Influence of increasing levels of oregano essential oil on intestinal morphology, intestinal flora and performance of Sewa sheep

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ABSTRACT

The purpose of this experiment was to study the effects of oregano essential oil (OEO) on the performance, intestinal morphology and intestinal flora of fattening Sewa sheep. Sixty 20-month-old Sewa sheep with similar body weights (BWs) and in good health were randomly divided into four groups. The groups were fed a diet containing 0 mg/kg OEO (group A), 150 mg/kg (group B), 300 mg/kg (group C) or 450 mg/kg (group D). Daily gain, slaughter rate and other production performance parameters were analysed in the test sheep (mean ± standard error). Intestinal morphology was analysed by tissue sectioning, and intestinal flora was analysed by 16S rRNA genome sequencing. The indexes, including average daily gain (ADG), slaughter rate, villus length of the small intestine and number of beneficial bacteria in the intestinal flora, in group C were significantly higher than those in the other groups. Supplementation with 300 mg/kg OEO concentrate in the diets can improve the growth performance of Sewa sheep by changing their intestinal morphology and modifying their intestinal flora structure. Conclusively, these encourage to further verifying in practice positive evidence in improving growth performance of OEO supplementation in the diets for Sewa sheep.

HIGHLIGHTS

- Oregano essential oil (OEO) can improve the performance of Sewa sheep by changing the intestinal morphology and regulating the intestinal flora structure.

Introduction

Oregano essential oil (OEO) is globally recognised as a natural feed additive that can promote the growth of livestock and poultry, enhance host health (Zeng et al. 2015) and improve the structure of intestinal flora (Allen et al. 2011; Yan et al. 2017). It can also improve the quality of pork to a certain extent (Hector et al. 2019) and improve the performance and intestinal microflora structure of laying hens (Ri et al. 2017). The antioxidant and bactericidal effects of OEO have been well documented in experiments in various animals (Gopal and Asmita 2014). The main phenolic components in OEO can effectively treat bacterial diseases in the digestive tracts of livestock and poultry, especially those caused by intestinal Escherichia coli, the curative effect on diseases caused by Salmonella is greatest. OEO can also be used to prevent coccidiosis (Paulina et al. 2018). OEO is an antibacterial, growth-promoting additive approved by the Ministry of Agriculture of China. It is prepared as a 10% premix and used as a feed additive. It can promote the growth of animals, promote the digestion and absorption of nutrients, improve the utilisation rate of feed and have a good fattening effect on animals (Alagawany et al. 2018). OEO can be used as a nutritional feed additive for ruminants to improve the performance and feed efficiency of dairy cows and meat animals. OEO can improve the performance of chickens (Botsoglou et al. 2002; Amad et al. 2013; Peng et al. 2016; Ramirez et al. 2021; Zhang et al. 2021; Roofchaee et al., 2011), pigs (Forte et al. 2017; Liang et al. 2017; Cheng et al. 2018; Deng et al. 2018; Jugl-Chizzola et al., 2006), and rabbits (Botsoglou et al. 2004) to achieve the effect of fattening animals. On the Qinghai-Tibet Plateau, the oxygen content is low. This experiment was conducted to compare the effects of dietary OEO supplementation on performance, intestinal morphology and intestinal microorganism of Sewa sheep. An
experiment was carried out in Naqu, Tibet, which has an average elevation of approximately 4800 m. The region experiences long-term hypoxic conditions, a large temperature difference between day and night, and a windy and dry climate that persists throughout the year. However, the effects of OEO as a concentrated supplement on the performance, intestinal flora and microflora structure of Sewa sheep are await further studies.

In this study, we hypothesised that dietary inclusion of OEO would positively alter the villi length and intestinal morphological structure of the ileum, jejunum and duodenum. Therefore, this study aimed to investigate the effects of dietary OEO supplementation on the growth performance.

The purpose of this experiment was to study the effects of OEO supplemented with 0 mg/kg (group A), 150 mg/kg (group B), 300 mg/kg (Group C) and 450 mg/kg (Group D) on the growth performance, slaughter performance, intestinal morphology and intestinal flora of Sewa sheep. Daily weight gain, slaughter rate and production performance of Sewa sheep were analysed. Additionally, the intestinal morphology of Sewa sheep was analysed, and the intestinal flora was analysed by 16S rRNA genome sequencing. Analyses were conducted to explore the effects of OEO on the growth performance, slaughter performance, intestinal morphology and intestinal flora of fattening Sewa sheep; to provide strong support for the fattening of Sewa sheep; and to promote the development of the Sewa sheep industry.

Materials and methods

Animal care

All of the methods used in this study comply with the standards of the institutional guidelines for ethics in animal experimentation (Rule number 86/609/EEC-24/11/86), and all experimental procedures were approved by the Institutional Animal Care and Use Committee of Tibet Agricultural and Animal Husbandry University (Linzhi, China). The institutional certification number is 12540000MB0P013721.

The OEO was purchased from Jiangxi Tianjia Biotechnology Co., LTD., Nanchang, Jiangxi province, China. OEO is the volatile oil component of oregano, a traditional medicine plant (Attia et al. 2017). The effective ingredients of OEO are carvacrol and thymol. The carrier materials include gelatine, sucrose, starch and dextrin. The concentration of carvacrol and thymol in OEO determined by high-performance liquid chromatography (HPLC) was ≥5.5% and ≥0.15%, respectively, in the final OEO purity of 5.65%.

The experiment was conducted at the Sewa Sheep Fattening Base Farm, in Duoerge Village, Pubao Town, Bange County, Naqu City, Tibet Autonomous Region (90°01'63.64 N, 31°39'86.41 E), at an altitude of about 4800 m. In this study, compared with indoor feeding on the Tibetan Plateau, grazing sheep had to endure poor weather and walk long distances climb high mountains for various feedstuff under grazing circumstances. Sixty 20-month-old Sewa sheep with similar body weights (BW) and in good health were randomly divided into four groups. Each group was fed a diet containing 0 mg/kg (OEO, group A), 150 (Group B), 300 (Group C) or 450 (Group D), with three replicates per group and five sheep per replicate. The sheep grazed in the morning and were supplemented with the fodder in the afternoon. Experimental animals were fed in indoor regimes twice a day at 9:00 and 17:00 h and grazed from 12:00 to 16:00 h, respectively, every day. Sheep were adaptive to the experiment diets for 10 d and then fed for 60 d. OEO was sprayed on a carrier and dilute to appropriate amount with carrier step by step, and then stir evenly in premix, then added to the diet. All the experimental diets were prepared every week, packed in covered containers and stored in a dry and well-ventilated storeroom. The basic diet was comprised of pellet feed, which was provided in a semi-open house. The basal diet composition and nutrient levels are shown in the Supplementary information (Table S1) which was formulated to meet the nutritional requirements for growing sheep for 100 g weight gain per day, and the fed amount was adjusted according to the sheep BW. The concentration of digestive energy was calculated from the ingredient values based on the feeding standard for meat-producing sheep and goats in accordance with the China Agricultural Standard (NY/T816, 2004).

Growth performance

All sheep remained in good health and medical intervention was not applied to any sheep during the whole feeding period. The experimental sheep were weighed with an empty stomach in the morning on the sixtieth day of the formal study period, during which the daily feed intake was measured. The growth performance data of each group, such as the average daily gain (ADG), dry matter intake (DMI), feed-to-gain ratio (F/G) were calculated.
Slaughter performance
At the end of the formal study period, five Sewa sheep were randomly selected from each of the four groups for slaughter. Prior to slaughtering, the sheep were fasted for 24 h, and stopped drinking water for 2 h by electrically stunning and exsanguinating were withheld for 24 and 2 h, respectively, before slaughter. The carcass weight, eye muscle area, and slaughter rate were measured immediately after slaughter. The specific determination method of slaughter performance was carried out according to Wang and Tao (2008).

Determination of the morphology and structure of the small intestine in Sewa sheep
The jejunum, ileum and duodenum of three sheep in each experimental group were removed, and three samples from each intestinal segment were obtained. After removal, sections were prepared to observe the height of the villi, depth of the crypts and thickness of the muscle layer. Tissue blocks fixed with 10% formaldehyde were embedded in paraffin to prepare the sections. After haematoxylin-eosin (H.E.) staining, the villus height and crypt depth of the intestine were measured with Image-Pro Plus 6.0 software is (Media Cybernetics, Inc. 1700 Rockville Pike, Suite 240, Rockville, Maryland USA 20852.), and the ratio of the villus height to the crypt height (V/C) was calculated. The specific method with which to assess small intestinal morphology was carried out according to Lu et al. (2020).

Analysis of intestinal flora in Sewa sheep
At the end of the experiment, sheep were slaughtered after 60 d of experimental feeding. Immediately after slaughter, the contents of the small intestine were removed with surgical scissors that had been disinfected with alcohol and were placed in marked tubes, which were then stored in liquid nitrogen and then preserved at –80°C until intestinal flora analysis. Shanghai Personal Biotechnology Co., Ltd. (Shanghai, China) for the 16S rRNA genome sequencing of the intestinal flora. The specific method of intestinal microflora determination was carried out according to Cheng et al. (2018) and Li et al. (2021).

Statistical analysis
The test data were analysed and sorted in Excel, and one-way ANOVA was performed with SPSS version 19.0 (SPSS Institute Inc., Chicago, IL). ANOVA was used for the statistical analysis, and Tukey’s multiple comparison test was used to analyse the results. The test results are expressed as the means ± standard errors to determine the significance of differences. $p < .05$ was considered statistically significant.

Results
Effects of OEO on the growth performance of Sewa sheep
The effects of OEO on the growth performance of Sewa sheep are shown in Table 1. Table 1 shows that the ADG values in the groups supplemented with OEO (groups C and D) were significantly higher than that of the group A ($p < .05$), and the ADG in group C was the highest. In the four experimental groups, the lower the F/G ratio was, the better the feed performance and the more effective the feed was in the experimental sheep. Among the four groups, the F/G ratios in the OEO supplementation groups (groups B–D) were significantly lower than those in group A ($p < .05$), and the F/G ratio in group C was significantly different from that of group A ($p < .05$). The total weight gain in groups B–D was significantly higher than that in group A ($p < .05$), the total weight gain in group C was the highest, but there was no significant difference between groups C and D ($p > .05$). Among the four groups, there was no significant difference in DMI between group A and group B ($p > .05$). The DMI of groups C and D was significantly different from that of groups A and B, but there was no significant difference in the DMI between groups C and D ($p > .05$). There was no significant difference between group C

| Table 1. Effects of OEO on the growth performance of Sewa sheep. |
|---|---|---|---|
| Group | Initial weight (kg) | Final weight (kg) | Total weight gain (kg) | Average daily gain (g) | Feed/gain ratio | Dry matter intake (DMI) |
| Group A | 33.18 ± 0.76$^a$ | 37.20 ± 0.31$^c$ | 4.02 ± 0.30$^b$ | 67.03 ± 0.75$^b$ | 6.16 ± 0.50$^a$ | 363.33 ± 5.29$^a$ |
| Group B | 33.28 ± 0.85$^a$ | 37.82 ± 0.06$^b$ | 4.54 ± 0.36$^b$ | 75.67 ± 0.83$^a$ | 5.43 ± 0.40$^b$ | 361.66 ± 3.46$^a$ |
| Group C | 33.08 ± 0.97$^a$ | 39.12 ± 0.43$^a$ | 5.22 ± 0.35$^a$ | 86.97 ± 0.61$^a$ | 5.49 ± 0.23$^b$ | 422.67 ± 3.46$^b$ |
| Group D | 33.9 ± 0.51$^a$ | 38.24 ± 0.35$^b$ | 5.16 ± 0.35$^a$ | 86.00 ± 0.88$^a$ | 5.54 ± 0.90$^b$ | 420.67 ± 3.00$^b$ |

Note: $^a,b,c$Means within columns with different superscripts differ significantly ($p < .05$). Different superscript letters in the same row indicate significant differences ($p < .05$); absent or repeated superscript letters indicate a non-significant difference ($p > .05$). Group A: add 0 mg/kg oregano oil; group B: add 150 mg/kg oregano oil; group C: add 300 mg/kg oregano oil; group D: add 450 mg/kg oregano oil. The test results are expressed as the means ± standard errors to determine the significance of differences.
and group D (p > .05), considering economic benefit, group C had the best weight gain effect.

**Effect of OEO on the slaughter performance of Sewa sheep**

As shown in Table 2, the carcase weights of the OEO groups were significantly higher than those of group A (p < .05). The carcase weight and eye muscle area of groups B–D were significantly higher than those of group A (p < .05). Although the carcase weight and eye muscle area in group C were the highest, there were no significant differences among the three OEO groups (p > .05). The slaughter rate of OEO group was higher than that of group A, but the slaughter rate of group C was the highest. There was no significant difference in slaughter rate among groups B–D (p > .05). It can be concluded that adding OEO to the diet can improve the slaughter performance of Sewa sheep.

**Effects of OEO on the morphology and structure of the small intestine of Sewa sheep**

As shown in Table S2 (Supplementary material) and Figures 1–3, the villus lengths in the ileum, duodenum, and jejunum in the group C were all higher than those in group A, and the differences were significant for the duodenum and jejunum (p < .05). The villus length in group C was the longest among those in the OEO groups, and the difference was significant (p < .05). The V/C ratios in the ileum, duodenum, and jejunum were higher in the OEO groups than in group A, and those in group C were significantly different from those in the other three groups with respect to various intestinal segments (p < .05). There were significant differences in the V/C ratio in the ileum between group C and group A (p < .05) and in the ileum and duodenum between group C and group A (p < .05).

**Effects of OEO on the intestinal flora of Sewa sheep**

As shown in Table 3 and Figure 4, the rarefaction curve gradually stabilises, indicating that under

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**Table 2. Effects of OEO on the slaughter performance of Sewa sheep.**

| Group | Carcase weight (kg) | Slaughter rate (%) | Loin eye muscle area (cm²) |
|-------|---------------------|--------------------|---------------------------|
| Group A | 13.88 ± 1.22b | 41.20 ± 1.72b | 15.16 ± 1.36b |
| Group B | 16.71 ± 1.42a | 43.61 ± 2.12a | 17.23 ± 2.01a |
| Group C | 17.96 ± 1.72a | 45.86 ± 1.82a | 18.22 ± 1.67a |
| Group D | 15.87 ± 2.02a | 42.81 ± 2.62a | 17.38 ± 1.32a |

Note: Loin eye muscle area measure the cross-sectional area of the longissimus dorsi muscle of the spine, between the 12th and 13th ribs (that is at the twelfth and the thirteenth ribs). The contour of eye muscle cross section was drawn with sulphuric acid drawing paper, and then the area was calculated by quadrature instrument. If an integrator is not available, the following formula can be used to estimate the eye muscle area (cm²) = eye muscle height × eye muscle width × 0.7.

a,bMeans within columns with different superscripts differ significantly (p < .05). Different superscript letters in the same row indicate significant differences (p < .05); absent or repeated superscript letters indicate a non-significant difference (p > .05). Group A: add 0 mg/kg oregano essential oil; group B: add 150 mg/kg oregano essential oil; group C: add 300 mg/kg oregano essential oil; group D: add 450 mg/kg oregano essential oil. The test results are expressed as the means ± standard errors to determine the significance of differences.

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**Figure 1. Ileum sections from each group of Sewa sheep.** Ileum group A, H. E, 40×, Bar = 500 µm. Villus length (200.2), crypt depth (154.3) and muscle layer thickness (91.2). Ileum group B, H. E, 40×, Bar = 500 µm. Villus length (242.4), crypt depth (121.2) and muscle layer thickness (120.4). Ileum group C, H. E, 40×, Bar = 500 µm. Villus length (650.2), crypt depth (161.2) and muscle layer thickness (232.3). Ileum group D, H. E, 40×, Bar = 500 µm. Villus length (230.2), crypt depth (117.5) and muscle layer thickness (109.3).
reasonable and effective sample volumes. At the phylum level, there was no significant difference between the OEO groups and group A ($p > .05$), and the number of bacteria in group C was the highest. At the class level, the value in OEO group B was higher than those in OEO groups C and D, and there was a significant difference between OEO groups A and B ($p < .05$); there was no significant difference between OEO groups C and D ($p > .05$). At the order level, the values in the OEO groups were higher than those in group A. The value in OEO group A was less than those in OEO groups B and C, and there was a significant difference between OEO groups C and D ($p < .05$). There was no significant difference between

Figure 2. Intestinal sections of the jejunum of Sewa sheep. Jejunum from group A, H. E, 40×, Bar = 500 μm. Villus length (423.5), crypt depth (202.7) and muscle layer thickness (142.3). Jejunum from group B, H. E, 40×, Bar = 500 μm. Villus length (474.2), crypt depth (177.3) and muscle layer thickness (188.9). Jejunum from group C, H. E, 40×, Bar = 500 μm. Villus length (698.4), crypt depth (145.6) and muscle layer thickness (212.3). Jejunum from group D, H. E, 40×, Bar = 500 μm. Villus length (459.3), crypt depth (172.3) and muscle layer thickness (162.3).

Figure 3. Duodenal sections from each group of Sewa sheep. Group A, H. E, 40×, Bar = 500 μm. Villus length (248.3), crypt depth (133.5) and muscle layer thickness (81.3). Group B, H. E, 40×, Bar = 500 μm. Villus length (322.3), crypt depth (240.3) and muscle layer thickness (87.3). Group C, H. E, 40×, Bar = 500 μm. Villus length (578.5), crypt depth (171.2) and muscle layer thickness (182.8). Group D, H. E, 40×, Bar = 500 μm. Villus length (562.3), crypt depth (252.3) and muscle layer thickness (142.3).

Table 3. Statistical table for the number of microbial bacteria at each level.

| Group | Phylum (the door) | Class (the outline) | Order (orders) | Family (families) | Genus (belong to) | Species (kind of) |
|-------|------------------|---------------------|----------------|------------------|-------------------|------------------|
| A     | 11.7 a           | 17.0 a              | 21.0 b         | 26.6 b           | 26.0 a            | 7.7 a            |
| B     | 12.0 a           | 20.0 a              | 23.0 a         | 31.0 a           | 31.0 a            | 7.0 a            |
| C     | 12.6 a           | 19.0 a              | 22.3 b         | 26.6 b           | 29.0 b            | 5.3 c            |
| D     | 12.5 a           | 19.3 a              | 23.3 b         | 28.0 b           | 27.7 c            | 4.2 b            |

Note: Table 3 shows the number of intestinal microorganisms in Sewa sheep at different levels with the addition of oregano oil at different concentrations. The higher the number of microorganisms, the better the concentration of oregano essential oil, which is beneficial to the fattening of Sewa sheep.

$^{a,b,c,d}$Means within columns with different superscripts differ significantly ($p < .05$). Different lowercase letters in the same column indicate significant differences ($p < .05$), while no letter or the same letter indicates a non-significant difference ($p > .05$). Group A: add 0 mg/kg oregano essential oil; group B: add 150 mg/kg oregano essential oil; group C: add 300 mg/kg oregano essential oil; group D: add 450 mg/kg oregano essential oil.
OEO groups D and A \((p > 0.05)\). At the family level, the values in OEO groups B and D were significantly higher than those in group A \((p < 0.05)\). There was a significant difference between OEO groups A and D \((p < 0.05)\), and there was no significant difference between OEO groups A and C \((p > 0.05)\). At the genus level, the values in each OEO group were higher than those in group A. There was a significant difference between the three OEO groups compared with group A \((p < 0.05)\). At the species level, the value of the OEO group was lower than that of group A, and the value of OEO group B was higher than that of OEO groups C and D. There was a significant difference between OEO groups A and C \((p < 0.05)\), and there was a significant difference between oregano oil groups C and D \((p < 0.05)\).

As shown in Figure 5, the top 20 genera in the figure were selected for analysis. Among the OEO groups, compared with group A, *coppococcus, clostridium, anaerofustis, butyrivibrio, adlercreutzia, bulleidia, oscillosira, 17A-E11, prevotella, rumincoccus, cupriavidus, acinetobacter, dehalobacterium, P-75-A5* and *anaerostipes* had higher abundance values. The abundances of *prevotella, rumuncoccus, cupriavidus and acinetobacter* were significantly increased in group C. The abundances of *P-75-A5, adlercreutzia, L7A-E11* and *bulleidia* were significantly increased in the OEO D group. The figure shows that OEO can improve the richness of intestinal flora and improve the intestinal flora structure.

**Discussion**

**Effects of OEO on the growth performance of Sewa sheep**

Daily gain is often used to express the growth rate of livestock and is an important index to reflect the growth performance and feed utilisation rate of livestock. Zhang Shanzhi and others found that adding OEO to the diet can reduce heat stress, improve feed intake in beef cattle, promote growth, prevent diarrhoea and increase the economic benefits of beef cattle fattening in summer (Zhang 2011). Halle found that adding plant extracts or OEO into diets can improve the production performance and meat quality of pigs (Halle et al. 2001). Dietary addition of OEO can also effectively delay microbial growth in rabbits during 7 d of cold storage of the carcass (Soultos et al. 2009). The main OEO compounds, such as carvacrol and thymol, have antcoccidial action against *Eimeria tenella* (Giannenas et al. 2018). Such as the phenolics can be absorbed in the intestine and enter the egg yolk through blood circulation of the hen, providing their superior antioxidant properties to the egg (Giannenas et al. 2018). In this experiment, The results showed that the ADG values in groups B, C and D were significantly higher than that in group A \((p < 0.05)\), and the ADG in group C was the highest. The ADG in group C was significant, indicating that OEO can improve the daily gain in Sewa sheep; these results are similar to those obtained in sheep (Chu 2019), chickens (Botsoglou et al. 2002; Amad et al. 2013; Peng et al. 2016; [AQ2]; Ramirez et al. 2021; Zhang et al. 2021), pigs (Forte et al. 2017; Liang et al. 2017; Cheng et al. 2018; Deng et al. 2018) and rabbits (Botsoglou et al. 2004). The total weight gain of groups B, C and D was significantly higher than that of group A \((p < 0.05)\), and group C had the greatest total weight gain. The ratio of feed to gain in group C was significantly different from that in group A \((p < 0.05)\). In the four groups, there was no significant difference in DMI between group A and group B \((p > 0.05)\), and there was no significant difference in DMI between group C and group D \((p > 0.05)\).
However, the DMI of group A was significantly different from that of group C and D. In summary, OEO can improve the growth performance of Sewa sheep in Tibet, and the effect of 300 mg/kg OEO in group C was the best.

Effect of OEO on the slaughter performance of Sewa sheep

Slaughter performance is an important reference for the slaughtering value of mutton sheep. The slaughter rate is an important index reflecting the slaughtering performance of animals. The eye muscle area reflects the development degree of animal carcasses and has an important impact on the economic benefits of breeding (Cai 2006; Alvarez-Rodriguez et al. 2007). Jing Hui (Jiang et al., 2018) stated that dietary OEO can improve daily gain in and the carcass weight of Hexi goats and can significantly improve their fattening performance. In this study, we found: the carcass weight, eye muscle area, and slaughter rate, reflecting slaughter performance, were significantly higher in the OEO groups than in group A, but the differences among the OEO groups were not significant ($p > .05$). However, the values of these parameters in group C were the highest. Therefore, adding OEO to the diet can improve slaughter performance, and adding OEO at 300 mg/kg has the best fattening effect.

Effects of OEO on the morphology and structure of the small intestine of Sewa sheep

The phenolics can be absorbed in the intestine and enter the egg yolk through blood circulation of the hen, providing their superior antioxidant properties to the egg (Giannenas et al. 2018). The small intestine is the main site of nutrient absorption in animals and plays a major role in animal growth (Botsoglou et al. 2004). Studies have shown that the shortening of villi in the small intestine affects the number of absorbing cells per villus, reduces digestion and absorption capabilities, and reduces animal productivity (Xue 2011). In this experiment, OEO was added to feed as microcapsules with two layers of encapsulation structure coating for sustaining targeted release in the intestinal tract. The comprehensive ability of the small intestine...
to absorb nutrients in feed depends on the V/C ratio, and the ratio is directly correlated with the absorption of nutrients which OEO can enhance in the small intestine of Sewa sheep. In this experiment, in the ileum, duodenum, and jejunum, the V/C ratios were significantly higher in the OEO groups than in group A, which illustrates that OEO can improve the small intestinal structure of Sewa sheep and improve the ability of the small intestine to absorb nutrients. These results are similar to those found for chicken (Han 2013) and piglet diets supplemented with OEO (Li 2018). Clearly, adding OEO to the diet enhances the digestion and absorption of nutrients in the small intestine.

Effects of OEO on the intestinal flora of Sewa sheep

Dietary addition of OEO can also effectively delay microbial growth in rabbits during 7 d of cold storage of the carcasse (Soultos et al. 2009). Experiments have shown that adding OEO to the diet can improve animal growth performance, reduce local oxidative stress, improve the production of natural antibodies and have a good regulatory effect on the composition of intestinal flora (Hall et al. 2021; Ruan et al. 2021). It can be seen from the test data that OEO increased the richness in terms of some bacterial genera, such as *Coprococcus* (faecal coccus), *Clostridium* and *Acetobacter*, all of which were significantly increased in this study. With an increase in richness, the digestive enzymes secreted by different microorganisms increase, which is conducive to absorption in the intestinal tract and the utilisation of nutrients (Zhou et al. 2019; Su et al. 2021). In this experiment, the richness of the intestinal flora was most significant in OEO group C, corresponding to the greatest improvement in digestion and absorption, which is in accordance with the production performance and other experimental data obtained in this study.

Conclusions

In conclusion, the results demonstrate that add of 300 mg/kg OEO (purity of OEO was 5.65%) in Sewa sheep have a positive effect on fattening performance which may be the result of the digestion and absorption of nutrients in the small intestine by regulating intestinal morphology and intestinal microorganisms. Thus, the finding of this study can provide reference information on feed additives improving the production application of OEO in the fattening sheep improving the production performance of Sewa sheep. This study provides a useful animal model for studying the growth-promoting effect of OEO in the Qinghai-Tibet Plateau.

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Disclosure statement

No potential conflict of interest was reported by the authors. Conceptualisation, J.S. and Z.R.; Data curation, Z.C.; Formal analysis, J.S.; Investigation, J.S., Z.C., Y.Z., Y.W., H.W. and Z.R.; Writing-original draft, J.S.; Writing-review and editing, J.S. and Z.R. All authors read and approved the final manuscript.

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Data availability statement

All data generated or analysed during this study are included in this article and its supplementary information files.

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