Effects of Different Nutritional Intervention Strategies on Growth and Development, Hematological Parameters, Plasma Antioxidant Capacity, and Immunological Indices in Stunted Yaks (Postprint)

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Abstract

This experiment aimed to identify methods for alleviating oxidative and immune stress while promoting growth in stunted yaks through nutritional regulation. Based on the criterion of being less than 1.5 standard deviations below the mean body weight of the same-age and same-breed yak population, 40 one-year-old stunted Qinghai plateau-type yaks and 10 normal yaks were selected. The 40 stunted yaks were randomly allocated into 4 groups according to body weight: stunted grazing group, concentrate supplementation group, cysteamine group (concentrate supplementation with 80 mg/kg BW cysteamine), and yeast group (concentrate supplementation with 0.3% active dry yeast). Normal yaks served as the normal grazing group, with 5 replicates per group and 2 yaks per replicate. The preliminary period lasted 15 days, and the formal experimental period lasted 60 days. The results showed: 1) Compared with the stunted grazing group, the concentrate supplementation, cysteamine, and yeast groups significantly improved the body measurement indices of stunted yaks ($P<0.05$). 2) The concentrate supplementation group exhibited significantly higher blood red blood cell count and hemoglobin content than the stunted grazing group ($P<0.05$), and significantly lower blood white blood cell count than the stunted grazing group ($P<0.05$). 3) On day 1, the normal grazing group displayed significantly lower plasma malondialdehyde (MDA) content, and significantly higher total superoxide dismutase (T-SOD) activity, glutathione peroxidase (GSH-Px) activity, and total antioxidant capacity (T-AOC) than the other 4 groups ($P<0.05$). On day 60, the cysteamine and yeast groups of stunted yaks showed significantly lower plasma MDA content than day 1 ($P<0.05$), and significantly lower than the stunted grazing group ($P<0.05$); plasma T-SOD activity and T-AOC were significantly higher than day 1 ($P<0.05$), and significantly higher than the stunted grazing group ($P<0.05$); the yeast group exhibited plasma GSH-Px activity significantly higher than day 1 ($P<0.05$), and significantly higher than the stunted grazing group ($P<0.05$). 4) On day 1, the normal grazing group demonstrated plasma immunoglobulin A (IgA) and immunoglobulin G (IgG) contents significantly higher than the other 4 groups ($P<0.05$). On day 60, the concentrate supplementation group showed plasma IgG content significantly higher than day 1 ($P<0.05$), and significantly higher than the stunted grazing group ($P<0.05$); the cysteamine group exhibited plasma IgA content significantly higher than day 1 ($P<0.05$), and significantly higher than the stunted grazing group ($P<0.05$); the yeast group displayed plasma IgA and IgG contents significantly higher than day 1 ($P<0.05$), and significantly higher than the stunted grazing group ($P<0.05$). These results suggest that concentrate supplementation and the addition of 80 mg/kg BW cysteamine or 0.3% active dry yeast to concentrate can enhance the antioxidant and immune capacity of stunted yaks, promote compensatory growth in stunted yaks, with concentrate supplementation combined with 0.3% active dry yeast demonstrating the optimal effect.

Full Text

Effects of Different Nutritional Regulation Methods on Growth and Development, Blood Routine, and Plasma Antioxidant and Immune Indexes of Yaks with Growth Retardation

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Abstract

This study aimed to identify nutritional regulation strategies to alleviate oxidative and immune stress while promoting growth in yaks with growth retardation. Forty one-year-old Qinghai high-plateau yaks with growth retardation (selected as being 1.5 standard deviations below the average weight of same-age, same-breed yaks) were randomly assigned to four groups: a grazing retardation group, a concentrate supplementation group, a cysteamine group (concentrate + 80 mg/kg BW cysteamine), and a yeast group (concentrate + 0.3% active dry yeast). Ten normal one-year-old yaks served as a healthy grazing control group.

Each group comprised five replicates with two yaks per replicate. The pre-trial period lasted 15 days, followed by a 60-day formal trial. The results showed: (1) Compared with the grazing retardation group, the concentrate, cysteamine, and yeast groups exhibited significantly improved body measurements ($P < 0.05$). (2) The concentrate group showed significantly higher red blood cell count and hemoglobin content, but significantly lower white blood cell count compared to the grazing retardation group ($P < 0.05$). (3) On day 1, the healthy grazing group had significantly lower plasma malondialdehyde (MDA) content and significantly higher total superoxide dismutase (T-SOD) activity, glutathione peroxidase (GSH-Px) activity, and total antioxidant capacity (T-AOC) than the other four groups ($P < 0.05$). On day 60, the cysteamine and yeast groups showed significantly reduced plasma MDA content compared to day 1 ($P < 0.05$), which was also significantly lower than the grazing retardation group ($P < 0.05$). Their plasma T-SOD activity and T-AOC were significantly higher than both day 1 values ($P < 0.05$) and the grazing retardation group ($P < 0.05$). The yeast group also showed significantly higher plasma GSH-Px activity than day 1 ($P < 0.05$) and the grazing retardation group ($P < 0.05$). (4) On day 1, the healthy grazing group had significantly higher plasma immunoglobulin A (IgA) and immunoglobulin G (IgG) contents than the other four groups ($P < 0.05$). On day 60, the concentrate group showed significantly higher plasma IgG content compared to day 1 ($P < 0.05$) and the grazing retardation group ($P < 0.05$). The cysteamine group exhibited significantly higher plasma IgA content than day 1 ($P < 0.05$) and the grazing retardation group ($P < 0.05$). The yeast group demonstrated significantly increased plasma IgA and IgG contents compared to day 1 ($P < 0.05$), which were also significantly higher than the grazing retardation group ($P < 0.05$). These results indicate that concentrate supplementation, particularly with the addition of 80 mg/kg BW cysteamine or 0.3% active dry yeast, can enhance antioxidant capacity and immunity while promoting compensatory growth in retarded yaks, with the combination of concentrate and 0.3% active dry yeast showing the best effects.

Keywords: yak with growth retardation; body measurement; antioxidant; immune; cysteamine; active dry yeast

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Introduction

Yaks are traditional and dominant livestock on the Qinghai-Tibet Plateau, serving as essential livelihood resources for herders and forming a pillar industry in Tibetan regions. However, under traditional extensive grazing systems, yak nutrition intake is affected by seasonal variations in forage yield and nutrient content. When forage supply is insufficient or nutritional levels are too low, pregnant cows and newborn calves experience chronic nutritional deficiency, leading to retarded postnatal growth and development, or even stagnation, ultimately resulting in "stunted yaks" [1]. Stunted yaks exhibit poor feed conversion, small and emaciated body size, high disease and mortality rates, and growth performance far below that of same-age, same-breed cattle, thereby reducing herders' economic returns.

Several factors contribute to yak growth retardation. First, the traditional grazing system in pastoral areas, combined with harsh plateau environments and long cold seasons, causes sharp declines in forage supply and nutritional levels [2], leaving pregnant yaks in chronic undernutrition and resulting in intrauterine growth retardation that hinders postnatal development [3]. Second, due to insufficient nutrient intake, nursing cows cannot maintain adequate milk yield and quality, and competition for milk between humans and calves further reduces nutrient intake for calves, causing growth retardation [4]. Third, the harsh plateau environment leads to high disease incidence in yak calves, and sub-health status can impede growth and development [5]. Our previous research indicated that insufficient growth axis hormone secretion is a primary cause of growth retardation, and adding cysteamine to concentrate can promote growth axis hormone secretion and thus enhance growth [6]. Studies have shown that oxidative stress in mammalian cells can damage cellular macromolecules and cause organ dysfunction, reducing production performance and increasing disease susceptibility [7]. Meanwhile, immune stress can also alter livestock behavior, metabolism, and neuroendocrine function, ultimately inhibiting growth. Therefore, stunted yaks in sub-health condition may be affected by both oxidative and immune stress, though no relevant reports exist. Research has demonstrated that cysteamine and active dry yeast can improve animal antioxidant and immune capacity [8-9], and that concentrate supplementation with added cysteamine can promote body measurement and gastrointestinal development in stunted yaks [1].

Given these considerations, this study investigated the effects of different nutritional regulation methods on growth performance, blood routine, and plasma antioxidant and immune indexes in stunted yaks to explore the potential for initiating compensatory growth through nutritional interventions, thereby providing technical support for alleviating stunted yak problems and promoting efficient, healthy yak production in pastoral areas.

Materials and Methods

1.1 Experimental Animals

Based on the criterion of being 1.5 standard deviations below the average weight of same-age, same-breed yaks [10], forty one-year-old Qinghai high-plateau yaks with growth retardation were selected from natural grazing conditions, with an average body weight of (72.7 ± 6.0) kg. Additionally, ten normal one-year-old yaks of the same age and breed were selected under the same conditions, with an average body weight of (93.5 ± 6.0) kg.

1.2 Experimental Design

The 40 stunted yaks were randomly divided into four groups based on body weight: a grazing retardation group, a concentrate group (concentrate supplementation), a cysteamine group (concentrate + 80 mg/kg BW cysteamine), and a yeast group (concentrate + 0.3% active dry yeast). Normal yaks served as the healthy grazing control group. Each group had five replicates with two yaks per replicate. The pre-trial period lasted 15 days (during which the grazing retardation and healthy grazing groups were grazed, while the other three groups were housed and fed the same basal diet), followed by a 60-day formal trial.

Grazing retardation group: Natural grazing without concentrate supplementation.
Concentrate group: Housed and fed the basal diet.
Cysteamine group: Housed and fed the basal diet with cysteamine (effective content 30%, Shanghai Xumu Lian Biotechnology Co., Ltd.) added to the concentrate at 80 mg/kg BW [11].
Yeast group: Housed and fed the basal diet with active dry yeast (Angel Yeast Co., Ltd.) added to the concentrate at 0.3% [12].
Healthy grazing group: Natural grazing without concentrate supplementation.

1.3 Experimental Diets

Diet formulation referenced the recommended formulas in China' s "Beef Cattle Feeding Standards" (NY/T 815-2004), calculated for an average body weight of 60 kg and daily gain of 400 g. The concentrate primarily consisted of corn, soybean meal, rapeseed meal, wheat bran, rapeseed oil, sodium bicarbonate, salt, and vitamin-mineral premix. The roughage was oat hay. The basal diet (formula not disclosed due to patent application) had the following nutritional levels: crude protein (CP) 16.73%, net energy for gain (NEg) 25.19 MJ/kg, calcium (Ca) 0.88%, phosphorus (P) 0.58%, ether extract (EE) 3.79%, neutral detergent fiber (NDF) 34.92%, and acid detergent fiber (ADF) 17.93%.

1.4 Feeding Management

All experimental yaks were uniformly numbered and received immunization and deworming. Other disinfection and immunization procedures followed the farm' s standard management protocols. Grazing yaks were naturally grazed, while supplemented groups were housed in pens with two yaks per pen (one replicate). Feed was provided twice daily at 08:00 and 16:00. The basal diet was offered based on intake measured during the pre-trial period, with a concentrate-to-roughage ratio of 35:65 mixed as a total mixed ration (TMR). Yaks had free access to feed and water, with slight leftovers ensured after each feeding. Residual feed was collected and weighed before the next morning' s feeding. Pens were cleaned daily and disinfected weekly.

1.5 Sample Collection

Body measurements were taken on days 1 and 60 before morning feeding. On days 1 and 60, fasting jugular vein blood samples were collected using vacuum anticoagulant tubes before morning feeding. Samples were divided into two portions: one stored at 4°C for immediate analysis, and another centrifuged to obtain plasma stored at -20°C for later analysis.

1.6 Measurement Indicators

Body measurement indicators: Body height, body length, chest girth, chest depth, and cannon bone circumference.
Blood routine indicators: Red blood cell (RBC) count, hemoglobin (HGB) content, white blood cell (WBC) count, and platelet (PLT) count were measured using a Japanese SYSMEX-XS-800i hematology analyzer.
Plasma antioxidant indicators: Glutathione peroxidase (GSH-Px) activity, total superoxide dismutase (T-SOD) activity, total antioxidant capacity (T-AOC), malondialdehyde (MDA) content, and catalase (CAT) activity were measured using kits from Nanjing Jiancheng Bioengineering Institute.
Plasma immune indicators: Immunoglobulin A (IgA), immunoglobulin G (IgG), and immunoglobulin M (IgM) contents were measured by immunoturbidimetry using kits from Nanjing Jiancheng Bioengineering Institute.

1.7 Data Processing

Data were analyzed using SPSS 19.0 software. Inter-group comparisons were performed using one-way ANOVA followed by Duncan' s multiple comparison test. Comparisons between day 1 and day 60 data were performed using independent samples t-tests. Results are expressed as mean ± standard deviation, with $P < 0.05$ considered statistically significant.

Results

2.1 Effects of Different Nutritional Regulations on Body Measurements of Stunted Yaks

As shown in Table 1 , on day 1, all stunted yak groups had significantly lower body height, body length, chest girth, and chest depth compared to the healthy grazing group ($P < 0.05$). After 60 days of nutritional intervention, the concentrate, cysteamine, and yeast groups showed significantly higher body height, chest girth, chest depth, and cannon bone circumference than the grazing retardation group ($P < 0.05$), with no significant differences from the healthy grazing group ($P > 0.05$). The average daily gain in chest girth was significantly higher in the concentrate, cysteamine, and yeast groups than in the healthy grazing group ($P < 0.05$), while the yeast group also showed significantly higher average daily gains in body height and body length ($P < 0.05$). The concentrate group had significantly greater body length than the grazing retardation group ($P < 0.05$) but significantly lower than the cysteamine, yeast, and healthy grazing groups ($P < 0.05$). On day 60, the concentrate group showed no significant increase in body length compared to day 1 ($P > 0.05$), while other measurements were significantly higher ($P < 0.05$). The cysteamine and yeast groups showed significant increases in all body measurements from day 1 to day 60 ($P < 0.05$), with significantly higher average daily gains in body length, chest girth, and cannon bone circumference than the grazing retardation group ($P < 0.05$), with the yeast group showing the greatest improvement.

Table 1 Effects of different nutritional regulations on body measurements of yaks with growth retardation

Items	Time/d	Farming yaks with growth retardation	Concentrate group	Cysteamine group	Yeast group	Farming healthy yaks group
Body height/cm	1	83.7±4.8b	84.9±4.8b	86.6±3.2b	87.3±4.8b	90.5±3.2Ba
	60	84.1±4.0Bb	90.9±5.0Aa	87.2±3.1b	88.8±4.9b	94.8±4.9Aa
	Average daily grow/(cm/d)	0.02±0.00c	0.11±0.01a	0.03±0.00b	0.03±0.00b	0.07±0.00b
Body length/cm	1	105.3±5.4b	107.1±6.3b	108.8±4.8Bb	109.1±4.3Bb	117.0±3.7a
	60	86.2±4.1Bb	91.0±5.0Aa	118.6±6.3Aa	120.4±6.3Aa	122.1±4.4a
	Average daily grow/(cm/d)	0.03±0.00c	0.08±0.01b	0.16±0.01a	0.19±0.01a	0.09±0.00b
Chest girth/cm	1	21.3±2.2b	23.3±1.5b	21.9±1.3Bb	23.0±0.8Bb	24.0±0.7a
	60	87.7±4.3Bb	93.8±2.9Aa	108.1±3.5Bb	119.6±6.6Aa	108.1±3.5a
	Average daily grow/(cm/d)	0.03±0.00c	0.10±0.00a	0.05±0.00b	0.03±0.00b	0.04±0.00b
Chest depth/cm	1	11.7±0.7	12.1±0.8b	11.5±0.7B	11.2±0.9B	12.7±0.5B
	60	85.1±3.9Bb	92.7±4.3Aa	132.14±33.46a	131.58±28.28a	138.14±33.46a
	Average daily grow/(cm/d)	0.01±0.00b	0.02±0.00ab	0.03±0.00a	0.03±0.00a	0.02±0.00ab
Cannon bone circumference/cm	1	11.5±0.7B	12.9±0.7Aa	11.2±0.9B	11.5±0.7B	12.7±0.5B

Items	Time/d	Farming yaks with growth retardation	Concentrate group	Cysteamine group	Yeast group	Farming healthy yaks group
	60	87.7±4.3Bb	93.8±2.9Aa	542.02±65.69	547.57±29.63	556.95±57.03
	Average daily grow/(cm/d)	0.01±0.00b	0.03±0.00a	0.02±0.00ab	0.03±0.00a	0.02±0.00ab

In the same row, values with the same or no small letter superscripts mean no significant difference (P > 0.05), while different small letter superscripts mean significant difference (P < 0.05). In the same column, values of the same index with no capital letter superscripts mean no significant difference (P > 0.05), while different capital letter superscripts mean significant difference (P < 0.05). The same as below.

2.2 Effects of Different Nutritional Regulations on Blood Routine of Stunted Yaks

As shown in Table 2 , on day 60, the concentrate group had significantly higher red blood cell count than the grazing retardation group ($P < 0.05$). The concentrate, cysteamine, and yeast groups showed significantly higher hemoglobin content than the grazing retardation group ($P < 0.05$), with no significant differences from the healthy grazing group ($P > 0.05$). The grazing retardation group had significantly higher white blood cell count than the other four groups ($P < 0.05$). No significant changes were observed in platelet count among all groups ($P > 0.05$). Compared with day 1, red blood cell count on day 60 was significantly lower in both the grazing retardation and healthy grazing groups ($P < 0.05$).

Table 2 Effects of different nutritional regulations on blood routine of yaks with growth retardation

Items	Time/d	Farming yaks with growth retardation	Concentrate group	Cysteamine group	Yeast group	Farming healthy yaks group
RBC count/(×10¹²/L)	1	9.02±0.64A	8.28±0.50Bbc	8.60±0.66B	8.76±0.78	8.85±0.35A
	60	10.12±1.88Aa	9.08±0.57B	9.35±1.47Aab	8.94±1.95ab	7.26±0.68Bc
HGB content/(g/L)	1	135.50±5.26A	135.20±8.11	127.50±8.71	132.33±12.39	129.54±8.25
	60	126.38±22.65Bb	136.17±38.05a	132.14±33.46a	131.58±28.88a	138.71±7.65a
WBC count/(×10 /L)	1	8.77±0.92B	12.29±1.71Aa	8.69±1.51B	9.98±0.56AB	10.09±1.49

Items	Time/d	Farming yaks with growth retardation	Concentrate group	Cysteamine group	Yeast group	Farming healthy yaks group
	60	9.07±0.95	9.15±1.21b	9.34±1.77	10.37±2.31b	11.03±0.94b
PLT count/(×10 /L)	1	503.67±70.79	475.67±55.14	460.00±97.32	421.00±74.59	475.86±31.26
	60	522.71±94.76	508.17±86.44	484.29±85.22	504.71±109.06	490.60±80.65

2.3 Effects of Different Nutritional Regulations on Plasma Antioxidant Indexes of Stunted Yaks

As shown in Table 3 , on day 1, the grazing retardation, concentrate, cysteamine, and yeast groups had significantly higher plasma MDA content than the healthy grazing group ($P < 0.05$), while their plasma T-SOD, GSH-Px activities and T-AOC were significantly lower ($P < 0.05$). On day 60, the grazing retardation group showed significantly lower plasma T-AOC than on day 1 ($P < 0.05$). The concentrate group had significantly higher plasma T-SOD activity and T-AOC than the grazing retardation group ($P < 0.05$). The cysteamine group exhibited significantly lower plasma MDA content than day 1 ($P < 0.05$), which was also significantly lower than the grazing retardation group ($P < 0.05$), while its plasma T-SOD activity and T-AOC were significantly higher than day 1 ($P < 0.05$) and the grazing retardation group ($P < 0.05$). The yeast group showed significantly lower plasma MDA content than day 1 ($P < 0.05$), which was also significantly lower than the grazing retardation group ($P < 0.05$), while its plasma T-SOD, GSH-Px activities and T-AOC were significantly higher than day 1 ($P < 0.05$) and the grazing retardation group ($P < 0.05$).

Table 3 Effects of different nutritional regulations on plasma antioxidant indexes of yaks with growth retardation

Items	Time/d	Farming yaks with growth retardation	Concentrate group	Cysteamine group	Yeast group	Farming healthy yaks group
MDA/(nmol/mL)	1	15.65±2.05a	16.23±1.31a	15.41±1.51a	15.46±2.21Aa	14.73±1.67Aa
	60	14.73±1.67Aa	13.29±2.45ab	12.99±1.56Bb	11.65±2.21Bb	10.96±2.19b
T-SOD/(U/mL)	1	280.91±11.78b	278.05±17.31b	271.50±9.39Bb	280.97±13.73Bb	330.05±25.58a
	60	330.05±25.58a	285.06±15.24b	305.11±13.93a	328.31±13.76Aa	337.62±21.58Aa
GSH-Px/(U/mL)	1	915.24±38.13b	900.51±39.52b	915.44±33.20b	905.76±28.91Bb	960.88±24.84a
	60	960.88±24.84a	903.05±21.43b	933.89±27.01ab	918.91±19.52ab	955.60±28.29Aa
CAT/(U/mL)	1	386.34±23.39	384.09±21.76	399.26±30.59	390.92±25.30	395.84±17.58
	60	395.84±17.58	390.23±25.23	380.64±11.03	390.29±28.32	383.37±15.48
T-AOC/(U/mL)	1	32.79±4.47Ab	28.36±4.43Bb	32.12±1.82b	33.51±3.32a	32.66±5.47Bb

Items	Time/d	Farming yaks with growth retardation	Concentrate group	Cysteamine group	Yeast group	Farming healthy yaks group
	60	33.66±5.47Bb	32.22±3.30Bb	35.44±2.26Aa	35.43±6.69Aa	39.42±2.32a

2.4 Effects of Different Nutritional Regulations on Plasma Immune Indexes of Stunted Yaks

As shown in Table 4 , on day 1, the grazing retardation, concentrate, cysteamine, and yeast groups had significantly lower plasma IgA and IgG contents than the healthy grazing group ($P < 0.05$). On day 60, the concentrate group showed significantly higher plasma IgG content than day 1 ($P < 0.05$) and the grazing retardation group ($P < 0.05$). The cysteamine group exhibited significantly higher plasma IgA content than day 1 ($P < 0.05$) and the grazing retardation group ($P < 0.05$). The yeast group demonstrated significantly increased plasma IgA and IgG contents compared to day 1 ($P < 0.05$), which were also significantly higher than the grazing retardation group ($P < 0.05$).

Table 4 Effects of different nutritional regulations on plasma immune indexes of yaks with growth retardation

Items	Time/d	Farming yaks with growth retardation	Concentrate group	Cysteamine group	Yeast group	Farming healthy yaks group
IgA/(g/mL)	1	18.45±1.17b	19.84±2.54b	19.21±17.72b	20.36±2.32b	29.81±3.10a
	60	18.78±1.90Bb	22.91±2.25Aa	18.64±1.48Bb	23.07±2.01Aa	31.53±3.82a
IgG/(g/mL)	1	366.56±18.60b	352.44±14.66b	373.49±16.62b	337.81±12.56b	415.79±10.43a
	60	364.64±10.90b	396.85±16.27Aa	380.69±11.41b	410.06±12.03Aa	410.30±16.53a
IgM/(g/mL)	1	534.95±17.87	530.87±3.62	545.12±20.53	531.90±5.62	564.73±16.99
	60	535.97±65.97	542.02±65.69	547.57±29.65	546.51±15.28	553.95±57.03

Discussion

3.1 Effects on Body Measurements

Body measurements reflect animal growth and development and are commonly used as indicators of growth performance. Due to growth inhibition, stunted yaks have significantly smaller body measurements than normal yaks. Concentrate supplementation provides essential nutrients for growth, compensating for nutritional deficiencies and promoting development. However, after 60 days, the concentrate group showed no significant increase in body length, though chest girth, chest depth, and cannon bone circumference were significantly higher than the grazing retardation group but still lower than normal yaks, indicating that improved nutrition alone cannot fully restore normal growth levels. Adding cysteamine and active dry yeast to concentrate further enhanced body measurement gains. Animal growth is closely related to growth hormone, which is inhibited by somatostatin. Cysteamine can reduce somatostatin activity, increase microbial protein synthesis in ruminants, and enhance rumen digestive metabolism, thereby promoting growth [13]. Duodenal infusion of cysteamine in Hu sheep increased plasma growth hormone by 124.2% after 5 days, significantly improving growth rate [14]. Oral administration of cysteamine to sheep increased blood growth hormone by 56.20% within 6 days, promoting growth [15]. Active dry yeast can improve rumen environment stability, promote microbial fermentation, maintain rumen health, and enhance small intestine development, thereby improving nutrient digestibility and promoting growth [16]. Our results showed that adding active dry yeast to concentrate produced the greatest improvement in body measurements and the best growth-promoting effects.

3.2 Effects on Blood Routine

Blood routine indicators reflect nutritional and health status. Red blood cells transport essential substances for metabolism including oxygen, carbon dioxide, electrolytes, glucose, and amino acids, while also playing a buffering role in acid-base balance—functions mediated by hemoglobin [17]. The significant decrease in red blood cell count from day 1 to day 60 in both grazing groups may be attributed to harsh plateau grazing conditions. The concentrate and cysteamine groups had significantly higher red blood cell counts than both grazing groups, while the concentrate, cysteamine, and yeast groups showed significantly higher hemoglobin content than grazing stunted and normal yaks. These results indicate that concentrate supplementation and additives enhanced oxygen transport and metabolic functions, improving nutritional status and promoting growth. White blood cells phagocytize foreign substances and produce antibodies, playing crucial roles in wound healing, pathogen defense, and disease immunity [18]. Under traditional grazing, stunted yaks have poorer health status than normal yaks, and the significantly higher white blood cell count in the grazing retardation group may indicate inflammatory responses. However, cysteamine and active dry yeast supplementation maintained white blood cell counts at healthy levels similar to normal yaks, suggesting these additives help enhance immunity and promote healthy, efficient growth.

3.3 Effects on Plasma Antioxidant Indexes

Cellular function and vitality largely depend on the balance of redox status. Excessive reactive oxygen species (ROS) and free radicals disrupt this balance, causing oxidative damage to cellular macromolecules (lipids, proteins, DNA) and leading to functional decline or apoptosis [19]. MDA is a product of lipid peroxidation caused by free radical attack on biological membranes, and its content reflects the degree of lipid peroxidation and indirectly indicates cellular damage [20]. GSH-Px uses glutathione (GSH) as a reducing agent to reduce hydrogen peroxide and lipid hydroperoxides, helping cells resist oxidative damage [21]. Cells possess endogenous protective mechanisms against oxidative stress through enzymes like CAT and superoxide dismutase (SOD). T-AOC is a comprehensive indicator reflecting both enzymatic and non-enzymatic antioxidant capacity [22]. Our results showed significant oxidative stress in the grazing retardation group compared to the healthy grazing group, though whether oxidative stress inhibits calf growth requires further investigation [23]. The significant decrease in plasma T-AOC in the grazing retardation group on day 60 may be due to poor intrinsic antioxidant capacity combined with harsh plateau conditions. In this study, concentrate with cysteamine significantly increased plasma T-SOD activity and decreased MDA content, enhancing antioxidant capacity. Research indicates that the free hydroxyl groups in cysteamine have antioxidant effects, scavenging free radicals, increasing blood GSH content and SOD activity [24]. Our results also showed that concentrate with active dry yeast significantly increased plasma T-SOD, GSH-Px activities and T-AOC while decreasing MDA content, though the mechanism requires further study. Studies have shown that yeast culture supplementation in sheep diets can increase serum GSH-Px, SOD activities and T-AOC [25]. Liu et al. [26] reported that dietary yeast supplementation improved antioxidant capacity in cows with subclinical mastitis. Therefore, concentrate supplementation with cysteamine or active dry yeast can enhance antioxidant capacity and alleviate oxidative stress in stunted yaks.

3.4 Effects on Immune Function

Our results demonstrated that the grazing retardation group had significantly lower immune capacity than the healthy grazing group. Concentrate supplementation significantly increased plasma IgG content, likely due to improved nutrition. Numerous studies have shown that cysteamine can affect immune function directly or indirectly through hormonal changes. On one hand, immune function is closely related to the growth axis. Cysteamine can directly act on somatostatin, altering its configuration and depleting its immune activity, thereby relieving somatostatin' s inhibitory effect on immunity [27]. On the other hand, by relieving somatostatin' s inhibition of digestion-related hormones or enzymes, cysteamine promotes nutrient absorption and utilization, thereby improving immune function [28]. This study confirmed that concentrate with cysteamine significantly increased plasma IgA content and enhanced immune capacity. Yeast has good survivability and may beneficially affect intestinal flora balance through the rumen, thereby influencing the immune system and animal health [29]. Additionally, organic acids produced by yeast metabolism can lower gastrointestinal pH and effectively inhibit pathogen invasion [30]. Current reports on active dry yeast improving ruminant immune capacity are limited. However, studies have shown that yeast supplementation increased lactobacilli and decreased E. coli in goat feces [31], and significantly increased serum IgA and IgG contents in cashmere goats [32]. Our results demonstrated that concentrate with active dry yeast significantly increased plasma IgA and IgG contents, thereby enhancing immune capacity in stunted yaks.

Conclusion

Stunted yaks exhibit significantly impaired growth, antioxidant capacity, and immune function compared to normal yaks. Concentrate supplementation, particularly with the addition of 80 mg/kg BW cysteamine or 0.3% active dry yeast, can improve antioxidant and immune capacity while promoting compensatory growth in stunted yaks, with the combination of concentrate and 0.3% active dry yeast showing the best effects.

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Note: Figure translations are in progress. See original paper for figures.