Quality Assurance and Safety of Crops & Foods, 2023; 15(1): 182–192

Effects of different feeds on growth performance and meat quality of hybrid lambs

Taiwu Zhang[1,2†], Shaohua Wang[3†], Rong Liu[3], Ting Liu[1,2], Yanni Zhang[1,2], Le Yang[1,2], Letian Kang[1,2], Junkang Xie[1,2], Ye Jin[1,2], Yan Duan[1,2*]

[1]*College of Food Science and Engineering, Inner Mongolia Agricultural University, Hohhot, China;* [2]*Integrative Research Base of Beef and Lamb Processing Technology, Hohhot, China;* [3]*Inner Mongolia Autonomous Region Agriculture and Animal Husbandry Technology Promotion Center, Hohhot, China*

[†]These authors contributed equally to this work.

***Corresponding author:** Yan Duan, College of Food Science and Engineering, Inner Mongolia Agricultural University, Hohhot 010018, China. Email: duanyan@imau.edu.cn

Received: 11 December 2022; Accepted: 11 January 2023; Published: 14 February 2023

RESEARCH ARTICLE

Abstract

To improve the meat quality of Nei Mongol mutton and the benefits for farmers, we selected Australian salmon hybrid lambs as experimental subjects to investigate the effects of *Allium mongolicum* Regel powder (AMR) and yeast-fermented distiller's grains (DGS) on their production performance and economic efficiency. The results showed that the DGS group had higher kidney index, the AMR group had better meat quality, and the economic efficiency ratio of DGS and AMR was 2.08. In conclusion, both feeds had no adverse effects on the production performance of lambs, and the DGS group had greater potential for promotion.

Keywords: *Allium mongolicum* Regel powder; economic benefits; lamb; organ index; slaughter performance; yeast-fermented distiller's grains

Introduction

Due to the "preserving the grassland environment" government policy in the Inner Mongolia Autonomous Region, the method of raising lambs has shifted from grazing to barn-feeding. According to this study on mutton quality, the meat quality of barn-feeding sheep is inferior to that of grazing sheep (Jin *et al.*, 2021; Wang *et al.*, 2018, 2021). Therefore, it is important to discover feed supplements that can improve the meat quality of barn-fed sheep.

Distiller's grains are the leftover wheat and sorghum from the distillation of spirits. In addition to being abundant in crude proteins and crude fiber, distiller's grains are also abundant in important amino acids and minerals (Liu *et al.*, 2022). According to a number of studies, the use of distiller's grains by livestock can boost daily gain and carcass weight (Al-Suwaiegh *et al.*, 2002; Shee *et al.*, 2016). In addition, several studies have observed that distiller's grains can improve meat color (lower b* value), increase crude fat content, and decrease shear force (Kawecka *et al.*, 2018; Xie *et al.*, 2016). Additionally, feeding distiller's grains can decrease the thickness of back fat in cattle and enhance the cross-sectional area of the longissimus muscle in sheep (Beretta *et al.*, 2021; Hodges *et al.*, 2020). Hodges *et al.* (2020) and Kawecka *et al.* (2018) discovered that feeding distiller's grains improved the sensory qualities of mutton, such as tenderness and delicate texture. Additionally, brown, roasted, and umami flavors were amplified.

Allium mongolicum Regel (AMR) is a type of perennial and xerophytic Liliaceous allium plant. It grows in the grasslands of northern China affected by desertification. AMR contains abundant proteins, flavonoids, polysaccharides, and other compounds (Li *et al.*, 2019). Multiple studies indicate that dietary AMR, AMR extract, or

 ISSN 1757-837X online, DOI 10.15586/qas.v15i1.1252

AMR powder can improve the feed conversion ratio and daily weight gain in sheep (Du *et al*., 2019; Liu and Ao, 2021). Yaxing *et al*. (2021) discovered that the supplement AMR can also increase the loin eye cross-section area of DuHan (Dorper small-tailed Han) sheep. The addition of AMR extract to the diet can considerably improve feed utilization efficiency and lower the concentration of 4-methyl octanoic acid in the flavor and odor of lamb, with the exception of tail fat (Liu and Ao, 2021). In addition, flavonoids and phenolic acids in AMR have effects on intestinal motility rhythm and fat metabolism, and the extract has beneficial antioxidant and inhibitory effects on lipase and the angiotensin-converting enzyme (Dong *et al*., 2020; Wang *et al.*, 2019). Extensive research indicates that AMR consumption can increase the quality of lamb. Feeding AMR, for instance, can increase the water-holding capacity of lamb, minimize drip loss and cooking loss, improve lamb color and intramuscular fat content, and decrease Warner–Bratzler shear force (Ding *et al*., 2021). The majority of studies documented the effects of DGS and AMR on growth performance and meat quality, but few studies compared the two diets.

Sheep hybrids are the result of the genetic enhancement of indigenous flocks. Hybrid sheep are more productive and provide greater economic benefits. For the growth of the meat sheep breeding industry in Inner Mongolia, it is of utmost importance to improve the growth performance and meat quality of hybrid sheep, as well as to increase the economic benefits for breeders. Nonetheless, hybrid sheep have relatively high nutritional needs and should be supplemented with a supplementary diet. The addition of distiller's grains and AMR to a sheep's diet is relatively common and can support its growth and development. To our knowledge, no animal nutrition study has been conducted on Australian salmon hybrid lambs (ASH lamb, Australian white sheep × Suffolk sheep × Mongolian sheep). Therefore, ASH lamb was chosen as the object of study. The objective of this study was to investigate the effects of two supplements on lamb slaughter performance and meat quality and to provide a theoretical foundation for the economic development of animal husbandry. It is anticipated that the selected feeding methods that can improve mutton quality and provide economic benefits will be promoted to the majority of breeding operations in order to boost the quality of mutton purchased by consumers and the income of breeding enterprises and herders.

Materials and Methods

Animal experiments and feeding methods

This experiment was conducted at the Inner Mongolia Haojinbo Agriculture and Animal Husbandry Co., Ltd.'s experimental base. The control group (CON), yeast-fermented distiller's grains treatment group (DGS), and AMR powder treatment group each consisted of 10 3-months-old healthy ASH lambs with an initial body weight of 30 ± 2.1 kg (5 males and 5 females). The nutrition of the lamb strictly adheres to the "Feeding standard for sheep and goats used for meat production" (NY/T 816-2004). The CON group was fed a diet total mixed ration (TMR). The AMR group was supplemented with AMR powder (Alxa League Haohai Biotechnology Co., Ltd., Inner Mongolia, China, 30g/day/body), and pellet TMR was mixed uniformly. 30% of the distiller's grains (Al-Suwaiegh *et al*., 2002; Hodges *et al*., 2020) (Hubei Gaosheng Biological Feed Co., Hubei, China) and 70% pellet TMR were mixed evenly for the DGS group's diet. Each treatment was furnished with salt bricks. The nutritional content and composition of the basic diet are detailed in Table S1. In the experiment, consistency in the digestive energy of the three groups was ensured. The 100-day experimental period was followed by a 10-day adaptation period. The experimental lamb was cleansed of parasites, and anti-epidemic measures were implemented. During the normal 90-day experimental period, animals were fed at 08:00 and 18:00 and allowed to drink freely. The welfare of the experimental animals followed the requirements of the "Farm Animal Welfare Requirements for Meat Sheep" (T/CAS 242-2015), and the protocol was approved by the College of Food Science and Engineering of Inner Mongolia Agricultural University (Hohhot, China).

Determination of growth performance

Throughout the duration of the experiment (the first day after the end of the 10-day adaptation period is the zeroth day, and the test ends on the 90th day.), the body weight, height, length, bust circumference, and canal bone circumference of each subject were recorded 30 days prior to the morning feeding. The measuring positions of various lamb parts are depicted in Figure S1: bust circumference is the circumference around the chest measured by the vertical body axis at the posterior edge of the acromion; canal bone circumference is the circumference of the thinnest part of canal bone; body height is the vertical distance from the highest point of the withers to the ground; and body length is the linear distance from the shoulder end to the back end of the ischial tubercle.

Determination of slaughter performance, carcass characteristics, and meat quality

Following a 24-h fast at the conclusion of the feeding trial, 10 lambs from each treatment were slaughtered (Santos *et al.*, 2007). After storing their corpses at 4°C, specimens of the left lateral muscle longissimus dorsi between the 12th and 13th ribs were taken for analysis.

Slaughter performance and carcass characteristics determination

The live weight was determined following a 24-h fast and a 2 h water restriction prior to slaughter, and the carcass weight, carcass length, depth, and dressing percentage were determined after slaughter. As for the back-fat thickness, measure the fat thickness between the 12th and 13th ribs in the upper middle of the loin eye muscle (Ding *et al.*, 2021). The cross-sectional area of the loin eye muscle corresponds to the posterior edge of the 12th rib on the right side of the carcass. Measure the tissue thickness between the 12th and 13th pairs of ribs, 11 cm from the center of the spine; this is the thickness of the rib flesh. It serves as an indicator of carcass fat content. Finally, calculate the net mean percentage, the percentage of bone, and the ratio of flesh to the bone.

$$\text{Dressing percentage} = \frac{\text{carcass weight}}{\text{live weight}} \times 100\%$$

(Yaxing *et al.*, 2021), (1)

$$\text{Net meat percentage} = \frac{\text{net meat weight}}{\text{live weight}} \times 100\%, \quad (2)$$

$$\text{Meat-to-bone ratio} = \frac{\text{meat weight}}{\text{bone weight}}, \quad (3)$$

Organ weight determination

In the slaughter trial, the heart, liver, spleen, lungs, and kidneys were isolated and weighed. The organ index was obtained by dividing the organ weight by the live weight.

$$\text{Organ index} = \frac{\text{organ weight}}{\text{live weight}}, \quad (4)$$

pH determination

pH_{45min} and pH_{24h} were determined 45 min and 24 h, respectively, following the slaughter. The pH of the longissimus dorsi muscle was measured using the PB-10 portable pH meter at three random locations (Zhang *et al.*, 2022).

Determination of drip loss

To assess drip loss, 1.5 cm of the longissimus dorsi muscle was weighed (w1), placed in netting, and hung in a plastic bag that had been inflated. After 24-h of incubation at 4°C, the samples were reweighed (w2), and the drip loss was determined as a percentage of the sample's original weight (Honikel, 1998).

$$\text{Drip loss} = \frac{(w1 - w2)}{w1} \times 100\% \quad (5)$$

Meat quality grading

Referring to "Fresh and frozen mutton carcass" (GB 9961-2008) separate lamb, measuring the weight of the left side of meat at all levels. Determine the proportions of the meat, first-level (ham and loin), the second-level (ribs and neck meat), and the third-level by weighing the individual cuts (underbelly).

Lamb marbling determination

The longissimus dorsi of the lamb was removed after the slaughter test and stored at 4°C for 24 h. The textural structure of the fresh section was then inspected (Przybylak *et al.*, 2016) after the cross-section was recorded. The marbling scoring standard chart for American-style pork was utilized to examine and score using a five-point scale. Table S2 outlines the criteria.

Determination of cooking loss

At 24 h post-slaughter, the longissimus dorsi muscle samples of the three treatment groups were selected, the outer sarcolemma and fat were removed, approximately 100 g of meat samples were weighed (w3), and the meat samples were placed in a 72°C water bath until the internal core temperature reached 70°C (Cama-Moncunill *et al.*, 2020). After cooking, allow the meat to cool to room temperature and weigh it (w4).

$$\text{Cooking loss} = \frac{w3 - w4}{w3} \times 100\% \quad (6)$$

Economic evaluation

In this study, the mutton carcasses were deboned during the slaughter test, and all meat samples other than the test samples were sold as rolls; therefore, the price of the mutton was determined based on the price of the rolls.

$$\text{Average meat production} = \frac{\text{Meat weight}}{\text{100 days}} \quad (7)$$

$$\text{Meat production feed cost} = \frac{\text{Ration cost}}{\text{Meat production}} \quad (8)$$

Total production value = Meat production × Mutton price (9)

Other costs = Total production value – Ration cost, (10)

Statistical analyses

On SPSS 26 (IBM, New York, USA), the one-way analysis of variance (ANOVA) was performed to examine the influence of food treatments on growth performance, carcass attributes, organ index, and meat quality. Using Tukey's multiple-range tests, we examined the differences in means. The results are shown as means and standard errors of the means. Probability values of $P < 0.05$ were deemed statistically significant, whereas values of $0.05 < P < 0.10$ were deemed indicative of a trend. Using the "randomForest" R package, a random forest classification model was developed, and the confusion matrix and out-of-bag (OOB) estimate of error rate were utilized to describe the differences between the three groups of lambs.

Results

Effects of yeast-fermented distiller's grains and *Allium mongolicum* Regel powder on growth performance

The findings of measuring the growth in body size of 3- to 6-months-old ASH lambs in each group are shown in Table 1. In addition, the increase in the bust circumference of ASH lambs fed with AMR powder was considerably greater than that of ASH lambs that were given basal diets ($P < 0.05$). The rise in body height in the DGS group was larger than that of the CON and AMR groups ($0.05 < P < 0.1$).

Effects of yeast-fermented distiller's grains and *Allium mongolicum* Regel powder on carcass characteristics

After slaughter, the carcass characteristics of ASH lamb in each group were measured, and the findings are presented in Table S4. Neither DGS nor AMR powder had a significant effect ($P > 0.05$) on the weights of carcass, bone, meat, head, hoof, fur, bone ratio, meat-to-bone ratio, back-fat thickness, cross-sectional area of a loin eye muscle, and rib thickness of ASH lambs. *Allium mongolicum* Regel powder had a significant impact on the dressing percentage and net meat yield ($P < 0.05$) of ASH lambs. The AMR group exhibited the highest dressing percentage and net meat rate.

Effects of yeast-fermented distiller's grains and *Allium mongolicum* Regel powder on organ index

We determined the organ weights of each group of ASH lambs, and these are recorded in Table 2. The heart, lungs, and spleen indices of ASH lamb were unaffected by DGS and AMR powder ($P > 0.05$). The DGS group had the highest liver index ($P < 0.05$), while the CON group had the lowest ($P < 0.05$). The DGS group had a considerably higher kidney index than the other two groups ($P < 0.05$).

Effects of yeast-fermented distiller's grains and *Allium mongolicum* Regel powder on meat quality

The pH values of the longissimus dorsi muscle in each group were tested 45 min and 24 h after ASH lamb slaughter and were recorded as pH_{45min} and pH_{24h}, respectively. The results have been recorded in Table S5. The pH_{45min} value of the longissimus dorsi muscle was

Table 1. Effect of dietary supplementation with yeast-fermented distiller's grains and *Allium mongolicum* Regel powder on the growth performance of lambs.

Items	Treatment			SEM	P
	CON	AMR	DGS		
Initial body weight, kg	30.10^{a}	28.23^{a}	29.10^{a}	0.5108	0.3410
Final body weight, kg	42.15^{a}	40.89^{a}	40.34^{a}	1.0906	0.798
Average daily gain, g/day	119.86^{a}	133.16^{a}	123.18^{a}	2.5389	0.0795
Body length gain, cm	9.25^{a}	8.63^{a}	8.85^{a}	0.5703	0.911
Body height gain, cm	7.83^{a}	9.33^{a}	11.17^{a}	0.6332	0.0907
Bust circumference gain, cm	16.16^{b}	20.11^{a}	17.31^{ab}	0.6737	0.0423
Canal bone circumference gain, cm	2.68^{a}	2.58^{a}	2.78^{a}	0.1492	0.8685

^{a,b}Means within a row with no common superscripts are significantly different ($P < 0.05$).
SEM: standard error of measurement; AMR: *Allium mongolicum* Regel; CON: control group; DGS: yeast-fermented distiller's grains treatment group.

Table 2. Effects of yeast-fermented distiller's grains and *Allium mongolicum* Regel powder on organ index.

Items	Treatment			SEM	P
	CON	AMR	DGS		
Heart index, g/kg	5.80[a]	5.48[a]	5.04[a]	0.2095	0.3457
Liver index, g/kg	11.98[b]	13.56[ab]	14.23[a]	0.3225	0.0088
Lung index, g/kg	11.33[a]	10.60[a]	10.47[a]	0.2108	0.2043
Kidney index, g/kg	5.66[b]	5.50[b]	7.22[a]	0.2206	0.0006
Spleen index, g/kg	1.44[a]	1.50[a]	1.39[a]	0.0344	0.4681

[a,b]Means within a row with no common superscripts are significantly different (P < 0.05).
SEM: standard error of measurement; AMR: *Allium mongolicum* Regel powder; CON: control group; DGS: yeast-fermented distiller's grains treatment group.

considerably greater in the AMR group compared to the CON group (P < 0.05). The pH_{45min} of the DGS group was in the middle, and there was no difference in this value when compared with the other two groups (P > 0.05). The effect of AMR powder and DGS on the pH_{24h} of the longissimus dorsi muscle of ASH lambs was not significant (P > 0.05).

The findings of measuring the cooking loss and drip loss of the longissimus dorsi muscle of ASH lamb in each group are presented in Table S5. AMR and DGS showed no influence (P > 0.05) on the cooking loss of the longissimus dorsi of ASH lamb compared to the CON group. The drip loss in the AMR group was significantly lower than in the other two feed groups (P = 0.05). Compared to the CON group, the value of cooking loss was lower in the AMR group; therefore, feeding AMR powder tended to reduce the cooking loss (0.05 < P < 0.1); and AMR powder tended to improve ASH lamb water retention performance (0.05 < P < 0.1).

With regard to the pork marbling scoring standard (Przybylak *et al.*, 2016), the marbling score was measured on the longissimus dorsi muscle cross-section of the 12–13 ribs of each group's lamb carcasses. The results have been provided in Table S5. The prevalence of marbling was significantly higher in the AMR group than in the CON and DGS groups (P < 0.05). However, there was no statistically significant difference between the DGS and CON groups (P > 0.05).

The three groups of mutton obtained were rated according to the "Fresh and frozen mutton carcass" meat grading standard. According to Table S5, AMR powder and DGS had no effect on total meat weight, second-class or third-class meat weight, the proportion of first-class or second-class meat (P > 0.05). As shown in Table S5, the weight of first-class meat in the AMR and DGS groups was significantly greater than that in the CON group (P < 0.05), indicating that DGS and AMR powder can increase the weight of first-class meat and that there is no significant difference between the two feeding methods. According to Table S5, the proportion of third-class meat in the AMR group was considerably lower than in the CON group (P < 0.05), although there was no significant difference between the CON and DGS groups (P > 0.05). Feeding AMR powder and DGS reduced the weight of low-quality meat, according to the results.

Effects of yeast-fermented distiller's grains and *Allium mongolicum* Regel powder on the classification of the three groups of sheep

We created a random forest classification model using the "randomForest" R package. We examined whether the four primary data points, namely growth performance, carcass traits, organ index, and meat quality, could effectively differentiate between the three groups of crossbred sheep. The confusion matrix in Table S3 demonstrates that the three groups of crossbred sheep were correctly identified, as they were all assigned to their respective locations without crossing, and the OOB estimate of the error rate was 0.

Effects of yeast-fermented distiller's grains and *Allium mongolicum* Regel powder on economic benefits

The effects of AMR powder and DGS on the economic benefits of raising lambs are outlined in Table S6. Other expenditures (such as labor and machinery) other than the cost of feed in the breeding cost are not considered in the computation of economic benefits, and other costs are assumed to be the same for each group. According to the price of mutton lamb feed, the average meat production, and the price of mutton, it is determined that the addition of AMR powder increases the daily ration cost of each lamb from ¥13.09 to 15.74, despite the fact that the sand onion powder relatively increases the average meat production of this group of ASH lambs. In comparison to the CON group, it climbed by 9.4%, while the cost of meat production rose from ¥0.1002/kg to 0.1101/kg, resulting in a decrease in benefits from ¥1.43

to $1.35/day. The use of 30% DGS feed reduces the cost of the diet from ¥13.9 to 12.76, and the DGS feed enhances the meat production performance of the mutton lamb. Compared to the control group, the average meat production of mutton lamb in the DGS group increased by 7.2%; its economic benefit is 1.97 times that of the CON group and 2.08 times that of the AMR group.

Discussion

The majority of the active compounds in AMR are flavonoids, and adding flavonoids to the diet can increase the growth performance of lamb. Qi *et al.* (2017) discovered that the addition of 11–33 mg/kg of flavonoids to the diet of meat sheep significantly increased daily weight gain and average daily feed intake. Du *et al.* (2019) examined the influence and connection of flavonoids on rumen bacteria and the average daily gain of sheep. The results indicated that adding 10g/day of flavonoid extract to the basic diet of male Small Tail Han sheep might greatly increase their daily average weight gain. In their study, the average daily weight gain of the group fed with AMR was 176.8 g/day, which was 20.36% greater than that of the control group. In our study, the AMR group's average daily weight gain was 133.16 g, which was likewise greater than that of the CON and DGS groups.

Yeast-fermented distiller's grains are a new type of animal feed produced by secondary fermentation of byproducts of alcoholic beverage production. It is abundant in proteins, fats, and yeast. The study by Castro-Perez *et al.* (2014) showed that replacing corn and soybean meal with 45% distiller's grains in the basic diet of lambs tended to increase their daily average weight gain. Larson *et al.* (2023) found that feeding tillers grains to fatten cattle improved dry matter intake. A meta-analysis containing 81 publications found that feeding distributors' grains could significantly increase the final weight of cattles (de Nazaré Santos Torres *et al.*, 2022). Consistent with the aforementioned research, the DGS feed had no significant effect on the average daily weight gain of ASH lambs in this experiment.

During the feeding test, it was discovered that ASH lambs in both CON and AMR groups tore and consumed plastic goods. Pica is commonly seen as a nutritional disease affecting agricultural animals. The deficiency or imbalance of certain nutrients might result in impaired digestion and metabolic problems in lambs, causing pica (Nikvand *et al.*, 2018). The absence of pica in the DGS group for the entire fattening period under identical housing, feeding, and management settings suggests that the DGS feed may prevent the onset of pica to some extent. The reason may be that the DGS are pelleted feed produced by *Saccharomyces cerevisiae* during the secondary fermentation of the distiller's grains (Liu *et al.*, 2022). Beneficial microorganisms regulate the intestinal flora of ASH lambs; DGS contain functional substances such as microbial secondary metabolites and cell wall polysaccharides, which can increase the expression of IL-6 and IL-10 in the ileum and regulate intestinal immune function (Yang *et al.*, 2019).

Allium mongolicum Regel powder had a substantial impact on the dressing percentage of ASH lambs ($P < 0.05$), with AMR lambs having the highest dressing percentage ($P < 0.05$). In contrast, the DGS group has the greatest back-fat thickness and rib thickness. The thickness of the ribs serves as the basis for the carcass fat score (May *et al.*, 1992), which can be used to infer the distribution of carcass fat in mutton lambs.

The lamb's organ index might indicate the maturation of its body functions. An increase in the organ index within a specified range shows that organ function has improved; however, if the organ index is too high or too low, pathological alterations such as edema, congestion, and functional deterioration may be present. In this study, DGS and AMR powder had no significant effect on the heart, lung, or spleen indices of ASH lambs ($P > 0.05$), indicating that the development of the heart, lung, and spleen of the three groups of ASH lambs is related to the development of the body. Mutton lambs from the DGS group had the highest liver and renal indices ($P < 0.05$). In this study, when the replacement amount of DGS is higher, the dry matter intake of the body increases, and the nutrients and wastes produced by metabolism increase, thereby stimulating the development of the liver. As a result, the liver index increased more in this study than in the control group.

The liver is the primary digestive organ engaged in nutrition and metabolism. Before they can be turned into compounds that the body may use, the nutrients received by the gastrointestinal tract must be processed by the liver. The average daily weight increase of the AMR and the DGS group was greater than that of the CON group, indicating that the energy metabolism and transformation ability of the lambs in the DGS and the AMR group were greater than those in the CON group. AMR powder and DGS can stimulate liver growth in ASH lamb.

The kidney index is dramatically enhanced in the DGS group. In this investigation, distiller's grains fermented with yeast dramatically enhanced the kidney index. The reason may be that DGS can improve the absorption and deposition of nitrogen in mutton lambs, improve the function of nitrogen metabolism (Qi *et al.*, 2017), and promote the growth and development of kidneys to a certain extent; however, it may also be due to the excessive burden on the kidneys caused by the excessive addition of liquor grains to the feed, and the specific reasons must be studied further.

The pH_{24h} of the longissimus dorsi muscle declined from 6.58–6.79 to 5.74–5.77 after 24 h. After 24 h of anaerobic respiration, the muscle glycogen in the meat sample creates lactic acid, and the conversion of creatine phosphate to phosphoric acid lowers the meat's pH. However, because various sets of samples generate lactate at different rates, the pH_{24h} varies to varying degrees (Hamoen *et al.*, 2013). The pH value is influenced by the rate of muscle glycogenolysis and is directly related to the meat's water-holding capacity, glycogen, and lactic acid content. The pH value 45 min after slaughter is frequently used as a measure of the quality of meat. According to Table S5, the pH_{45min} value of each group's longissimus dorsi muscle was maintained between 6.58 and 6.79, which was within the normal range and met the pH value evaluation criterion for meat. The pH_{45min} value of the longissimus dorsi muscle was highest in the AMR group ($P < 0.05$), while it was lowest in the control group ($P < 0.05$). The pH_{45min} value of the DGS group was not substantially different from that of the control group. High pH correlates with increased water retention and improved flesh color (Qiao *et al.*, 2001). In this study, the longissimus dorsi muscle in the AMR group retained the most water, whereas the CON group retained the least. The cooking loss of the AMR and DGS groups decreased relative to the CON group, demonstrating that the AMR powder and DGS feed might improve the muscle water retention of ASH lambs.

In this study, there was no significant difference between DGS and AMR powder in the cooking loss of the longissimus dorsi of ASH lambs ($P > 0.05$). Longissimus dorsi leak loss was also the lowest in the AMR group ($P < 0.05$). Yaxing *et al.* (2021) discovered that supplementation with AMR and its extracts can reduce cooking loss and improve the water-holding ability of mutton to enhance the quality of the meat. The results of the Ding investigation also demonstrated that AMR and its extracts can reduce drip loss and cooking loss greatly (Ding *et al.*, 2021). The flavonoids derived from AMR have antioxidant properties that can enhance the ability of lambs to retain water (Zhang *et al.*, 2013) Both cooking loss and drip loss are significant markers of meat quality and can reveal how well meat retains water.

The amount of marbling in meat products is a significant predictor of texture because it can be used to quantify the juiciness and flavor softness of muscles. Scores for marbling indicate how fat is distributed throughout the muscle, and studies indicate that tenderness may increase as marbling increases. This could be because fat increases the muscle's water-holding capacity and decreases shear force (Wheeler *et al.*, 1994). *Allium mongolicum* Regel powder can improve the fat distribution and content of the longissimus dorsi of lamb, and an increase in intramuscular fat has a good influence on the softness of meat products (Swiatkiewicz *et al.*, 2021). Consistent with the findings of this investigation, marbling in the AMR group was substantially higher than that of the other two groups ($P < 0.05$), and AMR powder promoted the homogeneous distribution of intermuscular fat in ASH lambs. Existing research indicates that there are fewer fat deposits between muscles, which are adverse to meat quality (Nogalski *et al.*, 2019). The results demonstrated that feeding AMR powder improved meat quality, while giving DGS had no negative influence on meat quality.

In this investigation, DGS and AMR powder had no influence on total meat weight, rib, and neck meat weight, or their percentage to total meat weight ($P > 0.05$). The total weight of first-grade beef in the AMR and DGS groups was significantly higher than in the CON group ($P = 0.05$). In this experiment, the growth rate of high-grade meat in the ASH lamb is higher than that of low-grade meat, and its meat production performance is relatively good. The proportion of tertiary meat was lowest in the AMR group ($P < 0.05$), and there was no significant difference between the CON and the DGS groups ($P > 0.05$) in this regard. It was determined that DGS and AMR powder might enhance the quality of ASH lamb meat. The overall weight and proportion of the first and second meat were greater in the AMR group than in the DGS group, and the promoting effect of AMR powder was more effective than that of DGS.

The economic value of a mutton lamb is contingent on mutton output, mutton price, and production expenses. Feed, labor, and other expenses account for the majority of mutton lamb production costs. According to the input and output of enhanced mutton lamb in Inner Mongolia in 2018, the cost of mutton lamb feed comprised 63.58% of the entire production cost (Liu, 2020) and was the most significant production cost component. In this investigation, the makeup of basal TMR was identical across all groups. After adding AMR powder to the meal and substituting a portion of TMR with DGS, the AMR group's average meat yield increased by 9.4% compared to the control group. The price of freeze-dried feed powder was excessive. The feed cost increased by 20.24% compared to the control group, but the economic gain was reduced by 5.6%. The DGS group's meat production grew by 7.2% compared to the CON group and was 2.03% less than that of the AMR group. The DGS group's feed costs were 2.52% less than those of the CON group and 18.93% less than those of the AMR group. The DGS group's economic gain was 1.97 times that of the CON group and 2.08 times that of the AMR group.

Conclusions

This experiment was the first to investigate the effects of DGS and AMR powder on growth and slaughter performance and meat quality of Australian salmon hybrid lambs, and to evaluate the economic benefits of the three groups. In this experiment, growth performance, carcass characteristics, organ weights, and meat quality of ASH lamb were not adversely affected compared to the control group. The economic benefits of DGS were the highest, which has a great potential for promotion. Next, we will further investigate the mechanism by which DGS affect meat quality and expect to improve lamb quality while maintaining the high economic efficiency of DGS.

Acknowledgments

This research was funded by Inner Mongolia Natural Science Foundation Program of China (Grant number: 2021MS03012) and Department of Finance of Inner Mongolia Autonomous Region, Department of Science and Technology of Inner Mongolia Autonomous Region (Grant number: KCBJ2018068).

References

Al-Suwaiegh, S., Fanning, K.C., Grant, R.J., Milton, C.T. and Klopfenstein, T.J., 2002. Utilization of distillers grains from the fermentation of sorghum or corn in diets for finishing beef and lactating dairy cattle. Journal of Animal Science 80(4): 1105–1111. https://doi.org/10.2527/2002.8041105x

Beretta, V., Simeone, A., Franco, J., Bentancur, O., Novac, M., Panizza, V. and Rodriguez, M.V., 2021. Using sorghum dry distillers' grains plus solubles in sorghum-based finishing diets: feed utilization, cattle performance and carcass traits. Animal Feed Science and Technology 271: 114731. https://doi.org/10.1016/j.anifeedsci.2020.114731

Cama-Moncunill, R., Cafferky, J., Augier, C., Sweeney, T., Allen, P., Ferragina, A., Sullivan, C., Cromie, A. and Hamill, R.M., 2020. Prediction of Warner-Bratzler shear force, intramuscular fat, drip-loss and cook-loss in beef via Raman spectroscopy and chemometrics. Meat Science 167: 108157. https://doi.org/10.1016/j.meatsci.2020.108157

Castro-Perez, B.I., Estrada-Angulo, A., Rios, F.G., Davila-Ramos, H., Robles-Estrada, J.C., Contreras-Perez, G., Calderon-Cortes, J.F., Lopez-Soto, M.A., Barreras, A. and Plascencia, A., 2014. Effects of replacing partially dry-rolled corn and soybean meal with different levels of dried distillers grains with solubles on growth performance, dietary energetics, and carcass characteristics in hairy lambs fed a finishing diet. Small Ruminant Research 119(1–3): 8–15. https://doi.org/10.1016/j.smallrumres.2014.03.007

de Nazaré Santos Torres, R., de Melo Coelho, L., Paschoaloto, J.R., Ghedini, C.P., Neto, O.R.M., Chardulo, L.A.L., Baldassini, W.A., de Almeida Júnior, G.A. and Almeida, M.T.C., 2022. Does distillers' grains supplementation affect beef cattle performance, carcass characteristics, and meat quality? A meta-analysis study. Research in Veterinary Science 149: 21–35. https://doi.org/10.1016/j.rvsc.2022.06.004

Ding, H., Liu, W., Erdene, K., Du, H. and Ao, C., 2021. Effects of dietary supplementation with *Allium mongolicum* Regel extracts on growth performance, serum metabolites, immune responses, antioxidant status, and meat quality of lambs. Animal Nutrition 7(2): 530–538. https://doi.org/10.1016/j.aninu.2021.04.001

Dong, Y., Ruan, J., Ding, Z., Zhao, W., Hao, M., Zhang, Y., Jiang, H., Zhang, Y. and Wang, T., 2020. Phytochemistry and comprehensive chemical profiling study of flavonoids and phenolic acids in the aerial parts of *Allium mongolicum* Regel and their intestinal motility evaluation. Molecules 25(3): 577. https://doi.org/10.3390/molecules25030577

Du, H., Erdene, K., Chen, S., Qi, S., Bao, Z., Zhao, Y., Wang, C., Zhao, G. and Ao, C., 2019. Correlation of the rumen fluid microbiome and the average daily gain with a dietary supplementation of Allium mongolicum Regel extracts in sheep. Journal of Animal Science 97(7): 2865–2877. https://doi.org/10.1093/jas/skz139

Hamoen, J.R., Vollebregt, H.M. and van der Sman, R.G.M., 2013. Prediction of the time evolution of pH in meat. Food Chemistry 141(3): 2363–2372. https://doi.org/10.1016/j.foodchem.2013.04.127

Hodges, K.M., Kerth, C.R., Whitney, T.R., Wall, K.R., Miller, R.K., Ramsey, W.S. and Woerner, D.R., 2020. Replacing cottonseed meal and sorghum grain with corn dried distillers' grains with solubles in lamb feedlot diets: carcass, trained sensory panel, and volatile aroma compounds traits. Journal of Animal Science 98(6): skaa182. https://doi.org/10.1093/jas/skaa182

Honikel, K.O., 1998. Reference methods for the assessment of physical characteristics of meat. Meat Science 49(4): 447–457. https://doi.org/10.1016/S0309-1740(98)00034-5

Jin, Y., Zhang, X., Zhang, J., Zhang, Q. and Tana., 2021. Comparison of three feeding regimens on blood fatty acids metabolites of Wujumqin sheep in Inner Mongolia. Animals 11(4): 1080. https://doi.org/10.3390/ani11041080

Kawecka, A., Sosin-Bzducha, E., Puchala, M. and Sikora, J., 2018. Effect of maize DDGS addition on carcass and meat quality of lambs of native sheep breed. Journal of Applied Animal Research 46(1): 301–305. https://doi.org/10.1080/09712119.2017.1299014

Larson, H.E., Jaderborg, J.P., Paulus-Compart, D.M., Crawford, G.I. and DiCostanzo, A., 2023. Effect of substitution of distillers grains and glycerin for steam–flaked corn in finishing cattle diets on growth performance and carcass characteristics. Journal of Animal Science 101: skac348. https://doi.org/10.1093/jas/skac348

Li, M., Zhu, X., Niu, X., Chen, X, Tian, J., Kong, Y., Zhang, D., Zhao, L. and Wang, G., 2019. Effects of dietary *Allium mongolicum* Regel polysaccharide on growth, lipopolysaccharide-induced antioxidant responses and immune responses in Channa argus. Molecular Biology Reports 46(2): 2221–2230. https://doi.org/10.1007/s11033-019-04677-y

Liu, J., 2020. Studies on the production efficiency of Inner Mongolia mutton sheep breeding industry. D. Thesis, Inner Mongolia Agricultural University, Hohhot.

Liu, W. and Ao, C., 2021. Effect of dietary supplementation with Allium mongolicum Regel extracts on growth performance, carcass characteristics, and the fat color and flavor-related branched-chain fatty acids concentration in ram lambs. Animal Bioscience 34(7): 1134–1145. https://doi.org/10.5713/ajas.20.0246

Liu, Y., Liu, S., Huang, C., Ge, X., Xi, B. and Mao, J., 2022. Chinese Baijiu distiller's grains resourcing: current progress and future prospects. Resources Conservation and Recycling 176: 105900. https://doi.org/10.1016/j.resconrec.2021.105900

May, S.G., Mies, W.L., Edwards, J.W., Williams, F.L., Wise, J.W., Morgan, J.B., Savell, J.W. and Cross, H.R., 1992. Beef carcass composition of slaughter cattle differing in frame size, muscle score, and external fatness. Journal of Animal Science 70(8): 2431–2445. https://doi.org/10.2527/1992.7082431x

Nikvand, A.A., Rashnavadi, M. and Tabandeh, M.R., 2018. A study of pica in cattle in Iran. Journal of Veterinary Behavior-Clinical Applications and Research 23: 15–18. https://doi.org/10.1016/j.jveb.2017.10.006

Nogalski, Z., Pogorzelska-Przybylek, P., Sobczuk-Szul, M. and Purwin, C., 2019. The effect of carcase conformation and fat cover scores (EUROP system) on the quality of meat from young bulls. Italian Journal of Animal Science 18(1): 615–620. https://doi.org/10.1080/1828051X.2018.1549513

Przybylak, A., Boniecki, P., Koszela, K., Ludwiczak, A., Zaborowicz, M., Lisiak, D., Stanisz, M. and Slosarz, P., 2016. Estimation of intramuscular level of marbling among Whiteheaded Mutton Sheep lambs. Journal of Food Engineering 168: 199–204. https://doi.org/10.1016/j.jfoodeng.2015.07.035

Qi, M.S., Wang, T., Chen, R., Wang, C. and Ao, C., 2017. Effects of flavonoids from *Allium mongolicum* Regel on growth performance and growth-related hormones in meat sheep. Animal Nutrition 3(1): 33–38. https://doi.org/10.1016/j.aninu.2017.01.003

Qiao, M., Fletcher, D.L., Smith, D.P. and Northcutt, J.K., 2001. The effect of broiler breast meat color on pH, moisture, water-holding capacity, and emulsification capacity. Poultry Science 80(5): 676–680. https://doi.org/10.1093/ps/80.5.676

Santos, V.A.C., Silva, A.O., Cardoso, J.V.F., Silvestre, A.J.D., Silva, S.R., Martins, C. and Azevedo, J.M.T., 2007. Genotype and sex effects on carcass and meat quality of suckling kids protected by the PGI "Cabrito de Barroso." Meat Science 75(4): 725–736. https://doi.org/10.1016/j.meatsci.2006.10.003

Shee, C.N., Lemenager, R.P. and Schoonmaker, J.P., 2016. Feeding dried distillers grains with solubles to lactating beef cows: impact of excess protein and fat on cow performance, milk production and pre-weaning progeny growth. Animal 10(1): 55–63. https://doi.org/10.1017/S1751731115001755

Swiatkiewicz, M., Olszewska, A., Grela, E.R. and Tyra, M., 2021. The effect of replacement of soybean meal with corn dried distillers grains with solubles (cDDGS) and differentiation of dietary fat sources on pig meat quality and fatty acid profile. Animals (Basel) 11(5): 1277. https://doi.org/10.3390/ani11051277

Wang, B., Luo, Y., Wang, Y., Wang, D., Hou, Y., Yao, D., Tian, J. and Jin, Y., 2021. Rumen bacteria and meat fatty acid composition of Sunit sheep reared under different feeding regimens in China. Journal of the Science of Food and Agriculture 101(3): 1100–1110. https://doi.org/10.1002/jsfa.10720

Wang, B., Yang, L., Luo, Y., Su, R., Su, L., Zhao, L. and Jin, Y., 2018. Effects of feeding regimens on meat quality, fatty acid composition and metabolism as related to gene expression in Chinese Sunit sheep. Small Ruminant Research 169: 127–133. https://doi.org/10.1016/j.smallrumres.2018.08.006

Wang, W., Li, J., Zhang, H., Wang, X., Fan, J. and Zhang, X., 2019. Phenolic compounds and bioactivity evaluation of aqueous and methanol extracts of *Allium mongolicum* Regel. Food Science & Nutrition 7(2): 779–787. https://doi.org/10.1002/fsn3.926

Wheeler, T.L., Cundiffm L.V. and Kochm R.M., 1994. Effect of marbling degree on beef palatability in Bos taurus and Bos indicus cattle. Journal of Animal Science, 72(12), 3145–3151. https://doi.org/10.2527/1994.72123145x

Xie, H.D., Bu, L.J., Zhong, Z.Z., Huang, Y., Peng, X.W. and Li, D.J., 2016. Effects of sorghum distillers dried grains with solubles on the carcass characteristics and muscle quality of China Micro Duck drakes aged from 4 to 8 weeks. Poultry Science 95(11): 2633–2639. https://doi.org/10.3382/ps/pew166

Yang, Y., Shen, Y., Pan, Y., Xia, P., Zhang, D., He, Z., Yang, J., Li, H. and Lu, J., 2019. Effects of dietary sorghum dried distiller's grains with solubles on growth performance, diet nutrient digestibility, carcass characteristics and immunity in growing rabbits. Journal of Animal Physiology and Animal Nutrition 103(1): 363–369. https://doi.org/10.1111/jpn.13008

Yaxing, Z., Erdene, K., Changjin, A., Zhibi, B., Hongxi, D., Zejun, F., Umair, A. and Chen, B., 2021. Effects of *Allium mongolicum* Regel and its extracts supplementation on the growth performance, carcass parameters and meat quality of sheep. Italian Journal of Animal Science 20(1): 1899–1908. https://doi.org/10.1080/1828051X.2021.1971572

Zhang, M., Guo, Y., Su, R., Corazzin, M., Li, J., Huang, H., Zhang, Y., Yao, D., Su, L., Zhao, L. and Jin, Y., 2022. Effects of physical exercise on muscle metabolism and meat quality characteristics of Mongolian sheep. Food Science & Nutrition 10(5): 1494–1509. https://doi.org/10.1002/fsn3.2768

Zhang, Y., Luo, H., Chen, Y., Yan, L., Chang, Y., Jiao, L. and Liu, K., 2013. Effects of liquorice extract on the pH value, temperature, drip loss, and meat color during aging of *Longissimus dorsi* muscle in Tan sheep. Small Ruminant Research 113(1): 98–102. https://doi.org/10.1016/j.smallrumres.2013.03.008

Supplementary

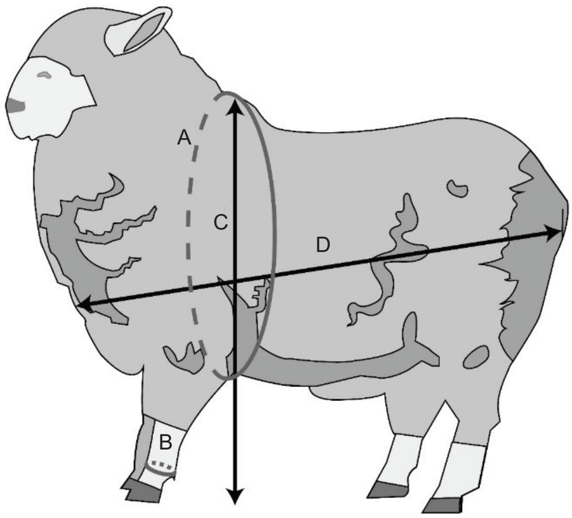

Figure S1. Determination of body height, body length, bust circumference, and canal bone circumference in lamb. A is bust circumference, B is canal bone circumference, C is body height, and D is body length.

Table S1. Composition and nutrient levels of the basal diets.

Items	Content
Corn, %	52.3
Soybean meal, %	15.3
Naked oats, %	10.9
Premix, %	0.9
Complete feed, %	16
Chloride sodium, %	2
Baking soda, %	2.6
Crude protein, %	14.6
Neutral detergent fiber, %	37.2
Calcium, %	0.57
Phosphorus, %	0.28
Digestible energy in CON group, MJ/kg	12.41
Digestible energy in AMR group, MJ/kg	12.40
Digestible energy in DGS group, MJ/kg	12.43

Table S2. Pork marbling scoring standard.

Grading Criteria	Score
No marble-like structure	1 point
Indistinct marble-like structure	2 points
Marbled but not prominent	3 points
The marble-like structure is more pronounced	4 points
Reasonable intermuscular fat, obvious marbling	5 points

Table S3. Confusion matrix.

	CON	AMR	DGS	Class error
CON	10	–	–	0
AMR	–	10	–	0
DGS	–	–	10	0

OOB estimate of error rate: 0%

Table S4. Effect of dietary supplementation with yeast-fermented distiller's grains and *Allium mongolicum* Regel powder on the carcass characteristics of lambs.

Items	Treatment			SEM	P
	CON	AMR	DGS		
Carcass weight, kg	17.71	18.95	18.1	0.4350	0.5066
Bone weight, kg	4.14	4.52	4.24	0.0774	0.1092
Meat weight, kg	13.64	14.3	14.02	0.3399	0.7435
Head weight, kg	1.96	1.98	1.96	0.0336	0.9654
Hoof weight, kg	0.82	0.82	0.81	0.0093	0.8902
Fur weight, kg	3.03	3.08	3.12	0.0241	0.3122
Dressing percentage, %	44.84^{b}	46.40^{a}	44.88^{b}	0.2641	0.0169
Net meat rate, %	34.42^{b}	46.32^{a}	37.82^{b}	1.3901	0.0003
Bone rate, %	23.27	23.95	23.27	0.4897	0.8176
Bone-to-meat ratio	3.33	3.15	3.34	0.0423	0.1001
Backfat thickness, cm	0.60	0.60	0.66	0.0179	0.2986
Cross-sectional area of loin eye muscle, cm^2	22.52	22.75	22.08	0.2671	0.6007
Rib meat thickness, cm	1.92	1.77	1.94	0.0471	0.2599

^{a,b}Means within a row with no common superscripts are significantly different (P < 0.05). SEM: standard error of measurement.

Table S5. Effects of yeast-fermented distille's grains and *Allium mongolicum* Regel powder on meat quality.

Items	Treatment			SEM	P
	CON	AMR	DGS		
pH_{45min}	6.58[b]	6.79[a]	6.75[ab]	0.0366	0.0341
pH_{24h}	5.77	5.77	5.74	0.0279	0.9068
Cooking loss, %	45.89	41.95	43.61	0.7675	0.0896
Drip loss, %	2.73[a]	2.47[b]	2.68[a]	0.0291	0.0001
Marbling score	2.01[b]	3.50[a]	1.52[b]	0.1770	<0.0001
Total meat weight, kg	12.35	14.29	14.00	0.4321	0.1395
First-class meat weight, kg	3.48[b]	4.45[a]	4.21[a]	0.1092	0.0001
Second-class meat weight, kg	5.95	6.33	6.32	0.2270	0.7483
Third-class meat weight, kg	1.53	1.71	1.87	0.0624	0.0838
First-class meat weight ratio, %	28.56	31.06	30.24	0.4454	0.0608
Second-class meat weight ratio, %	45.30	45.31	45.09	0.3783	0.967
Third-class meat weight ratio, %	13.59[a]	11.78[b]	13.34[ab]	0.3125	0.0308

[a,b]Means within a row with no common superscripts are significantly different ($P < 0.05$). SEM: standard error of measurement.

Table S6. Effects of different feeds on economic benefits of ASH lamb.

Items	Treatment		
	CON	AMR	DGS
Dry matter intake, kg/d	22.05	22.75	22.95
Diet cost, ¥/d×body	13.09	15.74	12.76
Average meat production, g/d	130.6	142.9	140.0
Meat production cost, ¥/g	0.1002	0.1101	0.0911
Mutton price, ¥/kg	111.2	119.6	111.2
Gross output value, ¥/d	12.51	17.09	15.57
Benefit, ¥/d	1.43	1.35	2.81

Diet cost: The feed prices used to calculate the dietary cost of different groups are: premix = 5.12 ¥/Kg, full price feed = 4.4 ¥/Kg, corn = 1.65 ¥/Kg, soybean meal = 2.6 ¥/Kg, naked oat=1 ¥/Kg, sodium chloride=0.3 ¥/Kg, baking soda=1.2 ¥/Kg, according to the formula in Table S1, the basic TMR=5.94 ¥/Kg; Allium mongolicum Regel powder=80 ¥/ Kg, yeast-fermented distiller's grains=4 ¥/Kg. Among them, the addition amount of Allium mongolicum Regel powder in the AMR group was 30g/piece/day; the substitution amount of the yeast-fermented distiller's grains in the DGS group was 30%.