Effects of Allium mongolicum Regel and its extracts supplementation on the growth performance, carcass parameters and meat quality of sheep

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ABSTRACT

The objective of this study was to investigate the effects of Allium mongolicum Regel (AM) and AM extracts on the growth performance, carcass parameters and meat quality of sheep. Forty sheep were randomly divided into four groups. The groups consisted of CON (basal diet), AM water extract (AWE; basal diet + 3.4 g/sheep/day AWE), AM ethanol extract (AEE; basal diet + 2.8 g/sheep/day AEE) and AM (basal diet + 10 g/sheep/day AM). The average daily gain (ADG) was improved (p < .05) and feed conversion ratio (FCR) was decreased (p < .05) in AWE, AEE and AM compared to CON. The loin eye area (LEA) and intramuscular fat (IMF) percentage were improved (p < .05) and cooking loss (CL) was decreased (p < .05) in AM, AWE and AEE compared to CON. The water holding capacity (WHC) was improved (p < .05) in AM and AWE compared to CON. The Warner–Bratzler shear force (WBSF) was decreased (p < .05) in AWE and AEE compared to CON. The levels of R polyunsaturated fatty acid (R PUFA) was increased (p < .05) and R saturated fatty acids (RSFA) was decreased (p < .05) in AM, AWE and AEE compared to CON. The levels of C16:0 and n6/n3 ratio were decreased (p < .05) and levels of Δ9-desaturase C16 and elongase enzymatic activity were improved (p < .05) in AWE and AEE compared to CON. In conclusion, supplementation with AM and AM extracts could increase the growth performance, carcass quality traits and some healthier fatty acids.

HIGHLIGHTS

• Allium mongolicum Regel extracts increased average daily gain and decreased feed conversion ratio, improves carcass parameters in sheep.
• Allium mongolicum Regel extracts increased fat content in the Longissimus dorsi muscle.
• Allium mongolicum Regel extracts had beneficial effects on the fatty acid composition in the Longissimus dorsi muscle.

Introduction

A number of antibiotics, such as ionophores (monensin), are commonly added to animal feed to improve performance by killing pathogenic bacteria in addition to preventing diseases (Bedford 2000). There have been increasing public and scientific concerns about antibiotic residues in animal products and antibiotic-resistant pathogenic bacteria. As a result, the use of antibiotics and ionophores as growth-promoting agents has been banned by the European Union (Schaberle and Hack 2014), and these circumstances have necessitated the need for the establishment of plant extracts (phytobiotics) as alternatives to antibiotics used in the diets of animals (Samolińska et al. 2018).

Among the various phytobiotics, Allium plants (garlic, shallot, onion, chive, leek) have been proposed as potential additives that could improve the productive performance and meat quality of animals (Wioletta et al. 2019). Aditya et al. (2016) found that broiler chicks provided with a 7.5 g of onion extracts per kilogram of diet had increased carcass weight. In ruminants, studies have reported that the inclusion of garlic leaf...
extracts increased the dry material intake (DMI) and the dressing percentage (DP) and concurrently increased the contents of crude protein in mutton from sheep (Redoy et al. 2020). It was also known that directly feeding garlic powder extract increased average daily gain (ADG) and feed conversion ratio (FCR) in West African Dwarf male sheep (Adegun et al. 2017).

*Allium mongolicum* Regel (AM) is a typical Allium plant that is widely cultivated in the desert and steppe of northern China (Wang et al. 2014). AM is a prized forage plant since it provides rich nutrients and the contents of protein, fat, flavonoids, polysaccharides, minerals, essential trace elements and other components are higher than those of *Leymus chinensis* and ryegrass steppe plants (Huang et al. 2011). The positive or even therapeutic effects of biologically active compounds in AM in ruminants have been reported by many authors (Xie et al. 2020; Mu et al. 2017). Our previous research explored the use of flavonoids from AM, which reportedly increase the intramuscular fat (IMF), lean meat yield, and cooking loss (CL) in the *longissimus dorsi* muscle of lambs (Wang et al. 2018).

Du et al. (2019) found that sheep provided with AM extract residues (10 g/sheep/day) had increased ADG. Moreover, previous study reported that AM water extract (AWE) and AM ethanol extract (AEE) have higher phenolic contents and flavonoid contents (Wang et al. 2019).

Meat from ruminant animals can be a viable dietary source of bioactive fatty acids, including monounsaturated fatty acids (MUFAs), polyunsaturated fatty acids (PUFAs) and conjugated linoleic acids (CLAs) (Gu et al. 2019). However, ruminant meat also contains high levels of trans fatty acids (TFAs) and saturated fatty acids (SFAs), which are linked to an increased risk of atherogenic plaque on arteries of meat consumers and cardiometabolic diseases in humans (Mcafee et al. 2010). Thus, increasing the quantity of unsaturated fatty acids (UFAs) and CLAs and decreasing the quantity of TFAs and SFAs would result in higher-quality meat. Flavonoids from AM have been documented to have favourable effects on the fatty acid profile. For instance, flavonoids from AM supplementation increased the contents of PUFAs, MUFAs, and eicospentaenoic acid, exhibited a better n-6/n-3 ratio and decreased the contents of C18:0 in growing lambs (Wang et al. 2018).

We hypothesised that the positive attributes of AM and AM extracts would improve the performance of sheep. To test this hypothesis, we examined the effect of supplementation with AM and AM extracts on growth performance, carcass parameters and meat quality in sheep.

**Material and methods**

**Preparation of AM and AM extracts**

AM was purchased from Alashan Haohai Biotechnology Co., Ltd. (Alashan League, Inner Mongolia, China). Fresh AM was drastically cleaned by distilled water, and dried in 65 °C, then pulverised and screened by 80 mesh sieve. To obtain AWE, AM was mixed with distilled water at a ratio of 1:20 (v/v) and put in an oven at 80 °C for 8 h. Freeze dried in a freeze dryer, then pulverised. To obtain AEE, AM was mixed with 75% ethanol at a ratio of 1:5 (v/v). After sonication, the supernatant was obtained by vacuum pumping, concentrated by using a rotary evaporator, freeze dried in a freeze dryer, and then pulverised.

Previous study investigated that AWE having phenolic 10.20 gallic acid equivalent (GAE)/g DM and flavonoid 4.02 quercetin equivalent (QE)/g DM, AEE having phenolic 7.50 GAE/g DM and flavonoid 3.13 QE/g DM and AM having phenolic 9.48 GAE/g DM and flavonoid 3.92 QE/g DM (Zhao et al. 2010; Wang et al. 2019). Furthermore, Ding et al. (2021) indicated AWE and AEE also having organic acids, nucleotides, amino acids and their derivatives, and hydroxycinnamoyl derivatives, which are the secondary substances. Maisashvili et al. (2009) found AM also having alka-loids, essential oils and organic acids.

**Animals, experimental design, diet**

Forty healthy, male, Dorper × small-tailed Han cross-bred sheep, with mean BW (± SD) of 37.1 ± 0.5 kg and 4.5 months of age. All sheep were randomly allocated into four dietary groups with 10 replicates each: (1) a basal diet as the control group (CON, n = 10); (2) the basal diet supplemented with AWE at 3.4 g/sheep/day as the AWE group (AWE, n = 10); (3) the basal diet supplemented with AEE at 2.8 g/sheep/day as the AEE group (AEE, n = 10); and (4) the basal diet supplemented with AM at 10 g/sheep/day as the AM group (AM, n = 10). The dose of AM (10 g/sheep/day) was based on our previous study (Du et al. 2019). The dose of AWE (3.4 g/sheep/day) and AEE (2.8 g/sheep/day) in the diet were calculated according to their extraction rates (34% and 28%, respectively) from AM. The diet was formulated to meet the sheep requirements for maintenance, and an average daily gain of 150 g was stipulated (NRC 2012). The composition and nutrient levels of the diet are shown in Table 1.
The sheep were given free access to drinking water. One hundred grams concentrate of the basal diet was mixed with 10 g AM, 3.4 g AWE or 2.8 g AEE, respectively, and divided each mixture into two equal amounts at 07:00 h and 18:00 h, then they were provided for twice daily to ensure that the supplements were completely consumed by each sheep. The experiment lasted for 75 days, including a 15-day for adaptation and a 60-day for the experimental feeding period. Samples of diet were measured for dry matter (DM; method 934.01), crude protein (CP; method 920.87), ether extract (EE; method 920.85), Calcium (Ca; method 985.35) and phosphorus (P; method 986.24) according to the AOAC (1990). In accordance with Van Soest et al. (1991), the contents of neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined. NDF and ADF analysis were performed using α-amylase and the ash residue was included.

**Growth, slaughter, carcass parameters and meat sample collection**

The amounts of feed offered and refused were quantified daily throughout the experiment to calculate DMI. The amount of feed was adjusted daily, with the acceptable refusal amount corresponding to 10% of the total amount supplied to ensure ad libitum intake. Sheep were weighed at the start of the experiment (initial weight) and at the end of the experiment (final weight) to calculate ADG and FCR (DMI: ADG). All sheep were slaughtered in the local abattoir using halal methods (Wang et al. 2018). Before slaughtering, sheep were fasted for 12 h with free access to water. Sheep were weighed just before slaughter (SBW). The bodies were bleed, skinned and gutted (except kidney and the adipose tissue surrounding of kidney) and stored at 4 °C for 24 h. Then, carcasses were weighed (CW). The DP was calculated as: DP = 100 × CW/SBW. Loin eye area (LEA) was measured on the longissimus dorsi muscle between the 12th and 13th ribs. Muscle pH was analysed with a pH metre CPU (Mettler-Toledo International, Inc., Columbus, OH) at 45 min (pH 45 min) and 24 h (pH 24 h) after slaughter. Part of the longissimus dorsi muscle was cut into six slices (2.5 cm thick) and randomly assigned for CL, Warner-Bratzler shear force (WBSF) and water holding capacity (WHC) determination. The other samples of the longissimus dorsi muscle were trimmed of subcutaneous fat before homogenisation and then vacuum-packed and refrigerated at −20 °C for approximately 60 days until muscle chemical composition and fatty acid determinations.

**Muscle chemical composition**

The moisture, ash and protein contents were determined according to AOAC (1990). The IMF content was determined using a technique described by Zhang (Zhang et al. 2014). CL and WBSF were performed as described by Wheeler et al. (1993). Samples of the longissimus dorsi muscle were weighed (80 ± 2 g), placed in plastic bags and cooked in a preheated oven at 75 °C for 20 min. Then, the bags were placed under running water for 15 min. Samples were weighed again to estimate the percentage of CL. Four subsamples with a cross section of 1 cm² were then cut parallel to the muscle fibres, arranged in Warner-Bratzler Shear-WBF equipment (TA-XT plus, Stable Micro System, Surrey, UK). WBSF was recorded in Newton values (N/cm²). The WHC was measured as described by Miller and Groninger (1976).

### Table 1. Composition and nutrient levels of basal diets of the sheep (DM basis).

| Ingredients          | Content, % |
|----------------------|------------|
| Alfalfa              | 27.78      |
| Corn                 | 19.25      |
| Whole corn silage    | 15.52      |
| Gourd seed skin      | 12.15      |
| DDGSa                | 4.33       |
| Flax seed meal       | 4.62       |
| Sunflower seed meal  | 6.09       |
| Wheat bran           | 4.29       |
| Red dates            | 1.68       |
| Limestone            | 1.48       |
| CaHPO₄               | 0.69       |
| NaCl                 | 0.72       |
| Premixb              | 1.40       |
| Total                | 100.00     |

| Nutrient levels      |       |
|----------------------|-------|
| DE (MJ/kg)           | 16.83 |
| DM%                  | 91.20 |
| CP%                  | 15.32 |
| ADF%                 | 29.69 |
| NDF%                 | 50.98 |
| EE%                  | 3.09  |
| Ca%                  | 1.02  |
| P%                   | 0.55  |
| Fatty acid (g/100 g FAMEe) |  |
| C12:0                | 1.02  |
| C14:0                | 0.39  |
| C16:0                | 23.4  |
| C18:0                | 5.35  |
| C18:1c-9             | 16.8  |
| C18:2 (c-9, c-12)    | 41.52 |
| C18:3 (c-9, c-12, c-15) | 12.79 |

aDistillers Dried Grains with Soluble.
bThe premix provided the following per kilogram of diets: 25 mg iron (as FeSO₄), 29 mg zinc (as ZnSO₄), 8 mg copper (as CuSO₄), 30 mg manganese (as MnSO₄), 0.04 mg iodine (as KI), 0.1 mg cobalt (as CoSO₄), 3200 IU vitamin A, 1200 IU vitamin D, and 20 IU vitamin E.
cDigestible energy was a calculated value, whereas the others were measured values.
dDE: digestible energy; DM: dry matter; CP: crude protein; ADF: acid detergent fibre; NDF: neutral detergent fibre; EE: ether extract; Ca: Calcium; P: phosphorus.
eFAME: fatty acid methyl ester.
Fatty acid profile

The fatty acid composition in the diet and *longissimus dorsi* muscle were analysed by extraction of total lipids from 5.0 g of the samples using chloroform/methanol (2/1; v/v) for a period of five minutes, according to Folch et al. (1957). Lipids (25 mg) were extracted to fatty acid methyl esters by base-catalysed transesterification (Christie 1982) adding 2 mL of 0.5 M of sodium methoxide and 2 mL of hexane containing 1 mg/mL methyl heneicosanoate as an internal standard. One microliter of fatty acid methyl esters pipetted from the supernatant was quantified by Shimadzu 2010 Plus gas chromatography (GC, Shimadzu, Kyoto, Japan) equipped with a flame ionisation detector a fused silica capillary column (TR-CN100, 60 m in length, 0.25 mm i.d., and 0.20 μm film thickness; Teknokroma, Barcelona, Spain). The initial oven temperature was 45°C for 4 min, increased to 175°C at 13°C/min, held at 175°C for 27 min, increased to 215°C at 4°C/min and then maintained at 215°C for 35 min. The injector and detector temperatures were maintained at 250°C and 260°C. Helium was used as the carrier gas (flow rate of 30 mL/min). The identification of fatty acid methyl esters was accomplished by the retention times of an authentic standard. The concentration of individual fatty acid was expressed as the percentage of total FA methyl ester quantified. The activity of Δ9-desaturase (C16, C18) and elongase enzymes were estimated using the equations proposed by Smet et al. (2004) and the following equations: Δ9-desaturase C16 = [(C16:0 + C16:1c-9)] x 100 and Δ9-desaturase C18 = [(C18:0 + C18:1c-9) / (C16:0 + C16:1c-9 + C18:0 + C18:1c-9)] x 100.

Statistical analysis

One-way analysis of variance (ANOVA) was used to test the effects of dietary treatments on growth performance, carcass traits, meat quality and composition of fatty acids in each treatment by SAS (v 9.0) for 4 the treatments (SAS Inst. Inc., Cary, NC). The experimental unit was individual sheep. Differences among means were tested using Tukey’s multiple range tests. The results are presented as the least squares mean values and SEM. Probability values of \( p \leq 0.05 \) were declared as significant and the values of \( p \leq 0.10 \) were declared as trend.
Table 4. Effects of Allium mongolicum (AM) and extracts on pH and physical–chemical parameters in longissimus dorsi muscle of sheep.

| Treatments | CON | AM | AWE | AEE | SEM | p Value |
|------------|-----|----|-----|-----|-----|---------|
| pH<sub>45min</sub> | 6.41 | 6.57 | 6.45 | 6.42 | 0.378 | .004 |
| pH<sub>90min</sub> | 6.69 | 6.70 | 6.72 | 6.76 | 0.093 | .673 |
| CL (%) | 23.69<sup>a</sup> 21.72<sup>b</sup> 20.25<sup>b</sup> 21.33<sup>b</sup> | 0.623 | .004 |
| WHC (%) | 72.83<sup>b</sup> 76.38<sup>a</sup> 75.13<sup>–</sup> 74.37<sup>b</sup> | 0.980 | .038 |
| WBSF (N) | 45.10 Ab 43.40<sup>ab</sup> 42.07<sup>b</sup> 41.78<sup>b</sup> | 0.978 | .034 |
| Moisture (g/100 g) | 74.94 | 73.34 | 74.04 | 74.17 | 0.607 | .150 |
| Protein (g/100 g) | 19.09 | 21.07 | 20.47 | 19.74 | 0.720 | .105 |
| IMF (g/100 g) | 6.36<sup>a</sup> 6.65<sup>b</sup> 6.94<sup>a</sup> 6.70<sup>b</sup> | 0.093 | .002 |
| Ash (g/100 g) | 5.65 | 6.01 | 5.85 | 5.82 | 0.144 | .181 |

<sup>a</sup>Treatments: CON = basal diet; AM = basal diet supplemented with 10 g/sheep/day of Allium mongolicum Regel; AWE = basal diet supplemented with 3.4 g/sheep/day Allium mongolicum Regel water extract; AEE = basal diet supplemented with 2.8 g/sheep/day of Allium mongolicum Regel ethanol extract.  
<sup>b</sup>CL: Cooking loss; WHC: Water holding capacity; WBSF: Warner–Bratzler shear force; IMF: instramuscular fat.

Table 5. Effects of Allium mongolicum (AM) and extracts on fatty acids composition and ratios in longissimus dorsi muscle of sheep (%).

| Treatments | CON | AM | AWE | AEE | SEM | p Value |
|------------|-----|----|-----|-----|-----|---------|
| ∑SFA | 40.64<sup>a</sup> 38.28<sup>b</sup> 39.06<sup>b</sup> 38.26<sup>b</sup> | 0.681 | .025 |
| ∑MUFA | 49.42 | 49.02 | 50.20 | 49.55 | 5.119 | .996 |
| ∑PUFA | 10.93<sup>a</sup> 13.18<sup>b</sup> 12.79<sup>a</sup> 12.92<sup>b</sup> | 0.582 | .017 |
| ∑MUFA | 62.32<sup>a</sup> 62.14<sup>b</sup> 62.63<sup>a</sup> 62.27<sup>a</sup> | 0.716 | .039 |
| ∑PUFA | 0.31 | 0.34 | 0.35 | 0.35 | 0.040 | .013 |
| ∑n6/n3 ratio | 1.65<sup>a</sup> 1.54<sup>b</sup> 1.49<sup>a</sup> 1.46<sup>b</sup> | 0.061 | .042 |
| Δ<sup>9</sup>-desaturase C16 | 9.48<sup>b</sup> 10.21<sup>a</sup> 10.90<sup>a</sup> 10.87<sup>b</sup> | 0.352 | .011 |
| Δ<sup>9</sup>-desaturase C18 | 70.58<sup>a</sup> 71.36<sup>a</sup> 72.49<sup>a</sup> 70.83<sup>a</sup> | 0.565 | .040 |
| Elongase | 0.72<sup>a</sup> 0.73<sup>a</sup> 0.75<sup>b</sup> 0.76<sup>b</sup> | 0.011 | .023 |

<sup>a</sup>Treatments: CON = basal diet; AM = basal diet supplemented with 10 g/sheep/day of Allium mongolicum Regel; AWE = basal diet supplemented with 3.4 g/sheep/day Allium mongolicum Regel water extract; AEE = basal diet supplemented with 2.8 g/sheep/day of Allium mongolicum Regel ethanol extract.  
<sup>b</sup>Different lower case letter superscripts mean significant difference (p < .05).

Fatty acid

The effects of AM and AM extracts on the fatty acid composition in the longissimus dorsi muscle are shown in Table 5. Dietary supplementation with AM and its extracts increased (p < .05) the composition of C14:0, UFA, PUFA and decreased (p < .05) the composition of SFA compared to CON. Dietary supplementation with AM and AEE decreased (p < .05) the composition of C18:0, but there was no difference (p > .05) between AWE and CON. Dietary supplementation with AM and its extracts increased (p < .05) the composition of C17:1c-9 compared to CON and the value was higher (p < .05) in AWE than in AM and AEE. Dietary supplementation with AM and its extracts decreased (p < .05) the composition of C18:3n-6 compared to CON and the values were higher (p < .05) in AWE and AEE than in AM. Dietary supplementation with AWE and AEE decreased (p < .05) the composition of C16:0 and n6/n3 ratio and increased (p < .05) the composition of C21:0 compared to CON, but there was no difference (p > .05) between AM and CON. Dietary supplementation with AM and AEE increased (p < .05) the composition of C18:1t-9, C18:1t-10 and C18:1t-11 compared to CON, but there was no difference (p > .05) between AWE and CON. The inclusion of dietary AWE and AEE improved (p < .05) the enzymatic activity of Δ<sup>9</sup>-desaturase C16 and elongase, but there was no difference (p > .05) between AM and CON. Compared with CON, the inclusion of dietary AM and AWE improved (p < .05) the enzymatic activity of Δ<sup>9</sup>-desaturase C18, but there was no difference (p > .05) between AEE and CON.

Discussion

Performance, carcass and physical–chemical parameters

In this study, the animal growth performance parameters excluding DMI were substantially changed in the
groups receiving AM and AM extracts. Consistent with our results, Mu et al. (2017) noted an increased value of ADG and a decreased FCR in sheep receiving 11–33 mg/kg flavonoids from AM in their diets. In a recent study, Du et al. (2019) also observed that inclusion of AM extract residue (10 g sheep⁻¹ d⁻¹) to the diets of sheep improved ADG. In agreement with these results, changed growth performance parameters were also observed by Lin et al. (2011), in which dietary polysaccharides from AM addition increased ADG and decreased FCR in sheep. In turn, Ding et al. (2021) noted that inclusion of AWE and AEE which contain organic acids, nucleotides, amino acids and their derivatives, and hydroxycinnamoyl derivatives, to the diets of lambs had no effect on improvement of ADG and FCR. Based on the abovementioned facts, Mu et al. (2017) observed the improvement in ADG could be attributed to an increasing circulating insulin-like growth factor 1 (IGF-1) levels in sheep by flavonoids from AM supplementation. It has been reported that IGF-1 is positively associated with growth (Hossner et al. 1997). Another explanation for increasing ADG is the positive effects of AM on nutrient digestibility and antioxidant activity (Li et al. 2019).

One of the most significant meat quality characteristics requiring evaluation is the ultimate pH of the carcass, as it is related to changes in meat quality indicators such as WHC. Variation in pH may be related to the glycogen content in muscles. The pH of muscle decreases continuously, resulting in the polypeptide chain of protein molecules closing up and the molecular spacing shrinking, and then the water molecules in muscle are crowded out (Chun et al. 2020). For most ruminants, a pH₂₄₉ within a range between 5.5 and 5.8 is considered appropriate (de Abreu et al. 2019). In the available literature, Ding et al. (2018) reported only an inconsiderable effect of the addition of AM leaves (0.46% DM) to sheep diets on increasing the pH₂₄₉ of carcasses. In the present study, an average pH value of 5.71 was observed, indicating that there was likely to be no preslaughter stress, which could be concerned with the muscle glycogen stores, leading to lactic acid accumulation and consequently decreased pH value (Bouton et al. 1971). This was in agreement with previous studies in lambs because the addition of flavonoids from AM has positive effects on carcass parameters (Wang et al. 2018).

Gilmour et al. (1994) stated that LEA is positively related to the carcass lean meat rate. Interestingly, dietary supplementation with AM extracts in the present study increased the LEA of sheep, indicating that AM extracts might improve the lean meat yield. The WBSF of muscle can be affected by many factors, including age and breed of animal, IMF, type of muscle, level of nutrition, stress at slaughter, and cooking operation. Wojtysiak (2013) mentioned that the change in IMF during the growth of animals was a vital factor affecting the WBSF. Therefore, the positive effect of the AM and AM extract addition on the WBSF in sheep might be associated with its effect on increasing the fat contents in the longissimus dorsi muscle. Similar results were obtained by Realini et al. (2017) when garlic was included in the diet of lambs. However, Ding et al. (2021) revealed the addition of AWE and AEE which contain organic acids, nucleotides, amino acids and their derivatives, and hydroxycinnamoyl derivatives, did not modify WBSF in lambs. The WBSF range obtained in this study was below the threshold of <49 that has been formulated for acceptable tenderness in mutton (Chikwanha et al. 2019), indicating that the longissimus dorsi muscle of sheep in our research was acceptable.

In the present study, the addition of AM and AM extracts to the diet of sheep clearly improved the WHC. A similar effect was reported by Wang et al. (2018), who found that an increase in flavonoids from AM (11 mg/kg, 22 mg/kg and 33 mg/kg of the diet) enhanced WHC in lambs. The reason for this phenomenon was that the type of lipids deposited in the muscle of the AM and AM extract groups may have altered the permeability of the muscle fibre membrane, leading to the post-mortem retention of a larger volume of water. The WHC is significant in technology and gastronomics, as it can contribute flavour and ameliorates during the cooking process. It also plays a role in maintaining tenderness and juiciness, several advantages that are highly accepted by consumers. The present study also demonstrated an increasing effect of AM and AM extracts on CL. These results may be related to factors such as AM and AM extracts, cooking methods, cooking temperatures and rates, muscle fibre length, sample size and dimension (Chikwanha et al. 2019).

**Fatty acid profile**

Fatty acid profiles of meat were vital factors determining nutritional quality (Fiems 2012). The fatty acid composition in ruminant meat can be altered by the action of lipogenic enzymes (Raes et al. 2004). Zhang et al. (2019) found that in AM extracts, the expression of the gene encoding sterol regulatory element-binding protein (SREBP-1c), which is responsible for
positively regulating the expression of genes participating in FA elongation, is increased. Therefore, the higher elongase activity shown in sheep receiving AWE and AEE might result from the increased expression of SREBP-1c. The enhancement in elongase activity illustrated the reduction percentage of C16:0 in the longissimus dorsi muscle of sheep fed AWE and AEE, since elongase plays an important role in adding two carbon atoms to C16:0, generating C18:0 (Lara et al. 2018). It would be reasonable to expect an increased proportion of C18:0 in the AWE and AEE. However, the concentration of C18:0 in the present study was decreased in AM and AEE compared with the control diet.

Apart from being affected by the action of lipogenic enzymes, the fatty acid composition in ruminant meat can be altered by ruminal biohydrogenation process. Comprehending the ruminal biohydrogenation of ingested fatty acids and confirming the concentrations of fatty acids that are absorbed by the intestine and incorporated into the tissues are crucial to exploring lipid metabolism and the quality of ruminant meat and milk. Ruminal biohydrogenation involves PUFAs, including C18:2 (c-9, c-12) and C18:3 (c-9, c-12, c-15), which are gradually isomerised and saturated. In this pathway, stearic acid is the final product. Thus, garlic extracts have been added to lactating goat diets to inhibit ruminal biohydrogenation by the Butyrivibrio community in this process, which was beneficial to greater flows of C18:1c-9, C18:1t-10 and C18:3 (c-9, c-12, c-15) to milk fat (Kholif et al. 2012). The results of this study showed that adding AM and AEE to the diets of sheep resulted in increasing of the percentages of C18:1t-9, C18:1t-10 and C18:1t-11, which are intermediates of PUFA and MUFA biohydrogenation in the rumen. It was revealed the AM and AEE were efficient in modifying biohydrogenation. Because the AM and AEE might restrain the ruminal biohydrogenation process, it would be sensible to promise that the concentration of C18:0 in the longissimus dorsi muscle would be lower in the animals that received AM and AEE than in the control animals. In addition, the lack of significant differences between control and AWE suggested that the effect on the concentration of C18:0 observed with AWE was primarily due to inhibitory ruminal biohydrogenation being equal to the stimulatory expression of elongase gene.

In our study, the lower concentration of C16:0 in the AWE and AEE than in the control sheep was also likely associated with greater expression of Δ9-desaturase C16 activity. Fan et al. (2019) and Zhang et al. (2019) affirmed that animals fed AM extracts showed greater expression of the enzyme Δ9-desaturase. This behaviour explained the higher concentrations of C16:1c-9 in the longissimus dorsi muscle, since this enzyme is necessary for the synthesis of MUFAs (Gu et al. 2019).

Additionally, there were increases in the concentrations of C21:0, ΣPUFA, C17:1c-9, C18:3n-6 and ΣPUFA and decreases in the concentrations of ΣSEA, all of which seemed to have a beneficial effect on human health (Bezerra et al. 2016), in the meat of sheep fed diets containing AM and AM extracts.

The total IMF content, n-6/n-3 ratio fatty acid ratios and ΣPUFA:ΣSFA are generally considered significant when judging the nutritional value of meat (Abdallah et al. 2019). In our study, values from 6.36 to 6.94 g/100 g in IMF of the longissimus dorsi muscle were considered normal for a slaughter between 45 kg and 50 kg (Jonival et al. 2018). In this study, the addition of AM extracts to the diet of sheep clearly modified the n-6/n-3 ratio in meat, and they were within the recommended level for human health (≤4.0, Department of Health 1994). The tendency of ΣPUFA increases was considerable, and they were precursors of different eicosanoids, such as prostaglandins, thromboxanes and leukotrienes, which played a role in cell and metabolic regulators and whose specific functions were of particular attention in the study of cardiovascular diseases. Furthermore, the benefits of its use were associated with its ability to decrease the amount of serum lipids and retain the integrity of the cell membrane (Jonival et al. 2018). A ΣPUFA:ΣSFA ratio for high meat quality of > 0.4 was recommended by Wood et al. (2008), who reported that a ΣPUFA:ΣSFA ratio > 0.15 in sheep was generally considered sufficient. In this study, the mean ratio received for ΣPUFA:ΣSFA was 0.33 and did not differ significantly between treatments. This suggested that dietary supplementation with AM and AM extracts had no negative effect on the quality of lamb meat.

Based on the above discussion, although the AM was included directly in diets and the AM extracts involved a preparation step, with energy, time and solvents costs, AM extracts exerted better effects than that of AM on the growth performance, carcass parameters and meat quality of sheep, which makes the sheep industry obtain more economic benefits and mutton is accepted by more people.

Conclusions

The current experiment demonstrated that adding AM and its extracts in dietary promoted growth
performance by increasing ADG and decreasing FCR, enhanced meat quality by reducing CL in the longissimus dorsi muscle, improved body composition by increasing IMF content and augmented meat nutrition by stimulating the accumulation of PUFA and decreasing SFA. It can be concluded that the AM and AM extracts are alternatives to antibiotics could be beneficial for growth performance, carcass characteristics and meat quality in sheep. Among the three additives, although the extraction processes of AM extracts are complicated, they are more significant to the sheep industry than AM.

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Ethical approval
All procedures carried out in the experiment followed the China Agricultural University Animal Care and Use Committee on Animal Ethics. The protocol was approved by the College of Animal Science of Inner Mongolia Agricultural University.

Disclosure statement
The authors declare that research was conducted with no conflict of interest.

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Data availability statement
The data that support the findings of this study are available from Xu Shan. Restrictions apply to the availability of these data, which were used under licence for this study. Data are available from the Xu Shanshan with the permission of Xu Shan. E-mail: zhaoxing0926@foxmail.com

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