Supplementation of *Aloe vera* extract in lactating goats’ diet: effects on rumen fermentation efficiency, nutrient utilization, lactation performance, and antioxidant status

P. S. Banakar1 · Sachin Kumar1 · V. V. Vinay1 · Sonam Dixit1 · Nitin Tyagi1 · Amrish Kumar Tyagi1,2

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Abstract

The present work was conducted to investigate the effects of supplementing *Aloe vera* extract on rumen fermentation efficiency, nutrient utilization, lactation performance, and antioxidant status of goats. Twenty-four crossbreed lactating goats (Alpine × Beetal) were divided into three experimental groups (AV0, AV2, and AV4). AV0 had no supplementation, groups AV2 and AV4 received ready to feed aqueous extract of *Aloe vera* at 20 and 40 g/kg dry matter intake, respectively, along with basal diet and experiment lasted for 100 days. Average DMI did not vary (P > 0.05) among treatment groups; however, the metabolic bodyweight of AV4 was significantly lower (P < 0.05) than the AV0 and AV2 groups (AV0 = AV2 > AV4). Intake and digestibility of DM, OM, CP, NDF, ADF, and EE were unaffected (P > 0.05) by *Aloe vera* supplementation. The milk production, yield of milk fat, protein, lactose, and solid not fat (SNF) of goats in the AV4 group were significantly higher (P < 0.05) than other groups (AV4 > AV2 = AV0). The activity of superoxide dismutase and catalase enzymes and levels of plasma ferric reducing total antioxidant power were high (P < 0.01) in the *Aloe vera* supplemented group (AV4 = AV2 > AV0). There was no significant difference (P = 0.979) in the pH, acetic acid (P = 0.449), and butyric acid (P = 0.864) concentration of the rumen liquor among the treatment groups. The propionic acid concentration was similar between AV2 and AV4 and significantly higher (P = 0.024) than the AV0 group (AV4 = AV2 > AV0). Moreover, C2:C3 values were significantly lower (P = 0.037) in the AV4 group compared to the control (AV0). Thus, *Aloe vera* supplementation enhanced milk yield, propionic acid production, and antioxidant status without affecting nutrient utilization; however, results were better in the AV4 group. The inclusion of *Aloe vera* at 40 g/kg of DMI would improve the rumen fermentation efficiency, lactation performance, and overall health status of the dairy goats.

Keywords *Aloe vera* · Lactating goats · Antioxidant · Milk yield · Propionic acid

Introduction

The instigation of the one-health notion has gained paramount importance for food safety, food security, and sustainable food production systems (Garcia et al. 2020). One-health is a multidisciplinary holistic approach, where the health of humans, animals, and the environment is inextricably linked (Lainé and Morand 2020). Globally, and particularly, countries in tropical latitudes require sustainable food production systems to ensure the complexity and scale of food safety and security to feed a growing population (King et al. 2017). Animals reared for food production undergo tremendous stress due to the cascade of events occurring around the parturition and lactation period; consequently, compromising their immunity and further exposure to diseases (Colitti et al. 2019). The application of conventional antimicrobials agents to combat infections and upsurge production has been standard practice in farm animal rearing (Singh et al. 2021a; Mann et al. 2021). However, growing concerns about in-feed antibiotic usage due to their devastating effects caused by the emergence of multidrug-resistant...
pathogens have led to an antibiotics ban by the European Union and other countries (Singh et al. 2021b; Benchaar 2021). A paradigm shift has driven animal nutritionists to look for safe and natural feed additives to conventional antimicrobials for sustainable animal production with one health concept in consideration (Huang et al. 2018). Several newer emerging feed additives, which can be used as an alternative to antibiotics, have been suggested within the livestock industry. One such category gaining interest is natural phytogenic feed additive (PFA) (Wanapat et al. 2011; Banakar et al. 2019), which leaves no residue in the animal products (Zhou et al., 2020), or its presence in minor quantity increases its nutraceutical value (Santos et al. 2017) and further strengthening animal antioxidant status making resilient to stress (Suman et al. 2015).

Plant-derived products or the plant secondary metabolites (PSMs), viz. essential oils, saponins, condensed tannins, flavonoids, and phenolic compounds, form the major constituents of PFAs (Wanapat et al. 2011; Frutos et al. 2020). Research findings indicate that feeding certain tropical and sub-tropical plant extracts containing PSMs at appropriate levels modulates protozoal populations and increases bacterial and fungal abundance. This results in reduced methanogenesis, increased propionate production, microbial yield, and improved performance of ruminants (Banakar et al. 2019). The shift in the fermentation pattern is primarily ascribed to the antimicrobial and antioxidant properties of PFAs that improve rumen fermentation efficiency, further enhancing their production performance (Huang et al. 2018).

*Aloe vera* (AV) is one such source of PSMs that comprises the potential properties of PFAs. *Aloe vera* (L.) Burm. F. is the scientific name of AV with *Aloe barbadensis* Mill as a synonym, which belongs to the Aloeaceae family (Giannakoudakis et al. 2018) and is commonly found in tropical and sub-tropical environments. *Aloe vera* is used in ethnoveterinary medicine and has a positive impact on animal health and welfare. Around 75 bioactive compounds are identified in *Aloe vera* extract. Anthraquinones, polyphenols, and polysaccharides are among the major constituents, whereas vitamins (α-tocopherol, β-carotene, and folic acid) and minerals constitute the minor components (Kumar et al. 2019). Various in vitro studies report antioxidant, anti-inflammatory, and antimicrobial properties of AV (Lucini et al. 2015), indicating the potential of AV to modulate the animals’ rumen fermentation and health status. Besides, in vivo studies on AV supplementation in monogastric animals (poultry and swine) have marked nutrigenomic effects on animal products and welfare (Darabighane et al. 2011; Ghasemi-Sadabadi et al., 2020). However, there are no in vivo studies in ruminants reporting its interaction with the animals’ rumen fermentation and it is a source of interest. The present work was designed to investigate the effects of supplementing *Aloe vera* extract on rumen fermentation efficiency, nutrient utilization, lactation performance, and antioxidant status of goats.

### Materials and methods

#### Lactating goats and experimental diets

Twenty-four crossbreed lactating goats (Alpine × Beetal) were selected after 10 days of parturition, i.e., early to mid-lactation period, from the Livestock Research Center, NDRI, Karnal. Based on the average body weight (37.28 ± 1.69 kg) and the milk yield (1776.21 ± 93.21 g/day), animals were randomly assigned into three groups of 8 animals each. Goats were fed with a basal diet containing fresh berseem (*Trifolium alexandrinum*) as green fodder (roughage) and concentrate mixture in 60:40 to fulfill the animals’ nutrient requirement (ICAR 2013). The ingredients’ composition and chemical composition of the diets are presented in Tables 1 and 2, respectively. Goats were housed in well-ventilated pens with individual animal feeding arrangements and had 24-h free access to water. After an adaptation period of

| Table 1 | Ingredient composition of the diet (on DM basis) |
|---------|---------------------------------|
| **Concentrate mixture: 40** | |
| Maize | 33 | 33 | 33 |
| Groundnut cake | 18 | 18 | 18 |
| Mustard oil cake | 10 | 10 | 10 |
| Cottonseed cake (decorticated) | 5 | 5 | 5 |
| Bajra | 20 | 20 | 20 |
| Wheat bran | 6 | 6 | 6 |
| De-oiled rice bran | 5 | 5 | 5 |
| Mineral mixture | 2 | 2 | 2 |
| Common salt | 1 | 1 | 1 |
| **Green fodder (Berseem): 60** | |
| *Aloe vera* plant extract (%) | 0 | 2 | 4 |

| Table 2 | Chemical composition of diets (% DM basis) |
|---------|---------------------------------|
| **Nutrients** | Berseem | Concentrate |
| Dry matter (DM) | 16.18 ± 0.37 | 89.95 ± 0.39 |
| Organic matter (OM) | 90.87 ± 0.20 | 92.63 ± 0.52 |
| Crude protein (CP) | 16.71 ± 0.17 | 17.62 ± 0.36 |
| Ether extract (EE) | 2.45 ± 0.04 | 3.67 ± 0.04 |
| Neutral detergent fiber (NDF) | 53.31 ± 0.50 | 30.72 ± 0.40 |
| Acid detergent fiber (ADF) | 30.52 ± 0.34 | 14.05 ± 0.14 |
| Crude fiber (CF) | 25.96 ± 0.23 | 7.54 ± 0.23 |
| Total ash (TA) | 9.05 ± 0.12 | 7.37 ± 0.52 |
10 days, the animals were switched over to their respective experimental diets for 90 days. Group I (AV0) had no supplementation, and animals in group II (AV2) and group III (AV4) received ready-to-feed aqueous extract of Aloe vera (procured from Herbal consultant®, India) at 20 and 40 g/kg dry matter intake, along with basal diet. The calculated amount of powdered Aloe vera extract was thoroughly mixed with concentrate mixture before feeding. Per gram of Aloe vera extract, the quantum of total tannins, total polyphenols, and total flavonoids was 198.7, 37.90, and 23.11 mg, respectively.

Data recording

The experimental animals’ daily dry matter intake (DMI) was recorded by assessing the difference in the dry matter of diet offered and residue left (offered DM − residual DM). The residual left ranged between 5 and 10% of offered DM. The feed offered was changed every fortnight after recording the differences in the milk yield and DMI to supply nutrients as per the requirements. The lactating goats’ daily milk yield and fortnightly body weight were measured using an automated electronic weighing scale. Metabolic body weight was calculated using the formula, BW^0.75.

Sample collection

Feed samples were collected daily to ascertain the DMI of individual lactating goats after assessing the dry matter of feed offered and residue left. Milking of individual animals was carried out twice daily, i.e., at 5:30 AM and 4:00 PM. The sampling (1/100th of milk yield) was done at every fortnight interval from each milking and analyzed immediately for composition. Blood was collected from the jugular vein a sterile vacutainer containing acid citrate dextrose as an anticoagulant on the 0, 30, 60, and 90th day of the experiment. At the end of the investigation (90th day), rumen liquor was collected by passing (oro-ruminal) a rumen tube fitted with an esophageal probe and guided through a wooden mouth gag. A manual suction pump was attached to the free end of the rumen tube to facilitate the collection of rumen liquor. The first 50–100 mL was discarded to reduce contamination with saliva. Collected liquor (200 mL) was used to estimate the pH and individual volatile fatty acids (IVFA). After 90 days of feeding, a digestion trial of a 7-day collection period was conducted to evaluate the apparent nutrients’ digestibility. Total feces from individual animals were collected in plastic containers and mixed thoroughly to obtain a composite sample. Part (1/1000th) of the total collected feces was acidified with H2SO4 for nitrogen estimation (Maheswari et al. 2021).

Sample processing and analysis

Proximate analysis and apparent nutrient digestibility

Representative feces and feed (offered and residue) samples were oven-dried at 60 °C for 48 h, ground, and passed through 1-mm sieve and stored in a ziplock plastic bag until analysis. Proximate principles, viz. dry matter (DM) (method 934.01), organic matter (OM) (method 930.05), crude protein (CP) (method 984.10), and ether extract (EE) (method 920.39), were estimated as per the standard procedures of the Association of Official Analytical Chemists (AOAC, 1995). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined as per Van Soest et al. (1991). Apparent digestibility was calculated using the formula (Singh et al. 2021a) Apparent digestibility (g/kg)= Nutrient intake – Nutrient output/Nutrient intake respectively.

Milk components

Milk composition was determined using a pre-calibrated automatic milk analyzer (Lactostar, FUNKE GERBER, Berlin) to calculate the yield of milk fat, protein, lactose, and solid not fat (SNF). In total, 8 samples/group/period were analyzed for milk components and to determine the yield. The composition was corrected for the variations in milk produced between morning and evening milking’s.

Animals’ antioxidant status

Collected blood samples were immediately transferred to a laboratory with a cold chain maintained at 4 °C and centrifuged at 900 × g for 10 min to separate plasma from packed erythrocytes. Packed erythrocytes were washed thrice with ice-cold isotonic saline (0.9%). To 0.5 mL of packed erythrocytes, an equal quantity of normal saline was added to form RBC suspension. Hemolysate was prepared by adding 1.2 mL of ice-cold EDTA stabilizing solution (2.7 mM; prepared by dissolving 0.5025 g EDTA in 500 mL DW with 24.55 µL β-mercaptoethanol) to 0.2 mL of RBC suspension. The erythrocyte antioxidant enzyme activity and ferric reducing total antioxidant power (FRAP) were estimated using RBC hemolysate (prepared from the packed erythrocytes) and plasma, respectively. Antioxidant enzyme activity such as catalase (Aebi 1984), SOD (Madesh and Balasubramanian 1998), and GPx (Paglia and Valentine 1967) was determined spectrophotometrically (Specord 200, Germany) within 2 days after collection and processing of blood. FRAP assay was performed as described by Prakova et al. (2010).
Rumen liquor pH

Immediately after collecting rumen liquor, it was strained through double layered muslin cloth to measure pH using an electronic pH meter (pH Spear, EC- PHWPSEN04; Eutech instruments, Malaysia), calibrated against standard buffer solutions.

Individual volatile fatty acid estimation

For estimating IVFA, strained rumen liquor samples were preserved by adding 0.2 mL of 25% metaphosphoric acid per mL of rumen liquor (RL). Then samples were centrifuged (2400 × g for 20 min) after 2 h of the stand at 4 °C and the supernatant was used for estimation of IVFAs. The aliquot (3 µL) was injected using 10-µL Hamilton syringe (Hamilton, NV, USA) into gas chromatograph (GC, Nucon 5700, Nucon Engineers, New Delhi) equipped with a flame ionization detector and stainless steel column packed with Chromosorb –101 mesh 80–100 as described by Miri et al. (2015). For fractionation of IVFA, analytical conditions were as follows: injection port temperature, 250 °C; column temperature, 190 °C; and detector temperature, 260 °C. The flow rate of nitrogen (carrier gas) was maintained at 40 mL/min, hydrogen at 30 mL/min, and air, 300 mL/min. Based on the retention time and their concentration (mM), different IVFAs of each sample were identified and calculated by comparing the retention time as well as the peak area of standards after deducting the corresponding blank values.

Statistical analysis

The experimental data collected (dry matter intake, bodyweight, milk and milk composition yield, antioxidant enzyme activity, and FRAP values) were analyzed by repeated-measures ANOVA method. Statistical Package for the Social Sciences (SPSS for Windows, v21.0; SPSS Inc., Chicago, IL, USA) was used for the analysis. The following statistical model was used:

\[ Y_{ijkl} = \mu + D_i + P_j + G_k(D) + (D \times P)_{ij} + e_{ijkl} \]

where \( Y_{ijkl} \) is the dependent variable, \( \mu \) is the overall mean, \( D_i \) is the effect of \( i \)th dietary treatment, \( P_j \) is the effect of \( j \)th period, \( G_k \) is the random effect of lactating goats, \( (D \times P)_{ij} \) is the interaction effect of \( i \)th dietary treatment with \( j \)th period, and \( e_{ijkl} \) is the casual effect of each observation.

One-way ANOVA was performed for nutrient utilization and individual volatile fatty acid fatty. Tukey’s honest significant difference (HSD) test was used for the pairwise comparison of means. GraphPad Prism 8.1 (San Diego, CA, USA) was used to develop figures. The effects were considered significant at \( P < 0.05 \) (*) and high statistical significance at \( P < 0.001 \) (**), whereas non-significance at \( P > 0.05 \).

Results

Dry matter intake and metabolic body weight changes

The fortnightly DMI and metabolic body weight changes of goats are depicted in Fig. 1. Periodic changes in the DMI varied significantly \( (P<0.001) \) in all the treatment groups. There was a remarkable decrease \( (P<0.05) \) in the DMI of the AV4 group in the first fortnight in comparison to Control (AV0) and AV2 groups. However, this decrease in DMI got nullified in the subsequent weeks. The average total tannin intake through supplemented Aloe vera extract was 5.73 ± 0.04 and 11.25 ± 0.09 g/day for AV2 and AV4 groups, respectively, and the total polyphenol intake was 1.09 ± 0.01 and 2.10 ± 0.02 g/day. As a sequela of the changes in DMI, metabolic bodyweight changes displayed significant periodic changes \( (P<0.001) \) in different groups. Goats in the AV4 group exhibited decreased \( (P<0.05) \) metabolic bodyweight than AV2 and AV0 groups in the first fortnight; however, the values remained similar in the subsequent fortnights. Nevertheless, average DMI and metabolic bodyweight did not vary \( (P=0.979 \) and 0.430, respectively) among treatment groups (Table 3).
Table 3 Nutrient utilization in goats with supplementation of *Aloe vera* extract

| Attributes           | AV0     | AV2     | AV4     | SEM     | Significance |
|----------------------|---------|---------|---------|---------|--------------|
| **Nutrient intake (g/day)** |         |         |         |         |              |
| DM (kg/100 kg BW)    | 3.69    | 3.80    | 3.76    | 0.034   | 0.270        |
| DM (g/kg W0.75)      | 92.16   | 93.92   | 93.02   | 0.847   | 0.467        |
| OM                   | 1334.90 | 1322.20 | 1312.60 | 18.23   | 0.670        |
| CP                   | 274.83  | 274.5   | 275.95  | 2.153   | 0.816        |
| NDF                  | 668.96  | 676.16  | 679.99  | 6.934   | 0.580        |
| ADF                  | 305.43  | 311.9   | 312.56  | 6.057   | 0.684        |
| EE                   | 41.83   | 41.55   | 42.02   | 0.255   | 0.515        |
| **Apparent digestibility of nutrients (g/kg)** |         |         |         |         |              |
| DM                   | 658.41  | 661.19  | 672.23  | 3.731   | 0.170        |
| OM                   | 671.44  | 678.05  | 688.61  | 3.387   | 0.246        |
| CP                   | 688.31  | 687.45  | 692.51  | 4.593   | 0.704        |
| NDF                  | 570.58  | 578.85  | 581.90  | 3.899   | 0.293        |
| ADF                  | 376.39  | 388.70  | 384.59  | 4.322   | 0.184        |
| EE                   | 759.11  | 757.36  | 763.74  | 3.308   | 0.503        |

AV0, supplementation of 0% *Aloe vera* extract; AV2, supplementation of 2% *Aloe vera* extract; AV4, supplementation of 4% *Aloe vera* extract; SEM, standard error of means

**Antioxidant status**

The periodic changes and the values of erythrocyte antioxidant enzyme activities are shown in Fig. 3 and Table 5. There was a significant increase (*P* = 0.001) in the SOD and catalase enzyme activity in AV2 and AV4 groups over AV0 on 30th day of supplementation and followed the trend of AV4 > AV2 > AV0 throughout the experiment. Moreover, significant (*P* ≤ 0.001) periodic variations were observed in SOD, catalase activity, and FRAP values in all the treatment groups. Furthermore, over the whole experimental period, the activity of SOD and catalase was higher (*P* < 0.01) in the *Aloe vera* supplemented groups than in the control (AV4 = AV2 > AV0). Nevertheless, we could not comprehend any perceivable difference (*P* = 0.808) in the activity of GPx among the treatment groups. *Aloe vera* supplementation had a significant influence (*P* = 0.001) on the total antioxidant activity expressed in FRAP terms, which followed the same trend as SOD and catalase. Overall, the values of FRAP were significantly higher (*P* < 0.001) in AV2 and AV4 than in the control group.

Table 4 Production performance parameters of goats with supplementation of *Aloe vera* extract

| Attributes                      | AV0     | AV2     | AV4     | SEM     | Significance |
|---------------------------------|---------|---------|---------|---------|--------------|
| Dry matter intake (kg/100 kg BW) | 3.97    | 3.94    | 3.96    | 0.018   | 0.979        |
| Metabolic bodyweight, BWW0.75 (kg) | 15.29   | 15.25   | 14.61   | 0.179   | 0.430        |
| Milk yield (g/d)                | 1566.78b| 1582.96b| 1670.09a| 11.82   | 0.001        |
| Milk fat (g/d)                  | 59.95b  | 60.13b  | 63.86a  | 0.012   | < 0.001      |
| Milk protein (g/d)              | 57.72b  | 58.55b  | 61.63a  | 0.018   | < 0.001      |
| Milk lactose (g/d)              | 78.74a  | 79.97a  | 83.95a  | 0.019   | < 0.001      |
| Milk solid not fat (g/d)        | 123.26b | 125.20b | 131.41a | 0.069   | < 0.001      |

AV0, supplementation of 0% *Aloe vera* extract; AV2, supplementation of 2% *Aloe vera* extract; AV4, supplementation of 4% *Aloe vera* extract; SEM, standard error of means. Means with different superscripts in a row differ significantly (*P* < 0.05). D, diet effect; P, period effect
The individual volatile fatty acid and pH of rumen liquor

Data on IVFA (mmol/L) and pH of the rumen liquor are presented in Table 6. There was no significant difference ($P = 0.979$) in the pH of the rumen liquor among the treatment groups. Among the IVFA, acetic acid (C2) and butyric acid (C4) concentration did not vary ($P = 0.449$ and 0.864, respectively) among different groups. The propionic acid concentration was similar between AV2 and AV4 and significantly higher ($P = 0.024$) than the AV0 group (AV4 $>$ AV2 $>$ AV0). Also, C2:C3 values were significantly lower ($P = 0.037$) in the AV4 group compared to the control (AV0).

Fig. 2 Periodic changes in the milk yield of lactating goats in different treatment diets. AV0, supplementation of 0% *Aloe vera* extract; AV2, supplementation of 2% *Aloe vera* extract; AV4, supplementation of 4% *Aloe vera* extract. Values are expressed as mean $\pm$ SEM.
Table 6  Individual volatile fatty acid content in rumen liquor and pH of rumen of goats supplemented with Aloe vera extract

| VFA (mmol/L) | AV0 | AV2 | AV4 | SEM | Significance |
|--------------|-----|-----|-----|-----|--------------|
| pH           | 6.7025 | 6.6875 | 6.775 | 0.034 | 0.979 |
| Acetic acid (C2) | 129.67 | 129.08 | 127.13 | 0.811 | 0.449 |
| Propionic acid (C3) | 38.25<sup>b</sup> | 41.67<sup>b</sup> | 43.03<sup>a</sup> | 0.808 | 0.024 |
| Butyric acid (C4) | 1.59 | 1.63 | 1.57 | 0.030 | 0.864 |
| C2:C3        | 3.38<sup>a</sup> | 3.12<sup>b</sup> | 2.96<sup>b</sup> | 0.073 | 0.037 |

AV0, supplementation of 0% Aloe vera extract; AV2, supplementation of 2% Aloe vera extract; AV4, supplementation of 4% Aloe vera extract; SEM, standard error of means. Means with different superscripts in a row differ significantly (P<0.05)

Discussion

Levels of tannins or polyphenols can influence voluntary feed intake (VFA) (Frutos et al. 2004; Patra and Saxena 2011). DMI of 4% Aloe vera supplemented group decreased in the first fortnight, though subsequent fortnights did not show a significant difference in the DMI. Since the extract was supplemented by mixing it in the concentrate mixture and fed to goats, the present findings may be due to the short-term influence of the astringency effect (Landau et al. 2000) of Aloe vera polyphenols or tannins during the adaptation period. Also, the intake of secondary metabolites (tannins and polyphenols) through Aloe vera extract was considerably high in the AV4 group than AV2. Similar to DMI, fortnightly bodyweight changes followed the same trend. Since the nutrient intake during the first fortnight did not satisfy the animal’s requirement (maintenance and lactation), a decrease in bodyweight was observed. However, there was a steady intake of DM in the subsequent fortnight, resulting in increased body weight as the lactation progressed. It is well noted that with a low to moderate level of tannins in the diet, VFI remains unchanged. However, when tannin-rich diet is introduced to the animals, it may take some time to adjust to the newly introduced diet (Frutos et al. 2020). Nonetheless, goats can degrade tannins (Kumar et al. 2014; Tahmourespour et al. 2016) and have the ability to make it less astringent by secreting tannin binding proteins in the saliva (Schmitt et al. 2020). Our findings are in line with Buccioni et al. (2015b), (2017), Rana et al. (2012), Suman et al. (2015), and Toral et al. (2011), who found no significant difference in the total DMI with tannin or polyphenol levels varying between 1 and 40 g/kg diet.

In the current research work, DM, OM, CP, EE, NDF, and ADF intake and digestibility remained unchanged (P>0.05). Our results agree with Holtshausen et al. (2009), who observed no significant difference in DM, CP, NDF, and ADF’s apparent digestibility on supplementing Yucca schidigera and Quillaja saponaria at 10 g/kg of DM. Similarly, Rana et al. (2012) reported no change in the CP, NDF, and ADF digestibility when tannin-rich Terminalia chebula was included in the diets (0.59 and 1.79% of DM) of kids. In line with other findings, Silva et al. (2016) reported no significant difference in nutrient intake and digestibility with the inclusion of phytogenic feed additives in sheep diet. Nevertheless, Hristov et al. (2013) observed a reduced DMI in lactating Holstein Friesian cows with the inclusion of oregano at different levels (0, 250, 500, 750 g/day) in the diet; however, digestibility of nutrients was unaffected.

Aloe vera has bioactive compounds such as flavonoids and polyphenols that exhibit potent antioxidant, anti-inflammatory, and antimicrobial activity. These bioactive compounds can quench free radicals and activate antioxidant enzymes like catalase, SOD, and GPx to prevent oxidative stress (Danish et al. 2020; Kumar et al. 2019; Maan et al. 2018; Sánchez-Machado et al. 2017). Nonetheless, activation of the antioxidant system by bioactive compounds is more pronounced during stressful conditions (Rubió et al. 2013). Lactating animals undergo a state of oxidative stress, i.e., the disparity between animals’ antioxidant status and oxidants, especially after calving, early and mid-lactation stages (Berchieri-Ronchi et al. 2011; Sharma et al. 2011). Stress mainly prevails because of the metabolic and physiological changes occurring after kidding and during lactation.

Consequently, to counteract oxidative stress, there will be changes in the antioxidant enzyme activity, which is evident in the current study. Significantly higher values of antioxidant enzyme activity in Aloe vera supplemented groups point to its potential for easing oxidative stress (Huang et al. 2018) during the lactation period. Ferric reducing total antioxidant power (FRAP) is another parameter that provides essential information on the animal’s antioxidant status, explaining the imbalance between pro-oxidants and antioxidants (Hiselli et al. 2000). Aloe vera supplemented groups displayed higher FRAP values than the control, which further strengthens the fact that Aloe vera has a beneficial role in combating oxidative stress.

Current findings are in line with Zhong et al. (2012), who observed an increase in the total antioxidant capacity and SOD activities in plasma of lambs fed with Astragalus membranaceus root and Astragalus polysaccharide. Similarly, Fructus Liguistri Lucidi’s inclusion in the sheep diet improved the animal’s antioxidant status by enhancing SOD and glutathione reductase (Qiao et al. 2012). Suman et al. (2015) reported an increase in the erythrocyte SOD and catalase activity and increased plasma FRAP value when fed with a tanniniferous Terminalia chebula plant extract-based diet in goats.

The dairy animals’ production performance (reproduction and milk production) depends on their health status (Gross and Bruckmaier 2019). During the lactation period, external or abiotic (environmental) and internal or biotic (metabolic) stressors may have adverse effects on animal health (Colitti et al. 2012).
et al. 2019). Under such conditions, the animal homeorhetic system may repartition nutrients towards maintenance, resulting in a transient decrease in milk production (Bradford et al. 2015; Bruckmaier and Gross 2017). However, the animal can recover if the stressors are lessened and when an animal gets the required nutrients (Sordillo and Aitken 2009) for metabolic adaptation resulting in sustained milk production. The better antioxidant status of the lactating goats in the Aloe vera supplemented group contributes to the animal’s welfare; it might have resulted in a high overall milk yield compared to the non-supplemented group (Maheswari et al. 2021). As reported by Liu et al. (2013), condensed tannins (10 g/kg of DM) in the diet of transition dairy cows alleviate oxidative stress and increase the antioxidant status by inhibiting lipid peroxidation and enhancing the antioxidant enzyme activity.

Furthermore, the increase in propionic acid production in the present study might have improved milk production in the 4% Aloe vera supplemented group. In the current investigation, a decrease in the C2:C3 might have increased glucose production and improved fermentation efficiency leading to sustained milk production. As a consequence of the increased milk production, the milk fat, protein, lactose, and SNF yield were high in the 4% Aloe vera supplemented group. Our findings are consistent with Buccioni et al. (2015b), who observed an increase in the average milk yield with tannins (80 g/kg DM) in the dairy ewes’ diet. Similar results are reported by Tekippe et al. (2011) (oregano leaf), Heidarian Miri et al. (2013) (Cumin extract, 2.53% DMI), and Zhou et al. (2020) (Piper sarmentosum extract, 1200 mg/kg DM) with the plant extracts in the diet of dairy animals. However, at the same time, no effects on milk yield have been reported on inclusion of tannins or polyphenols, or herbal mixture in the diet of dairy animals (Moate et al. 2014; Jain et al., 2013, and Hristov et al. 2013; Buccioni et al. 2015a).

Overall, researchers contrasting findings could be due to (1) variations in the sources of PSMs; (2) the composition of polyphenols or bioactive compounds in the diet; (3) animal species. Nevertheless, low to moderate levels of tannins or polyphenols in the diet of dairy animals did not affect the animals’ overall performance.

Conclusions

Dietary inclusion of Aloe vera extract at 20 and 40 g/kg DMI improved antioxidant status, rumen fermentation efficiency, and milk yield of lactating goats without any adverse impact on overall dry matter intake and nutrient utilization. The best response was obtained when Aloe vera was supplemented at 40 g/kg DMI. Thus, Aloe vera supplementation would be beneficial in terms of improved antioxidant status and lactation performance.

Author contribution BPS, SK, AKT, and NT: conceptualization, data curation, funding acquisition, investigation, methodology, project administration, validation, writing — original draft, review, and editing. VVV and SD: laboratory work, formal analysis, software, visualization, graph development, writing — review and editing.

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Data availability The authors affirm that the data supporting the current study’s conclusions are found in the manuscript (and/or supplementary materials).

Declarations

Ethical considerations The present study of 100-day duration, including 10-day adaptation period, was carried out as per the guidelines laid down by Institutional Animal Ethics Committee (Reg No. 1705/GO/ac/13/CPCSEA, Dt. 3/7/2013), ICAR-National Dairy Research Institute, Karnal, India (IAEC. No. 116/16, Dt. 3/12/2016).

Conflict of interest The authors declare no competing interests.

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