutathione peroxidase, and superoxide dismutase in animals (Li et al., 2016; Liu et al., 2017). But there is no information about the effect of YCW on the activity of glutathione pathway.

Furthermore, the growth of animals is mainly dependent on the intake, digestion, and absorption of nutrients, especially proteins. Ghosh et al. (2012) reported that YCW improved feed conversion ratio of broiler chickens. Middelbos et al. (2007) found that apparent total tract digestibility of dogs responded cubically to YCW supplementation. Also, the YCW increased the activity of lipase in fish fed an aflatoxin-contaminated diet (Imani et al., 2017). However, the effect of YCW on proteolytic enzymes and nutrient transport in farm animals is unclear. Additionally, the YCW can modulate metabolism by influencing total cholesterol or free amino acids in the serum of broiler chickens or pigs (Li et al., 2016; Liu et al., 2017).

Therefore, given the known effect on stimulating growth, hypothetically, the YCW can improve the activities of glutathione pathway, proteolytic enzymes, and transporters in the gut mucosa of farm animals. The aim of this study was to investigate the effect of YCW on the growth performance, activities of reduced glutathione (**r-GSH**), glutathione *S*-transferases (**GSTs**), glutathione reductase (**GR**), pepsin, trypsin, chymotrypsin, dipeptidyl aminopeptidase (**Di-AP**) and leucine aminopeptidase (**Leu-AP**), the mRNA expression of solute carrier family 6 member 19 (**SLC6A19**, neutral amino acid transporter), solute carrier family 7 member 2 (**SLC7A2**, cationic amino acid transporter) and solute carrier family 15 member 1 (**SLC15A1**, oligopeptide transporter), and the concentrations of free amino acids in the plasma of growing broiler chickens.

MATERIALS AND METHODS

Animal Ethic Statement

The trial protocol was approved by the Institutional Committee for Animal Use and Ethics of the College of Animal Science of Henan University of Science and Technology (Luoyang, Henan, China).

Yeast Cell Walls, Diets, Animals, and Samples

The YCW comprises 46.2% of D-glucose and 29.8% of D-mannose from Hongxiang Biological

Feed Laboratory of Henan University of Science and Technology (Luoyang, China) and added at 0, 0.5, 1.0, and 1.5 g/kg of feed at the expense of corn in the formulation. The contents of D-glucose and D-mannose in YCW were determined according to China National Standard (GB/T 18104-2000). The nutrition levels of basal diet were recommended by China Agricultural Standard (NY/T 33-2004). All diets were fed in mash form on an air-dry basis. No antibiotics were offered to broilers via either feed or water throughout the trial. The formulation of basal diet was listed in Table 1.

A total of 480 1-d-old male Arbor Acres broilers were randomly distributed into 4 groups with pens of 20 chicks each. All chicks were reared on floor pens (1.2 × 2.0 m) with new wood shavings (8 to 10 cm thickness) in an environmentally controlled facility at the Research Center of the Henan University of Science and Technology and given *ad libitum* access to diets and water throughout the trial. The room temperature was maintained at 34 °C for 1 to 5 d and then gradually decreased to 24 °C by 21 d old. Birds received 24 h light at 1 d and then 16L:8D for the remainder days. Birds and feed in each pen were weighed at the beginning and end of the trial, and once mortality was occurred, ADFI, ADG, and G:F were adjusted on a pen basis. All birds were monitored for general health twice a day.

At 21 d of the trial, 6 birds per pen were randomly selected, weighed, euthanized by CO₂, and then dissected. Blood was immediately drawn from the heart with a syringe and aliquoted into sterile vials for the preparation for serum according to the method by Liu et al. (2008). Proventriculus and duodenum were dissected and flushed with phosphate buffer saline (0 to 4 °C). Then, proventricular mucosa was slightly scrapped and stored at collected -80 °C for the analysis of pepsin activity. Similarly, the duodenal mucosa was collected and stored for the analysis of trypsin, chymotrypsin, Leu-AP, Di-AP, glutathione pathway, and gene expression.

Sample Analysis

Commercial kits from Nanjing Jiancheng Bioengineering Institute (Nanjing, China) were used for the detection of r-GSH (detection range from 0.3 to 147.1 mg/liter), GSTs (detection range from 6.0 to 22.0 U/mL), and GR (detection range from 1.6 to 320 U/liter). The units of r-GSH, GSTs, and GR were expressed as mg/g, μmol/min·g (U/g), and U/g per gram protein, respectively, in the supernatant of tissue samples to minimize the errors

Table 1. Ingredients and nutrient levels of basal diet (air-dry basis)

Items	Contents, g/kg
Ingredients	
Corn	570.0
Soybean meal	270.0
Corn gluten meal	50.0
Full-fat soybean	50.0
Soybean oil	10.0
Limestone	11.0
Lys	2.0
Met	1.5
Salt	3.0
Dicalcium phosphate	21.0
Choline chloride	1.5
Premix ^a	10.0
Calculated nutrients^b	
Crude protein	215.8
ME, MJ/kg	12.40
Ca	9.9
Non-phytate P	4.9
Analyzed nutrients	
Met	5.8
Lys	10.1
Thr	7.8
Ala	4.7
Ile	8.4
Leu	19.6
Phe	10.4
Arg	13.3
Tyr	7.9

^aProvided per kg diet: vitamin A (retinyl acetate), 8,000 IU; cholecalciferol, 1,000 IU; vitamin E (DL-tocopheryl acetate), 20 IU; vitamin K, 0.5 mg; thiamin, 2.0 mg; riboflavin, 8.0 mg; d-pantothenic acid, 10 mg; niacin, 35 mg; pyridoxine, 3.5 mg; biotin, 0.18 mg; folic acid, 0.55 mg; vitamin B₁₂, 0.010 mg; manganese, 120 mg; iodine, 0.70 mg; iron, 100 mg; copper, 8 mg; zinc, 100 mg; and selenium, 0.30 mg.

^bCalculated chemical composition by Chinese Feed Database (Xiong et al., 2014).

during sample preparation. Three parallel tests with aliquots of the same sample were performed for all samples and all chemical and biochemical analyses.

The activities of proventriculus pepsin (A080-1, detection range from 0.15 to 120 U/mL), trypsin (A080-2, detection range from 1 to 185 U/mL), and chymotrypsin (A080-3, detection range from 0.01 to 50 U/mL) were detected using assay kits in accordance with the manufacturer's instructions of Nanjing Jiancheng Biotechnology Institute. The units of pepsin, trypsin, and chymotrypsin were expressed as U/mg of mucosal protein in order to minimize the errors. The activity of Leu-AP was determined spectrophotometrically at 405 nm by the enzymatic hydrolysis of Leu-pnitroanilide at pH 7.0 and 40 °C. One Leu-AP unit was defined as the amount of enzyme required to liberate 1 μmol

of p-nitroaniline per minute (Thompson et al., 1976). The activity of Di-AP was based on the enzymatic hydrolysis at pH 7.5 and 30 °C of Gly-Pro-p-nitroanilide into Gly-Pro and p-nitroaniline. Liberated p-nitroaniline was measured at 405 nm. One Di-AP unit is defined as the amount of enzyme required to liberate 1 μmol/min of p-nitroaniline (Tachi et al., 1992).

Total mRNA isolation and cDNA synthesis from mucosal samples were carried out according to the description by Liu et al. (2008), and the transcript levels were expressed as the relative expression to β-actin gene. Primer information for qPCR was listed in Table 2. The qPCR reactions were set at 10 μL with 5 μL of SYBR Green Master Mix, 1 μL of primer, and 4 μL of 10× diluted cDNA or DNA using ABI Prism 7900HT Fast Real-Time PCR System. All qPCRs were run in triplicates on the same thermal cycles (50 °C 2 min, 95 °C 10 min, 40 cycles of 95 °C 15 s, and 60 °C 1 min). No amplification signal was detected in water or no-RT RNA samples. Primers synthesis and qPCR reagents were provided by Dalian TaKaRa Co., Ltd. (Liaoning, China).

A 2.5 mL of trichloroacetic acid solution (7.5%) was added to 1-mL serum and mixed thoroughly. This mixture was centrifuged at 12,000 × g and 4 °C for 15 min. The supernatant was collected and applied to an ion-exchange amino acids auto-analyzer (Hitachi L8900, Tokyo, Japan) for the determination of amino acids according to the description by Zhang (2016).

Statistics

Data were analyzed using contrasts of one-way ANOVA procedure (IBM SPSS, Armonk, NY). Linear and quadratic equations of polynomial contrasts were used for the analysis of dose trends. Pen was the experimental unit for growth performance, and the average of 6 birds per pen was the statistical unit for glutathione pathway, enzyme activity, gene expression ($2^{-\Delta\Delta Ct}$), and amino acids. Differences of variables were separated using Tukey's-b test at $P < 0.05$ level of significance, and the Tamhane T2 test was used for Glu, Gly, Phe, and SLC6 because their variances were not homogenous.

RESULTS

Growth Performance and Glutathione Pathway

As shown in Table 3, the supplementation of YCW at 0.5, 1.0, and 1.5 g/kg increased ($P < 0.05$)

Table 2. Information of primers for quantitative real-time PCR

Names	GenBank	Primers (5'→3')		Length (bp)
		Forward	Reverse	
SLC6A19	xm_419056.5	Catgatcgacacaaagccca	agcatagaccagccaggata	193
SLC7A2	eu360448.1	gggatccctctgtgctttgt	gatgaccctgctgtcaagg	160
SLC15A1	nm_204365.1	tgctttggctacccttgag	ccaggatggcgctcaagtag	184
β-actin	L08165.1	accggactgttaccacaccc	cctgagtcagcgccaaaag	116

SLC6A19 = solute carrier family 6 (neutral amino acid transporter), member 19; SLC7A2 = solute carrier family 7 member 2 (cationic amino acid transporter); SLC15A1 = solute carrier family 15 member 1 (oligopeptide transporter).

ADFI by 10.4% to 17.9%, ADG by 10.5% to 18.9%, compared with the diet without YCW supplementation. But the dose increased from 1.0 to 1.5 g/kg did not show a better effect on ADFI and ADG. The linear and quadratic contrasts showed significant dose trends ($P < 0.001$) of YCW on ADFI and ADG.

In the treatments with YCW supplementation, the mucosal levels of r-GSH and GR were increased ($P < 0.05$) by 13.8% to 16.6% and 9.7% to 24.6%, respectively. Linear ($P = 0.001$) and quadratic ($P = 0.025$) increasing trends of YCW doses were found on r-GSH, and only linear ($P < 0.001$) increasing effect was observed on GR. For GSTs, there were no differences between treatments, but a linear ($P = 0.048$) increasing effect was found.

Proteolytic Enzymes and Transporters

In Table 4, there were no differences for proventricular pepsin activity between doses of YCW, but with the increase of supplementing doses, there was a linear ($P = 0.036$) trend. In the treatments with YCW supplementation, duodenal mucosal trypsin activity was increased by 10.9% to 13.9%, with linear ($P < 0.001$) and quadratic ($P = 0.001$) responses to the doses of YCW. Compared with the control, the Di-AP activity in the treatments containing

YCW was increased by 51.9% to 57.8%, with linear ($P = 0.006$) and quadratic ($P = 0.048$) trends of doses, whereas the activity of Leu-AP was also increased ($P < 0.05$) by 14.8% to 18.5%, with linear ($P < 0.001$) and quadratic ($P < 0.001$) trends.

Compared with the control, in diets with YCW supplementation, the mRNA profiles of SLC6A19 were increased ($P < 0.05$) by 45.3% to 86.5%, with a linear ($P < 0.001$) trend of doses. The mRNA expression of SLC7A2 was increased ($P < 0.05$) by 61.3 to 84.05, with linear ($P < 0.001$) and quadratic ($P = 0.022$) trends of doses. Compared with the control, the 0.5 g/kg of YCW increased ($P < 0.05$) SLC15A1 by 12.2%; however, the other two high doses had no effects on the mRNA expression of SLC15A1, and a linear ($P = 0.033$) increase was found on this gene.

Concentrations of Free Amino Acids in Systemic Plasma

Compared with the control, in the treatments with YCW supplementation, the concentrations of Thr, Met, Ile, Leu, Lys, Arg, and Tyr in systemic plasma were averagely increased ($P < 0.05$) by 9.0%, 31.7%, 39.2%, 26.0%, 8.8%, 22.8%, and 19.8%, respectively. The concentrations of Thr, Met, Ile, Leu, Phe, Arg, and Tyr increased linearly

Table 3. Effect of yeast cell walls[†] on the growth performance and glutathione pathway of broilers

Items	Yeast cell walls, g/kg of diet				SEM	Contrasts (<i>P</i> value)	
	0	0.5	1.0	1.5		Linear	Quadratic
Growth performance at 1 to 21 d of age							
ADFI, g/bird	43.71 ^c	48.24 ^b	51.54 ^a	51.40 ^a	0.682	0.000	0.000
ADG, g/bird	31.67 ^c	35.00 ^b	37.67 ^a	37.50 ^a	0.525	0.000	0.000
G:F	0.725	0.726	0.731	0.730	0.005	0.618	0.780
Duodenal mucosal glutathione pathway at 21 d of age							
r-GSH, mg/g	33.14 ^b	37.72 ^a	38.62 ^a	38.63 ^a	0.647	0.001	0.025
GSTs, U/g	339.22	351.81	351.95	356.81	2.532	0.048	0.071
GR, U/g	33.79 ^d	37.07 ^c	39.87 ^b	42.11 ^a	0.695	0.000	0.341

^{a-d}Means within a row with no common superscripts differ significantly ($P < 0.05$).

[†]Containing D-glucose 46.2% and D-mannose 29.8%.

GR = glutathione reductase; GSTs = glutathione S-transferases; r-GSH = reduced glutathione.

Table 4. Effect of yeast cell walls[†] on proteolytic enzymes and nitrogenous nutrient transporters in broilers

Items	Yeast cell walls, g/kg of diet				SEM	Contrasts, <i>P</i> value	
	0	0.5	1.0	1.5		Linear	Quadratic
Mucosal enzymes, U/mg							
Pepsin	5.40	5.50	5.49	5.73	0.053	0.036	0.518
Trypsin	4.83 ^b	5.42 ^a	5.50 ^a	5.36 ^a	0.069	0.000	0.001
Chymotrypsin	0.66	0.68	0.66	0.69	0.006	0.135	0.655
Di-AP	248.13 ^b	376.90 ^a	391.55 ^a	382.67 ^a	13.465	0.006	0.048
Leu-AP	0.27 ^b	0.32 ^a	0.31 ^a	0.32 ^a	0.006	0.000	0.000
Mucosal transporter mRNA, 2 ^{−ΔΔCt}							
SLC6A19	5.12 ^c	7.44 ^b	7.97 ^b	9.55 ^a	0.345	0.000	0.106
SLC7A2	1.50 ^b	2.42 ^a	2.43 ^a	2.76 ^a	0.112	0.000	0.022
SLC15A1	0.49 ^b	0.55 ^a	0.54 ^{ab}	0.55 ^a	0.008	0.033	0.079

^{a-c} Means within a row with no common superscripts differ significantly ($P < 0.05$).

[†]Containing D-glucose 46.2% and D-mannose 29.8%.

Di-AP = dipeptidyl aminopeptidase; Leu-AP = leucine aminopeptidase; SLC6A19 = solute carrier family 6 member 19 (neutral amino acid transporter); SLC7A2 = solute carrier family 7 member 2 (cationic amino acid transporter); SLC15A1 = solute carrier family 15 member 1 (oligopeptide transporter).

($P < 0.05$), whereas the concentrations of Met, Ala, Ile, Leu, Lys, Arg, and Tyr increased with a quadratic trend ($P < 0.05$). The concentrations of Asp, Ser, Glu, Gly, Val, and His were not affected by YCW supplementation (data not shown) (Table 5).

DISCUSSION

In this study, the YCW supplementation at 0.5, 1.0, and 1.5 g/kg improved ADFI and ADG, whereas the duodenal mucosal levels of r-GSH and GR were also increased. There were no differences between treatments for GSTs, but a linear increasing trend was found. These findings indicate the growth-promoting and antioxidative effects of YCW. It has been well documented that YCW or related products increased growth performance and antioxidative functions in broiler chickens. Zhang et al. (2005) reported that YCW lowered G:F and breast meat 2-thiobarbituric acid-reactive substances, and increased ADG. Ghosh et al. (2012) demonstrated that YCW had effects identical to antibiotic growth promoter on performance of broiler chickens and decreased mucosal *Salmonella* and *Escherichia coli*. Also, dietary addition of YCW at the level of 2 g/kg showed a positive protective effect on γ -glutamyl transferase and total superoxide dismutase in the serum of broiler chickens (Jiang et al., 2014).

The growth-promoting effect of YCW can be attributed to the beneficial functions on antioxidation, gut normal bacterial equilibrium, mucosal morphology, and immunity (Huyghebaert et al., 2011; Ghosh et al., 2012; Li et al., 2016; Liu et al., 2017). Nevertheless, the growth of animals is finally

dependent on the digestion, absorption, and assimilation of nutrients, especially proteins (Gilbert et al., 2007). Therefore, it is worth studying whether the YCW further affects the digestion and transport of nutrients in the digestive tract of animals. However, literature about this is very limited. Only one study showed that YCW increased lipase activity of fish fed an aflatoxin-contaminated diet (Imani et al., 2017). In this study, the activities of proventricular pepsin, duodenal trypsin, Di-AP, and Leu-AP showed linearly and/or quadratic increasing trends with YCW supplementation, indicating that YCW can improve protein digestion in the digestive tract of farm animals.

Additionally, YCW components as prebiotics can contribute to a better gut microbiota structure, mucosal function, and finally, an integrative health of animals (Middelbos et al., 2007; Park et al., 2016). In that case, the increased activities of proteolytic enzymes may be from the integrative health of animals. Furthermore, the higher proteolytic enzyme activity can improve the digestion of dietary protein, small peptides, and amino acids, although their digestibilities were not detected in this study. Indeed, Yang et al. (2008a,b) reported that mannanoligosaccharide increased the ileal digestibility of starch and reduced the concentration of arabinose in the soluble nonstarch polysaccharides fraction in the excreta of broiler chickens. The effect of YCW on the digestive enzymes of lipids and carbohydrates in farm animals needs further study.

In this study, the YCW also enhanced transmembrane transport of amino acids and oligopeptides by increasing mRNA expression of transporters that busily shuttle intestinal villi.

Table 5. Effect of yeast cell walls[†] on the serum profiles of amino acids[‡]

Items	Yeast cell walls, g/kg of diet				SEM	Contrasts, <i>P</i> value	
	0	0.5	1.0	1.5		Linear	Quadratic
Thr, µg/mL	70.14 ^b	76.09 ^a	73.73 ^{ab}	76.75 ^a	0.850	0.012	0.310
Met, µg/mL	64.81 ^b	89.15 ^a	81.54 ^a	86.23 ^a	2.204	0.000	0.000
Ala, µg/mL	149.28	156.40	156.64	154.93	1.097	0.062	0.034
Ile, µg/mL	23.65 ^c	30.65 ^b	34.25 ^{ab}	35.20 ^a	1.042	0.000	0.004
Leu, µg/mL	44.87 ^b	53.78 ^a	56.31 ^a	59.25 ^a	1.301	0.000	0.048
Phe, µg/mL	27.97	28.36	30.27	30.21	0.439	0.029	0.787
Lys, µg/mL	46.37 ^b	49.53 ^{ab}	50.46 ^a	48.17 ^{ab}	0.565	0.173	0.013
Arg, µg/mL	31.16 ^b	37.41 ^a	37.91 ^a	39.09 ^a	0.786	0.000	0.017
Tyr, µg/mL	34.27 ^b	41.04 ^a	42.47 ^a	42.46 ^a	0.871	0.000	0.005

^{a-c}Means within a row with no common superscripts differ significantly ($P < 0.05$).

[†]Containing D-glucose 46.2% and D-mannose 29.8%.

[‡]The serum profiles of Asp, Ser, Glu, Gly, Val, and His are not affected ($P \geq 0.05$) by yeast cell walls supplementation (data not shown).

The higher transport activity is possibly from an improved villi and crypt morphology as well as the prebiotic effect on microbiota due to the nutraceutical function of glucan and mannan oligosaccharides in YCW (Moran et al., 2004; Cheled-Shoval et al., 2011; Ghosh et al., 2012). However, literature about this is unavailable in animals. Cheled-Shoval et al. (2011) observed that in ovo administration of mannan oligosaccharides resulted in a hatching chick with more mature enterocytes and enhanced epithelial barrier and digestive and absorptive capacity, which implies that the mechanism underlying the observed changes is not mediated through gut microflora but rather involves a direct effect of mannan oligosaccharides on intestinal cells.

It is also worth mentioning that, in line with the nutrients, the glucan and mannan oligosaccharides can be transported in the intestine because they are skeletal substances that define the stability, shape, and morphology of cells (Breves et al., 2007; Kogan and Kocher, 2007). Furthermore, the interaction of inulin and oligofructose with carbohydrate receptors on intestinal epithelial cells and immune cells, or possibly even partial absorption of the oligosaccharides, can result in local and systemic responses (Seifert and Watzl, 2007). These receptors are host transmembrane molecules, such as Toll-like receptors (Harris et al., 2006), mannose receptors (Netea et al., 2006), galectin family receptors (Almkvist and Karlsson, 2004), and transmembrane mucins (Carraway et al., 2003). Additionally, mannan oligosaccharides may directly attach cells through carbohydrate receptors located on cells (Brown, 2006). The circular or attached oligosaccharides to cells also needs further study.

In this study, the supplementation of YCW also increased some amino acid levels in the blood of broiler chickens. This finding cannot be simply a consequence of increased ADFI, proteolytic

enzymes, and nutrient transport activity because of the complexity of amino acids metabolism, but it was consistent with the study that yeast extract increased serum Ile, Leu, Phe, and Arg in pigs (Liu et al., 2017). Additionally, YCW may modulate serum metabolites. Li et al. (2012) observed that YCW at 2 g/kg increased antibody titers of Newcastle disease in broiler chickens, but Sauerwein et al. (2007) argued that YCW extract added at 0.3 g/kg did not affect blood concentrations of haptoglobin and immunoglobulin G and A in weaning pigs. In this study, the YCW added at 0.5, 1.0, and 1.5 g/kg showed linear and/or quadratic beneficial effects on most parameters. The different YCW effects may be resulted from the contents of functional components, glucans and mannans, so once YCW or related products are commercialized, the accurate contents of functional components should keep users informed.

CONCLUSIONS

The YCW supplementation increased ADFI, ADG, the mucosal levels of r-GSH, GR, trypsin, Di-AP and Leu-AP, mRNA expressions of neutral, cationic, and oligopeptide transporters, and concentrations of Thr, Met, Ile, Leu, Lys, Arg, and Tyr in the blood of broiler chickens. These parameters showed linear and/or quadratic increasing trends with YCW doses at 0.5, 1.0, and 1.5 g/kg. The results indicate that YCW can promote animal growth by beneficially modulating intestinal anti-oxidation, nutrient digestion, and transport.

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