Effects of Selenium Yeast, Astragalus Polysaccharide and Their Combination on Growth Performance, Meat Quality and Antioxidant Capacity of Mule Ducks (Postprint)

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Abstract

This study aims to investigate the effects of selenium yeast, astragalus polysaccharides, and their combination on growth performance, meat quality, and antioxidant capacity of mule ducks. A total of 144 22-day-old mule ducks with similar body weight were selected from the same batch and randomly divided into 4 groups, with 3 replicates per group and 12 ducks per replicate, and the experimental period was 49 days. A 2$×$2 factorial design was adopted: the control group was fed a basal diet, experimental group I was fed the basal diet + 0.3% selenium yeast, experimental group II was fed the basal diet + 30 mg/kg astragalus polysaccharides, and experimental group III was fed the basal diet + a combination (30 mg/kg astragalus polysaccharides + 0.3% selenium yeast). Growth performance indices were measured during the experimental period, and at 70 days of age, 12 ducks per group (4 per replicate) were randomly selected for slaughter to determine breast muscle quality and antioxidant indices. The results showed: 1) The average daily gain, average daily feed intake, and feed-to-gain ratio of experimental groups I and II were not significantly different from those of the control group (P>0.05); the average daily gain of experimental group III was significantly higher than that of the control group (P<0.05), while the average daily feed intake and feed-to-gain ratio were not significantly different from the control group (P>0.05). 2) Compared with the control group, the 24 h pH of experimental groups I, II, and III was significantly or extremely significantly increased (P<0.05 or P<0.01), while the 48 h drip loss rate, cooking loss rate, and shear force were significantly or extremely significantly decreased (P<0.05 or P<0.01); the meat color redness (a*) value of experimental group III was significantly increased (P<0.05); the meat color yellowness (b*) values of experimental groups II and III were significantly decreased (P<0.05). 3) The

superoxide dismutase (SOD) activity, glutathione peroxidase (GSH-Px) activity, and total antioxidant capacity (T-AOC) of experimental groups I, II, and III at 24~120 h were significantly or extremely significantly higher than those of the control group (P<0.05 or P<0.01); the malondialdehyde (MDA) content of experimental groups I and II at 48~120 h and 72~120 h was significantly or extremely significantly lower than that of the control group (P<0.05 or P<0.01), and the MDA content of experimental group III at 24~120 h was extremely significantly lower than that of the control group (P<0.01). With the extension of storage time, SOD and GSH-Px activities and T-AOC in all groups showed a decreasing trend, while MDA content showed an increasing trend, but the rate of change of each antioxidant index in the three experimental groups was slower than that in the control group. 4) Selenium yeast and astragalus polysaccharides had significant or extremely significant interactive effects on muscle 24 h pH, shear force, SOD activity at 24~120 h, GSH-Px activity at 48~120 h, and MDA content at 120 h (P<0.05 or P<0.01). It can be concluded that both selenium yeast and astragalus polysaccharides can improve meat quality and enhance antioxidant capacity, reduce the degree of lipid peroxidation, and effectively extend shelf life in mule ducks, and the two have obvious synergistic effects on muscle antioxidant capacity, pH, and tenderness improvement.

Full Text

Effects of Selenium Yeast, Astragalus Polysaccharide and Their Compound on Growth Performance, Meat Quality and Antioxidant Capacity of Mule Ducks

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Abstract

This study investigated the effects of selenium yeast, Astragalus polysaccharide and their compound on growth performance, meat quality and antioxidant capacity in mule ducks. One hundred forty-four 22-day-old mule ducks with similar body weight were selected from the same batch and randomly allocated into four groups, with three replicates per group and twelve ducks per replicate. The experimental period lasted 49 days. A 2$×$2 factorial design was employed: the control group received a basal diet, treatment group I received the basal diet supplemented with 0.3% selenium yeast, treatment group II received the basal diet supplemented with 30 mg/kg Astragalus polysaccharide, and treatment

group III received the basal diet supplemented with the compound (30 mg/kg Astragalus polysaccharide + 0.3% selenium yeast). Growth performance indices were measured during the trial, and at 70 days of age, twelve ducks per group (four per replicate) were randomly selected for slaughter to determine breast muscle quality and antioxidant parameters.

The results showed: (1) Average daily gain, average daily feed intake and feed-to-gain ratio in groups I and II did not differ significantly from the control group ($P>0.05$). Group III exhibited significantly higher average daily gain than the control ($P<0.05$), while average daily feed intake and feed-to-gain ratio remained comparable ($P>0.05$). (2) Compared with the control, groups I, II and III showed significant or highly significant increases in 24-hour pH ($P<0.05$ or $P<0.01$), along with significant or highly significant reductions in 48-hour drip loss rate, cooking loss rate and shear force ($P<0.05$ or $P<0.01$). Group III demonstrated significantly increased redness (a*) values ($P<0.05$), while groups II and III showed significantly decreased yellowness (b*) values ($P<0.05$). (3) Superoxide dismutase (SOD) activity, glutathione peroxidase (GSH-Px) activity and total antioxidant capacity (T-AOC) at 24–120 h were significantly or highly significantly elevated in all treatment groups compared with the control ($P<0.05$ or $P<0.01$). Malondialdehyde (MDA) content in groups I and II was significantly or highly significantly lower than the control at 48–120 h and 72–120 h, respectively ($P<0.05$ or $P<0.01$), while group III showed highly significant reductions at 24–120 h ($P<0.01$). As storage time progressed, SOD activity, GSH-Px activity and T-AOC declined while MDA content increased across all groups, but the rate of change was slower in the three treatment groups. (4) Significant or highly significant interactions between selenium yeast and Astragalus polysaccharide were observed for muscle pH at 24 h, shear force, SOD activity at 24–120 h, GSH-Px activity at 48–120 h, and MDA content at 120 h ($P<0.05$ or $P<0.01$).

These findings indicate that both selenium yeast and Astragalus polysaccharide can improve meat quality and antioxidant capacity, reduce lipid peroxidation, and effectively extend shelf life in mule ducks, with clear synergistic effects on muscle antioxidant status, pH and tenderness improvement.

Keywords: selenium yeast; Astragalus polysaccharide; mule ducks; growth performance; meat quality; antioxidant

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Introduction

With rising living standards, consumers increasingly prioritize fresh meat quality, which is evaluated based on color, pH, tenderness, intramuscular fat content, flavor and water loss rate. Lipid oxidation in muscle generates peroxides and free radicals that damage cell membranes, causing sarcoplasmic fluid loss, increased drip loss, darkened color, deteriorated texture and reduced nutritional value. These changes compromise food safety and cause economic losses. Antioxidants

convert free radicals into non-toxic products, clear or repair damaged cells, and effectively delay or prevent lipid peroxidation, thereby improving meat quality and extending shelf life. Supplementing animal feed with antioxidants has become an economical and effective nutritional strategy to enhance antioxidant capacity and meat quality in livestock and poultry.

Selenium, an essential trace element, regulates most antioxidant defense mechanisms in living organisms. As an important organic selenium source, selenium yeast offers advantages of safety and high bioactivity compared with inorganic selenium. Studies have shown that selenium yeast can improve production performance, increase activities of various antioxidant enzymes in muscle and serum, reduce malondialdehyde (MDA) content in tissues, delay oxidation and enhance antioxidant capacity. Astragalus polysaccharide (APS), the primary immunologically active component of Astragalus membranaceus, constitutes the main ingredient responsible for its immune-enhancing effects. In livestock and poultry production, APS can improve growth performance and antioxidant capacity while strengthening immunity and disease resistance.

Current research on selenium yeast and Astragalus polysaccharide as feed additives for enhancing antioxidant capacity and improving meat quality has primarily focused on pigs, chickens and geese, with few reports on their application in mule ducks, either individually or in combination. Therefore, this study examined the effects of selenium yeast, Astragalus polysaccharide and their compound on growth performance, meat quality and antioxidant capacity in mule ducks, aiming to provide theoretical support and nutritional strategies for the rational development of green feed additives and improvement of meat quality and shelf life in mule duck production.

Materials and Methods

1.1 Experimental Materials The selenium yeast added to the diets was provided by Angel Yeast Co., Ltd., with a total selenium content of 3,000 mg/kg. Astragalus polysaccharide was supplied by North China Pharmaceutical Group Xiantai Pharmaceutical Co., Ltd., with a polysaccharide content $ $98%.

1.2 Basal Diet The basal diet was formulated and provided by Fujian Southeast Feed Co., Ltd., with composition and nutrient levels shown in Table 1 .

Table 1 Composition and nutrient levels of basal diets (air-dry basis) %

Content	1–21 days	22–70 days
Corn		
Middling		
Soybean meal		
Rapeseed meal		

Content	1–21 days	22–70 days
Rice bran meal		
Dry distiller' s grains with solubles		
Soybean oil		
Premix[1]		
Total		

[1]The premix provided the following per kg of diet: For 1–21 days: VA 7,000 IU, VD_3 2,000 IU, VE 30 mg, VK_3 4.0 mg, VB_1 3.0 mg, VB_2 7.0 mg, VB_6 9.0 mg, VB_{12} 0.03 mg, choline 450 mg, nicotinic acid 35 mg, pantothenic acid 20 mg, folic acid 1.0 mg, biotin 0.2 mg, Fe 60 mg, Cu 8 mg, Mn 85 mg, Zn 80 mg, I 0.35 mg, Se 0.3 mg. For 22–70 days: VA 6,000 IU, VD 2,000 IU, VE 10 mg, VK_3 1.0 mg, VB_1 2.0 mg, VB_2 4.0 mg, VB_6 3.0 mg, VB_{12} 0.02 mg, choline 400 mg, nicotinic acid 20 mg, pantothenic acid 10 mg, folic acid 0.6 mg, biotin 0.1 mg, Fe 55 mg, Cu 5 mg, Mn 80 mg, Zn 75 mg, I 0.3 mg, Se 0.2 mg.

[2]Nutrient levels were calculated values.

1.3 Experimental Design and Sample Collection This experiment was conducted at the Animal Testing Base of the Institute of Animal Husbandry and Veterinary Medicine, Fujian Academy of Agricultural Sciences. Two hundred eighty healthy 1-day-old mule ducklings from the same batch were raised during a 1–21 day pre-trial period under uniform management conditions: room temperature above 30°C, relative humidity around 65%, nipple drinkers with ad libitum water, 16 h/d lighting with supplementary light morning and evening, and routine vaccination. The experimental period comprised 22–70 days of age. At 22 days, 144 mule ducks with similar body weight were selected and randomly divided into four groups with three replicates each containing twelve ducks. A 2$×$2 factorial design was employed: control group received basal diet, treatment group I received basal diet + 0.3% selenium yeast, treatment group II received basal diet + 30 mg/kg Astragalus polysaccharide, and treatment group III received basal diet + compound (30 mg/kg Astragalus polysaccharide + 0.3% selenium yeast). Growth performance was recorded throughout the trial. At 70 days of age after 12-hour feed withdrawal, four ducks per replicate (twelve per group) were randomly selected for slaughter, and breast muscle tissue was collected for meat quality and antioxidant index determination.

1.4 Measurement Methods 1.4.1 Growth Performance

Body weight was measured at 22 days of age after fasting (initial body weight, IBW), then weekly by replicate, with final body weight (FBW) recorded at 70 days to calculate average daily gain (ADG). Daily feed allowance and residual feed were recorded for each group to calculate average daily feed intake (ADFI) and feed-to-gain ratio (F/G).

1.4.2 pH Measurement

Breast muscle was collected and initial pH (0 h pH) was measured 45 minutes post-slaughter using a Testo2052 portable pH meter (Germany) with the electrode completely embedded in the meat sample. Three parallel measurements were taken and averaged. Samples were then refrigerated at 4°C, and final pH (24 h pH) was measured after 24 hours using the same method. The pH meter was calibrated in phosphate buffer solution (pH 6.8) after each measurement.

1.4.3 Drip Loss

Fresh meat samples were weighed and placed in sealed bags inflated with air to prevent contact between meat and bag surface, then suspended with thread in a 4°C refrigerator. At 24 and 48 hours, bags and thread were removed, and surface moisture was gently blotted with filter paper before reweighing.

1.4.4 Shear Force

Meat samples were sealed in plastic bags and heated in an 80°C water bath until the core temperature reached 70°C. After cooling to room temperature, samples were cored perpendicular to muscle fiber orientation and shear force was measured using a C-LM3B muscle tenderness meter (Northeast Agricultural University Engineering College). Each sample was measured three times and averaged.

1.4.5 Meat Color

Under constant room temperature and lighting conditions, meat color was measured using a portable NR10QC-3nh colorimeter (Shenzhen Sanli Instrument Co., Ltd.) with three parallel measurements recorded for lightness (L*), redness (a*)* and yellowness (b*) values.

1.4.6 Cooking Loss Rate

Approximately 2 g of breast muscle was weighed and sealed in a plastic bag, heated in an 80°C water bath until the core temperature reached approximately 70°C. After cooling to room temperature, surface moisture was gently blotted with filter paper before final weighing.

1.4.7 Muscle Antioxidant Capacity

Breast muscle collected at slaughter was stored at 4°C. Samples of 3–5 g were taken every 24 h and stored at -80°C for six consecutive days (0, 24, 48, 72, 96 and 120 h). Samples were homogenized to 10% tissue homogenate with 0.86% saline using an HN-13K handheld homogenizer (Shanghai Hanuo Instrument Co., Ltd.), centrifuged at 2,000 r/min for 10 minutes. The supernatant was used to determine SOD activity, GSH-Px activity, T-AOC and MDA content using assay kits from Nanjing Jiancheng Bioengineering Institute. Absorbance was measured using an ELX800 microplate system (Gene Company Limited) following kit instructions.

1.5 Statistical Analysis Experimental data were analyzed using SPSS 17.0 for descriptive statistics, two-way ANOVA, multiple comparisons and significance testing.

Results

2.1 Effects on Growth Performance As shown in Table 2 , group III significantly increased average daily gain compared with the control (P<0.05). Groups I and II showed 5.36% and 1.27% improvements in average daily gain, respectively, though not statistically significant (P>0.05). No significant differences in average daily feed intake were observed among groups (P>0.05), though all treatment groups showed higher intake than the control, with group III showing the highest increase (5.69%). Feed-to-gain ratio did not differ significantly among groups (P>0.05), but all treatment groups had lower ratios than the control. Main effect analysis indicated that neither selenium yeast nor Astragalus polysaccharide significantly affected growth performance parameters (P>0.05), and no significant interactions were detected (P>0.05).

Table 2 Effects of selenium yeast, Astragalus polysaccharide and their compound on growth performance of mule ducks

Items	Control	Group I	Group II	Group III	Main Effect	P-value
IBW (kg)	1.22$±0.16\|1.30±0.29\|1.27±0.13\|1.32±0.14\|SY\|\|\|FBW(kg)$|3.09±0.16|3.19±0.29|3.17±0.27|3.23±0.28					

In the same column, values with different small letter superscripts differ significantly (P<0.05), different capital letter superscripts differ highly significantly (P<0.01), while same or no superscripts indicate no significant difference (P>0.05). The same applies below.

2.2 Effects on Muscle pH and Meat Color Table 3 shows that groups I, II and III significantly or highly significantly increased 24-hour pH compared with the control (P<0.05 or P<0.01). Group I increased redness (a*) and lightness (L*)* values by 4.13% and 1.59%, respectively (P>0.05), while decreasing yellowness (b*) by 4.93% (P>0.05). Group II significantly increased 24-hour pH and decreased b* value (P<0.05), increased a* value by 6.59% (P>0.05), and decreased L* value by 0.73% (P>0.05). Group III highly significantly increased 24-hour pH (P<0.01), significantly elevated a* value (P<0.05), significantly reduced b* value (P<0.05), and increased L* value by 2.32% (P>0.05). Among treatment groups, 24-hour pH and meat color parameters followed the pattern: group III > group I > group II, though differences were not significant (P>0.05). Main effect analysis revealed that selenium yeast significantly affected 24-hour pH (P<0.05), while Astragalus polysaccharide significantly or highly significantly

influenced 0 and 24-hour pH and a* and b* values (P<0.05 or P<0.01). A significant interaction between the two additives was observed for 24-hour pH (P<0.05).

Table 3 Effects of selenium yeast, Astragalus polysaccharide and their compound on muscle pH and meat color of mule ducks

Items	pH		Meat Color		
	0 h	24 h	L*	a*	b*
Control	5.94$\pm$0.08^{Bb}	5.37$\pm$0.03^{Bb}	36.99$\pm$2.21	18.36$\pm$0.69^{b}	7.91$\pm$0.62^{a}
$GroupI$	6.03$\pm$0.05^{ABa}	5.65			

2.3 Effects on Water Holding Capacity and Shear Force Table 4 demonstrates that groups I and II significantly reduced 48-hour drip loss rate, cooking loss rate and shear force compared with the control (P<0.05), while 24-hour drip loss decreased by 16.3% and 17.6%, respectively (P>0.05). Group III highly significantly reduced 48-hour drip loss rate and cooking loss rate (P<0.01), and significantly decreased shear force and 24-hour drip loss rate (P<0.05). Among treatment groups, 48-hour drip loss followed the pattern: group III < group I < group II, while 24-hour drip loss, cooking loss and shear force showed: group III < group II < group I, though no significant differences existed among treatment groups (P>0.05). Main effect analysis indicated that selenium yeast significantly or highly significantly reduced 48-hour drip loss rate and shear force (P<0.05 or P<0.01), while Astragalus polysaccharide significantly or highly significantly reduced cooking loss rate and shear force (P<0.05 or P<0.01). A highly significant interaction between the two additives was observed for shear force (P<0.01).

Table 4 Effects of selenium yeast, Astragalus polysaccharide and their compound on water holding capacity and shear force of mule duck muscle

Items	Drip Loss Rate (%)		Cooking Loss Rate (%)	Shear Force (kgf)
	24 h	48 h		
Control	4.82$\pm$0.01^{a}	8.91$\pm$0.01^{Aa}	36.86$\pm$0.01^{Aa}	4.01$\pm$0.06^{a}
$GroupI$	4.03$\pm$0.01^{ab}	6.49$\pm$0.02^{ABb}	33.42$\pm$0.04^{A}	

2.4 Effects on Muscle T-AOC Table 5 shows that during 4°C storage, muscle T-AOC decreased over time in all groups, with the control group showing the greatest decline—approximately 40% reduction within 0–24 h. All treatment groups exhibited slower decreases, with group III showing the slowest rate. At each time point, groups I and II had significantly or highly significantly higher T-AOC than the control (P<0.05 or P<0.01) except at 0 h (P>0.05). Group III maintained significantly or highly significantly higher T-AOC than the control

throughout 0–120 h (P<0.05 or P<0.01). Among treatment groups, groups I and II did not differ significantly at any time point (P>0.05). Group III showed significantly higher T-AOC than group I at 24, 72 and 120 h (P<0.05), and significantly or highly significantly higher values than group II at all time points except 0 h (P<0.05 or P<0.01). Main effect analysis revealed that both selenium yeast and Astragalus polysaccharide significantly or highly significantly increased muscle T-AOC at 24–120 h (P<0.05 or P<0.01), though their interaction was not significant (P>0.05).

Table 5 Effects of selenium yeast, Astragalus polysaccharide and their compound on muscle T-AOC of mule ducks

Storage Time (h)	Control	Group I	Group II	Group III	Main Effect	P-value
0	0.81$±0.09^{b}|0.89±0.08^{ab}|0.85±0.10^{ab}|0.91±0.09^{a}|SY|||24|0.52±0.05^{c}|0.72±0.10^{Ab}|0.69±0.11^{A}					

2.5 Effects on Muscle SOD Activity Table 6 indicates that muscle SOD activity declined with storage time in all groups. The decrease was smaller in treatment groups, while the control group showed a substantial 53% reduction at 120 h compared with 0 h. All three treatment groups exhibited highly significantly higher SOD activity than the control at all time points (P<0.01). Among treatment groups, group I showed significantly or highly significantly higher SOD activity than group II at all time points except 48 h (P<0.05 or P<0.01). Group III demonstrated highly significantly higher activity than group I at 96 h (P<0.01) and significantly higher values at 0 and 120 h (P<0.05). Group III was highly significantly superior to group II at all time points (P<0.01). Main effect analysis showed that both selenium yeast and Astragalus polysaccharide highly significantly increased muscle SOD activity (P<0.01), with significant or highly significant interactions observed at 24–120 h (P<0.05 or P<0.01).

Table 6 Effects of selenium yeast, Astragalus polysaccharide and their compound on muscle SOD activity of mule ducks

Storage Time (h)	Control	Group I	Group II	Group III	Main Effect	P-value
0	150.35$±13.03^{cd}|197.76±5.86^{Ab}|181.74±16.28^{Bc}|213.63±18.66^{Aa}|SY|||24|117.10±9.53^{cc}|187.5					

2.6 Effects on Muscle GSH-Px Activity Table 7 reveals that muscle GSH-Px activity decreased with storage time in all groups, with the control showing the most pronounced reduction—reaching a minimum of 14.08 U/mg prot at 120 h (60.80% decrease). Group III showed the slowest decline (45.37% reduction). All treatment groups exhibited highly significantly higher GSH-Px activity than the control at each time point (P<0.01). Group I was significantly or highly significantly higher than group II at 48–120 h (P<0.05 or P<0.01) but not at

0–24 h (P>0.05). Group III was highly significantly superior to both groups I and II at all time points (P<0.01). Main effect analysis demonstrated that both selenium yeast and Astragalus polysaccharide highly significantly increased muscle GSH-Px activity (P<0.01), with a highly significant interaction observed at 48–120 h (P<0.01).

Table 7 Effects of selenium yeast, Astragalus polysaccharide and their compound on muscle GSH-Px activity of mule ducks

Storage Time (h)	Control	Group I	Group II	Group III	Main Effect	P-value
0	35.92$\pm$2.29^{cc}	42.95$\pm$1.01^{Bb}	42.11$\pm$1.93^{Bb}	45.86$\pm$0.76^{Aa}	SY		
24	27.44$\pm$2.29^{cc}	34.94$\pm$1.88^{Bb}					

2.7 Effects on Muscle MDA Content Table 8 shows that muscle MDA content increased with storage time in all groups. The increase was gradual in treatment groups, with group II showing only 1.15 nmol/mg prot increase at 120 h compared with 0 h. The control group increased more rapidly, with a 3.32 nmol/mg prot rise at 120 h. Groups I and II showed significant or highly significantly lower MDA content than the control at 48–120 h and 72–120 h, respectively (P<0.05 or P<0.01), with no significant differences at other time points (P>0.05). Group III was highly significantly lower than the control at all time points except 0 h (P<0.01). Main effect analysis indicated that selenium yeast significantly or highly significantly reduced MDA content at 24–120 h (P<0.05 or P<0.01), while Astragalus polysaccharide significantly or highly significantly decreased MDA at 96–120 h (P<0.05 or P<0.01). A significant interaction was observed at 120 h (P<0.05).

Table 8 Effects of selenium yeast, Astragalus polysaccharide and their compound on muscle MDA content of mule ducks

Storage Time (h)	Control	Group I	Group II	Group III	Main Effect	P-value
0	15.09$\pm$0.82^{a}	14.76$\pm$1.20^{a}	14.77$\pm$1.38^{a}	14.25$\pm$1.08^{a}	SY		
24	15.63$\pm$0.78^{Aa}	14.56$\pm$0.72^{ABab}					

Discussion

3.1 Effects on Growth Performance Average daily gain, average daily feed intake and feed-to-gain ratio are important indicators for evaluating livestock growth performance. Sun et al. found that a compound additive of glucose oxidase and selenium yeast significantly improved average daily feed intake, average daily gain and survival rate while reducing feed-to-gain ratio in broilers at different ages. Jin et al. reported that Astragalus polysaccharide increased average daily gain and reduced feed intake and feed-to-gain ratio in chicks. In

contrast, our study found that selenium yeast or Astragalus polysaccharide alone did not significantly affect growth performance in mule ducks, possibly due to differences in breed, rearing environment, duration or supplementation level. However, the compound significantly improved average daily gain, suggesting a synergistic effect, although the interaction was not statistically significant.

3.2 Effects on Meat Quality pH, meat color and water holding capacity are crucial indicators for evaluating fresh meat quality. pH reflects muscle acidity and correlates closely with color and tenderness. Meat color is the primary sensory characteristic influencing consumer purchase decisions. Water holding capacity affects juiciness, tenderness and nutrient content, typically measured by cooking loss and drip loss.

Our analysis demonstrated that dietary supplementation with selenium yeast, Astragalus polysaccharide and their compound significantly increased breast muscle pH in 70-day-old mule ducks. Muscle pH is primarily influenced by lactic acid content, which depends on post-slaughter glycogenolysis. Faster glycogen breakdown leads to greater lactic acid accumulation. Antioxidants like Astragalus polysaccharide or selenium yeast may reduce glycogenolysis, decreasing lactic acid production and slowing pH decline. Studies by Sun et al. and Sun et al. in broilers confirmed that dietary selenium yeast or Astragalus polysaccharide significantly increased breast muscle pH and prevented pale, soft, exudative (PSE) meat formation.

Regarding meat color, our findings indicated that supplementation with selenium yeast, Astragalus polysaccharide and their compound increased a* values and decreased b* values, stabilizing meat color, with the compound showing the most pronounced effect. These results align with Zou et al. and Tapiero et al., who reported that selenium yeast delays oxidation of muscle fat, myoglobin and oxymyoglobin, enhances meat color stability and improves color scores, with a* values showing a positive correlation with selenium supplementation level. Sun et al. also found that Astragalus polysaccharide increased a* values and decreased b* values in broiler breast muscle, improving color.

For water holding capacity and tenderness, our results demonstrated that dietary Astragalus polysaccharide, selenium yeast and their compound significantly reduced drip loss rate, cooking loss rate and shear force, thereby improving water holding capacity and tenderness, with the compound showing superior effects. Juniper et al. reported that dietary selenium improved pork quality by significantly reducing drip loss and enhancing water holding capacity. Su found that compound Astragalus significantly reduced drip loss in broiler breast muscle and improved meat quality. These improvements may occur because Astragalus polysaccharide enhances nutrient and energy utilization, thereby increasing muscle water holding capacity, while selenium yeast reduces drip loss by improving tissue antioxidant capacity and maintaining cell membrane integrity. Overall, dietary supplementation with appropriate levels of selenium yeast, Astragalus polysaccharide and their compound can improve muscle pH, color, ten-

derness and water holding capacity in mule ducks, with clear synergistic effects on pH and tenderness.

3.3 Effects on Antioxidant Capacity Lipid oxidation in fresh meat reduces eating quality and represents the primary cause of meat deterioration aside from microbial spoilage. Superoxide dismutase (SOD) is a key antioxidant enzyme whose activity indirectly reflects the ability to scavenge oxygen free radicals and endogenous antioxidant capacity. Glutathione peroxidase (GSH-Px) is an important peroxide-decomposing enzyme that scavenges hydrogen peroxide and lipid peroxides, blocking further damage from reactive oxygen species. Total antioxidant capacity (T-AOC) is a comprehensive indicator of antioxidant system function, reflecting the compensatory capacity of enzymatic and non-enzymatic systems and the status of free radical metabolism. Malondialdehyde (MDA), as the end product of lipid peroxidation, indirectly reflects free radical production and the degree of lipid peroxidation in tissues. Therefore, enhancing antioxidant capacity, particularly SOD and GSH-Px activities, is crucial for preventing lipid oxidation and extending fresh meat shelf life.

Our study examined SOD activity, GSH-Px activity, T-AOC and MDA content in 70-day-old mule ducks. Compared with the control, dietary supplementation with Astragalus polysaccharide, selenium yeast and their compound significantly increased muscle SOD and GSH-Px activities and T-AOC, while significantly reducing MDA content and slowing the rate of antioxidant index changes. The compound showed the strongest antioxidant effect, followed by selenium yeast, with Astragalus polysaccharide showing the weakest effect. These findings demonstrate that selenium yeast, Astragalus polysaccharide and their compound can enhance muscle antioxidant enzyme activity and capacity, reduce free radical attack on biomembranes, decrease lipid peroxidation and reduce MDA production, thereby extending meat shelf life.

Previous studies have reported effects of selenium yeast on growth, development and antioxidant function in chickens, geese and pigs. Wang et al. and Tian et al. found that selenium yeast significantly increased GSH-Px activity and reduced MDA content in broiler plasma and liver. Wang et al. reported that dietary selenium yeast significantly increased GSH-Px, SOD activity and T-AOC in goose serum and liver at 4 and 9 weeks, while reducing MDA and hydrogen peroxide content. Hu et al. demonstrated that selenium supplementation in finishing pigs significantly increased muscle GSH-Px activity and antioxidant capacity while reducing MDA content and extending shelf life. Astragalus polysaccharide has also been shown to enhance antioxidant and immune functions. Sun et al. found that dietary Astragalus polysaccharide significantly improved muscle antioxidant capacity, intestinal microflora, immunity and disease resistance in broilers. Li et al. reported that Astragalus polysaccharide significantly increased serum GSH-Px and SOD activity while reducing MDA content, enhancing immune function. These results align with our findings, confirming that selenium yeast or Astragalus polysaccharide can enhance animal

antioxidant capacity.

Research has reported that selenized Astragalus polysaccharide exhibits stronger hydroxyl radical and superoxide anion scavenging activity than Astragalus polysaccharide alone, with antioxidant capacity positively correlated with polysaccharide concentration and selenium content. This supports our finding of synergistic antioxidant effects between Astragalus polysaccharide and selenium. Clinically, polysaccharides are often combined with selenium to form selenium polysaccharides, possibly because selenium can form stable five-membered ring selenite esters with two cis-connected hydroxyl groups on monosaccharides, fully exerting the physiological activities of both components and producing coordinated enhancement.

Conclusions

1. Dietary supplementation with selenium yeast, Astragalus polysaccharide and their compound significantly increased breast muscle pH, water holding capacity and tenderness, improved meat color a* values and reduced b* values, enhanced endogenous antioxidant enzyme activities (SOD, GSH-Px) and T-AOC, effectively suppressed MDA formation, slowed storage deterioration and protected meat quality, thereby extending fresh meat shelf life.
2. Combined use of selenium yeast and Astragalus polysaccharide was superior to individual supplementation for antioxidant effects, preservation and meat quality improvement, showing clear synergistic interactions particularly for pH, tenderness and antioxidant capacity enhancement.

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