



Physicochemical and Microbiological Characteristics of Processed Goat Milk with Lontar Fruit Using Different Types and Levels of Sweeteners

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ABSTRACT

Fresh goat milk is perishable and has a distinctive flavor that may reduce consumer acceptance. Incorporating lontar fruit and sweeteners such as honey and stevia may improve its physicochemical properties. The present study aimed to investigate the effects of different sweetener types and concentrations on the characteristics of goat milk supplemented with lontar fruit puree. A completely randomized design was employed, comprising seven treatments, including a control group with 5% sucrose, honey at three concentrations (2%, 4%, 6%), and stevia at three concentrations (0.05%, 0.1%, 0.15%), each with four replicates. Antioxidant activity, antibacterial activity, degree of acidity (pH), viscosity, and color values, including brightness (L*), redness (a*), and yellowness (b*), were evaluated. Honey-containing treatments demonstrated higher viscosity and lower pH than stevia-containing treatments, while the highest antioxidant activity was observed in the 0.15% stevia treatment (33.80%). No microbiological inhibition was observed against *Escherichia coli* and *Staphylococcus aureus*. The inclusion of honey in goat milk supplemented with lontar fruit puree resulted in higher viscosity than treatments containing stevia. Formulations with milk and honey had a lower pH than those with stevia. The 0.05% stevia treatment had the highest L* value (brightest color) and a negative a* value (a greener hue), while honey increased the intensity of red and yellow coloration with increasing concentration. The 0.15% stevia treatment demonstrated the highest antioxidant activity and favorable physicochemical characteristics.

Keywords: Goat milk, Lontar fruit, Microbiological characteristic, Physicochemical characteristic, Sweetener

INTRODUCTION

Goat milk is a nutrient-rich substance comprising proteins, fats, minerals, and other nutritional constituents that enhance its nutritional value (Nayik et al., 2021). Additionally, goat milk contains short- and medium-chain fatty acids, including caproic, caprylic, and capric acids, which contribute to its distinctive flavor and are readily digested and absorbed (Nayik et al., 2022). Furthermore, goat milk contains different bioactive components associated with potential health benefits (Verruck et al., 2019). However, fresh goat milk is highly perishable and prone to spoilage, and its characteristic flavor can limit consumer acceptance. Fresh goat milk is highly perishable and can spoil rapidly due to bacterial growth, which may compromise its quality during storage (Razali et al., 2021). Therefore, appropriate heat treatment is necessary to reduce microbial contamination and maintain the microbiological quality and safety of goat milk during storage (Prasanth and Wimalasiri, 2019).

Against this background, the development of dairy products combining appropriate heat treatment with natural ingredients may provide an approach to improving product quality, stability, and functional properties. Incorporating natural ingredients such as fruit purees, juices, and plant extracts not only improves sensory qualities but also increases levels of bioactive compounds, including polyphenols, flavonoids, and carotenoids, which may offer health benefits (Prestes et al., 2022).

One of the indigenous natural ingredients with potential for the development of processed dairy products is the lontar fruit (*Borassus flabellifer* L.; Rahman et al., 2023). Lontar fruit is known to contain several bioactive compounds, including flavonoids, saponins, tannins, and phenolic compounds, with potential antioxidant and antibacterial activities. In addition, lontar fruit contains protein, fat, and micronutrients such as calcium and phosphorus (Mary and Jasmin, 2022). These compounds help prevent food spoilage by inhibiting oxidation in fats and proteins (Rahman et al., 2023). Konay et al. (2019) reported that ethanol extract of lontar fruit exhibited antibacterial activity against the growth of *Staphylococcus aureus* (*S. aureus*). Rahman et al. (2023) demonstrated that the addition of lontar fruit to goat milk products can increase antioxidant activity and affect the physical characteristics of the product.



Excessive use of sucrose is currently a concern due to its association with increased risk of obesity, diabetes, and other cardiometabolic diseases (Malik and Hu, 2022). The increasing public awareness regarding healthy lifestyles is motivating consumers to choose food products that incorporate natural sweeteners, such as honey and stevia. These natural sweeteners may provide potential health benefits beyond their primary role as sweeteners (Schiatti-Sisó et al., 2023). Dias (2023) stated that increasing consumer awareness of the negative impacts of excessive sugar consumption has increased the demand for healthier natural sweeteners.

Honey contains high levels of simple sugars, particularly fructose (35.6-41.8 g/100 g) and glucose (25.4-28.1 g/100 g), as well as several minor components, including vitamins, minerals, flavonoids, phenolic compounds, and enzymes, such as diastase, invertase, glucose oxidase, and catalase (Alaerjani et al., 2022; Al-Kafaween et al., 2023). These bioactive components, particularly phenolic compounds, flavonoids, and enzymes, contribute to the antioxidant and antibacterial properties of honey. Almasaudi (2021) stated that the antibacterial activity of honey comes from its high sugar content, polyphenols, hydrogen peroxide, and bee defensin-1. In addition, honey has a distinctive aroma and flavor that may enhance the product's sensory characteristics. Its elevated sugar and total solids content are correlated with its viscosity and may impact the viscosity of the resulting dairy beverage (Evahelda et al., 2017).

Stevia is a natural, low-calorie sweetener that is approximately 150 to 450 times sweeter than sucrose (Peteliuk et al., 2021). Stevia comprises steviol glycosides, mainly stevioside and rebaudioside A, which exhibit adequate stability at elevated temperatures and across a wide pH range, thereby supporting their use in food products subjected to high-temperature processing (Satar-AlDavdi, 2022). In addition to providing sweetness, stevia contains bioactive compounds such as flavonoids, phenolics, tannins, and ascorbic acid, which have potential antioxidant and antibacterial properties (Ahmad et al., 2020; Chakma et al., 2023). Furthermore, stevia is considered safer for diabetics and consumers on low-sugar diets because it is non-caloric (Papaefthimiou et al., 2023). Therefore, the present study aimed to examine the physicochemical and microbiological characteristics of processed goat milk supplemented with lontar fruit, with honey and stevia added as natural sweeteners, as alternatives to sucrose.

MATERIALS AND METHODS

Ethical approval

The present study did not involve human participants or animals; therefore, ethical approval was not required. Additionally, the final product was not consumed by any living humans, animals, or other organisms. The study was conducted in accordance with the guidelines established by Hasanuddin University, Indonesia.

Experimental design

The main ingredients used in this study were goat milk obtained from Al-Fatih Farm, Gowa, Indonesia, fresh lontar fruit (*Borassus flabellifer* L.) purchased from a local market in Makassar, Indonesia, Uray® commercial honey (PT Rejeki Tujuh Alam, Indonesia); Stetes® commercial stevia (PT Ananta Hira Boga Pratama, Indonesia), and commercial granulated sucrose purchased from a local market in Makassar, Indonesia. The present study employed a Completely Randomized Design (CRD) with seven treatments and four replicates.

Product preparation and treatment groups

Fresh goat milk served as the base at 100%, with lontar fruit puree incorporated at 10% (w/v). The treatment groups comprised natural sweeteners at different concentrations, expressed as a percentage of the total volume (w/v). The control group (C) received 5% commercial granulated sucrose purchased from a local market in Makassar, Indonesia. For the stevia treatments, the sweetener was added at concentrations of 0.05% (S0.05), 0.1% (S0.1), and 0.15% (S0.15). For the honey treatments, honey was added at 2% (H2), 4% (H4), and 6% (H6). After adding the sweeteners, each combination was autoclaved (Tomy SX-500, Japan) at 105°C for five minutes. The heated products were then cooled to room temperature over 30 minutes.

Preparation of lontar fruit stock

The mature lontar fruit was utilized. The inner skin layer (mesocarp) was initially peeled, and the flesh (endosperm) was blended until smooth. Subsequently, lontar fruit puree was incorporated at a concentration of 10% (v/v), based on the volume of goat milk (Rahman et al., 2023).

Antioxidant activity

A volume of 3.9 mL of 75 µM 2,2-diphenyl-1-picrylhydrazyl (DPPH) solution prepared in methanol was combined with 100 µL of the methanol extract. The mixture was incubated for 30 minutes, after which its absorbance was recorded

at 517 nm. The percentage of antioxidant activity was determined using the DPPH assay according to Formula 1 (Hafeez et al., 2025).

$$\text{Free radical scavenging activity(\%)} = \frac{\text{Absorbance of reagent blank} - \text{Absorbance of sample}}{\text{Absorbance of reagent blank}} \times 100\% \quad (\text{Formula 1})$$

Antibacterial activity

The antibacterial activity was assessed through the well diffusion assay against *Escherichia coli* (*E. coli*) and *S. aureus*. Samples were placed in wells prepared on nutrient agar and incubated at 37°C for 24-48 hours. The diameter of the inhibition zone was measured five times for each well, and the mean value was used for calculation according to Formula 2 (Maruddin et al., 2019).

$$\begin{aligned} \text{Antibacterial activity} &= \text{Inhibition zone area} - \text{Well area} & (\text{Formula 2}) \\ \text{Zone area} &= \pi \cdot r^2 \text{ (r = radius of inhibition zone)} \\ \text{Well area} &= \pi \cdot r^2 \text{ (r = radius of ring)} \end{aligned}$$

where π (constant) was 3.14, the ring diameter was 0.83 mm, and r (radius) was calculated as $1/2 \times$ the diameter.

Degree of acidity (pH)

Prior to measuring the samples, the pH meter was calibrated using standard buffer solutions at pH 7.00 and pH 4.01. After calibration, the pH of each sample was measured using the calibrated pH meter (Liu et al., 2024).

Viscosity

An Ostwald viscometer (Pyrex®, USA) was used to determine viscosity based on the flow-time method (Thakur and Wadhwa, 2017; Formula 3). The flow time of the sample between the two calibrated marks of the U-shaped capillary tube was recorded. The same procedure was performed using water as the reference liquid (Thakur and Wadhwa, 2017).

$$\eta = \eta_0 \times \frac{d \cdot t}{d_0 \cdot t_0} \quad (\text{Formula 3})$$

where η was the viscosity of the sample (cP), η_0 was the viscosity of water (cP), d was the density of the sample (g/mL), d_0 is the density of water (g/mL), t was the flow time of the sample (seconds), and t_0 was the flow time of water (seconds).

Color

Color was measured using the CIE Lab color space. In this system, the L^* value represented lightness and ranged from 0 (black) to 100 (white), while the a^* and b^* values ranged from -120 to $+120$. Positive a^* indicated redness and negative a^* indicated greenness, whereas positive b^* indicated yellowness and negative b^* indicated blueness. Hue angle and chroma were calculated from these values. Measurements were performed using a colorimeter (TES-135A, TES Electrical Electronic Corp., Taiwan; Minz and Saini, 2021).

Data analysis

Data obtained in the present study were analyzed using analysis of variance (ANOVA) under a completely randomized design (CRD) to evaluate the effects of different types and levels of natural sweeteners on the observed parameters. When significant differences were identified, Duncan's multiple range test was employed at a significance level of p value less than 0.05 ($p < 0.05$). All statistical analyses were conducted using SPSS, version 25.

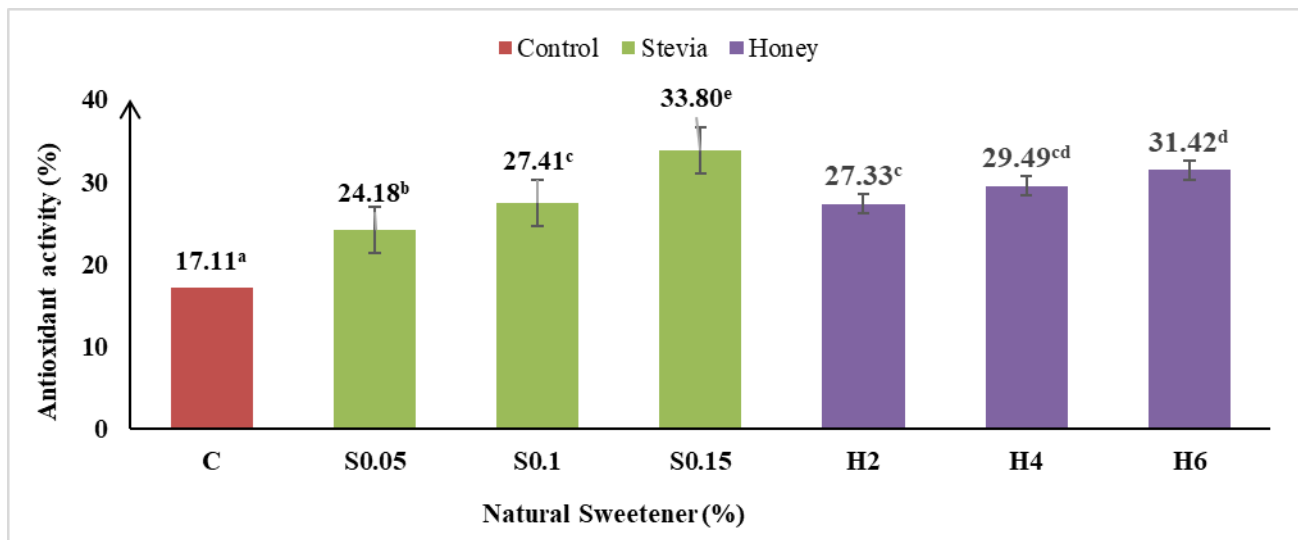
RESULTS

Antioxidant activity

The types and levels of natural sweeteners significantly affected the antioxidant activity of the product ($p < 0.05$; Graph 1). Compared with the control treatment, the addition of honey and stevia generally resulted in higher free-radical inhibition, with inhibition values ranging from 17.11% to 33.80%. The lowest antioxidant activity was observed in the control group (17.11%), whereas the highest inhibition value was recorded in the S0.15 treatment group at 33.80%.

Antibacterial activity

The antibacterial activity results demonstrated that all treatments, whether using honey or stevia at different concentrations, did not exhibit any inhibitory effect against *E. coli* and *S. aureus*. The absence of antibacterial activity was indicated by the absence of an inhibition zone (clear zone) around the sample area on the growth medium. Honey and stevia did not function as antibacterial agents in the goat milk supplemented with lontar fruit puree. As shown in Figure 1, honey and stevia did not function as antibacterial agents in the goat milk supplemented with lontar fruit puree.



Graph 1. Antioxidant activity of goat milk products supplemented with lontar fruit and different concentrations of stevia and honey as natural sweeteners. ^{a,b,c} Mean different superscript letters indicate a significant difference ($p < 0.05$). C: Control (5% sucrose), S: Stevia, H: Honey.

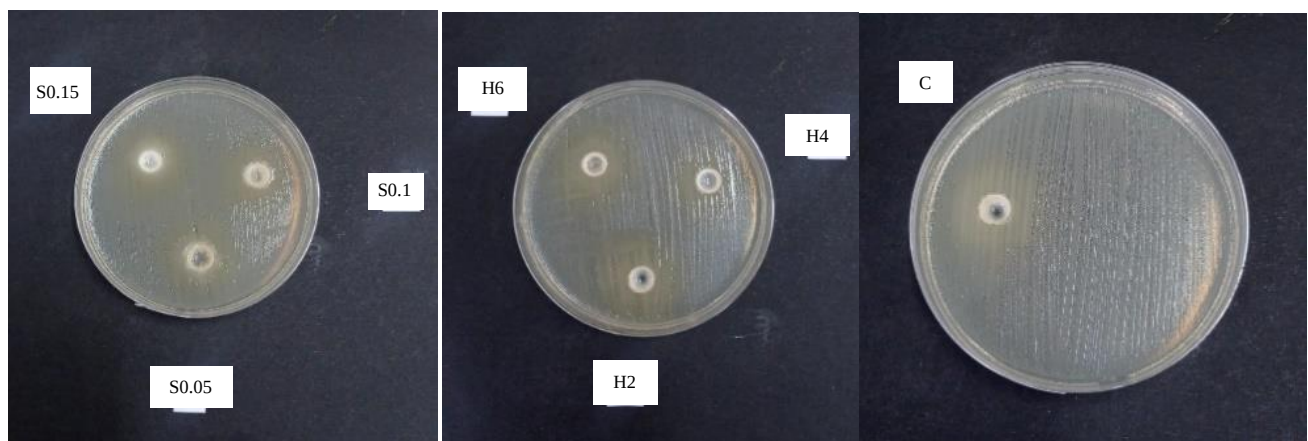


Figure 1. Antibacterial activity of goat milk products supplemented with lontar fruit and different concentrations of stevia and honey as natural sweeteners. C: Control (5% sucrose), S0.05: Stevia 0.05%, S0.1: Stevia 0.1%, S0.15: Stevia 0.15%, H2: Honey 2%, H4: Honey 4%, H6: Honey 6%.

Degree of acidity (pH)

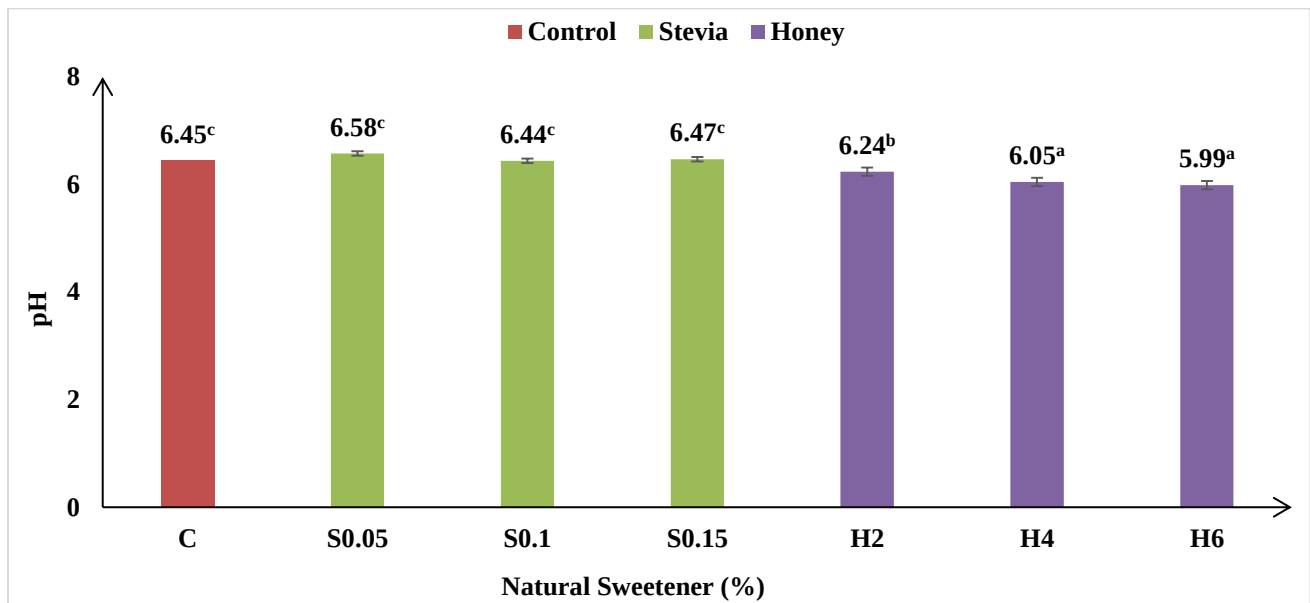
Different concentrations of stevia and honey significantly affected the pH of goat milk supplemented with lontar fruit puree ($p < 0.05$; Graph 2). The present results indicated that the average treatment values ranged from 5.99 to 6.58, with the highest value observed in the S0.05 treatment group (6.58) and the lowest pH in the H6 treatment group (5.99). The pH values for the control and all stevia treatment groups were within the normal range for fresh goat milk, which is 6.4-6.7 (Benyahia *et al.*, 2025).

Viscosity

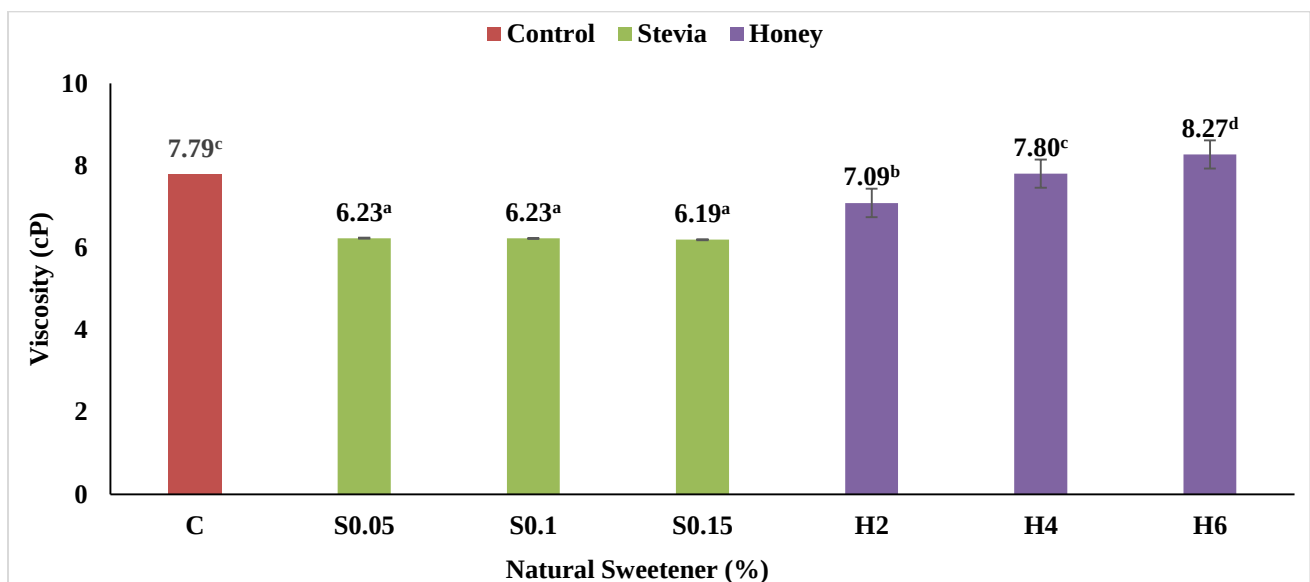
Different concentrations of stevia and honey significantly affected the viscosity of goat milk supplemented with lontar fruit puree ($p < 0.05$; Graph 3). Viscosity values ranged from 6.19 cP to 8.27 cP. The highest viscosity was found in the H6 treatment group at 8.27 cP, while the lowest viscosity was observed in the S0.15 treatment group at 6.19 cP.

Color

The current results indicated that the type and concentration of natural sweeteners significantly affected the color values of goat milk supplemented with lontar fruit puree ($p < 0.05$; Table 1). Adding honey reduced the L^* value (brightness) as its concentration increased. Similarly, higher stevia levels decreased the L^* value. The a^* value (redness/greenness) for all treatments was negative, indicating a tendency toward green color. Stevia reduced the a^* value (greener) with increasing its concentration, whereas honey increased the a^* value (more red) with increasing the honey concentration. The b^* value (yellowness/blueness) was positive across all treatments, indicating a yellowish color, with stevia producing lower b^* values (3.65-4.15) than honey, which yielded higher b^* values (7.71-9.89).



Graph 2. The acidity level (pH) of goat milk products supplemented with lontar fruit and different concentrations of stevia and honey as natural sweeteners. ^{a,b,c} Mean different superscript letters indicate a significant difference ($p < 0.05$). C: Control (5% sucrose), S: Stevia, H: Honey.



Graph 3. Viscosity of goat milk products supplemented with lontar fruit and different concentrations of stevia and honey as natural sweeteners. ^{a,b,c} Mean different superscript letters indicate a significant difference ($p < 0.05$). C: Control (5% sucrose), S: Stevia, H: Honey.

Table 1. Color values ($L^*a^*b^*$) of goat milk supplemented with lontar fruit and different concentrations of stevia and honey as natural sweeteners

Treatment groups	L^* (Lightness)	a^* (Redness/Greenness)	b^* (Yellowness/Blueness)
C	77.75 ± 0.93^{bc}	-5.31 ± 0.58^a	3.90 ± 0.25^a
S0.05	81.30 ± 1.34^e	-5.49 ± 0.84^a	3.65 ± 0.73^a
S0.1	80.70 ± 0.54^e	-5.85 ± 0.13^a	3.85 ± 0.87^a
S0.15	80.05 ± 0.86^e	-6.05 ± 1.22^a	4.15 ± 1.87^a
H2	78.92 ± 0.29^{cd}	-3.65 ± 0.55^b	7.71 ± 0.28^b
H4	76.29 ± 1.59^b	-3.23 ± 0.50^{bc}	8.49 ± 1.10^{bc}
H6	74.54 ± 1.48^a	-2.44 ± 0.07^c	9.89 ± 0.55^c

^{a,b,c} Mean different superscript letters within each column indicate significant differences ($p < 0.05$). C: Control group, S: Stevia, H: Honey

DISCUSSION

Antioxidant activity

Stevia exhibited superior antioxidant activity compared to the honey treatments and the control group containing 5% commercial granulated sucrose. The superior antioxidant activity of stevia was demonstrated by the DPPH free-radical inhibition value, which reached 33.80% in the 0.15% stevia treatment group, compared with 31.42% in the 6% honey treatment and 17.11% in the control group. The high antioxidant activity observed in the stevia treatment might be due to bioactive compounds present in *Stevia rebaudiana* leaves. Papaefthimiou et al. (2023) and Ibrahim et al. (2024) reported that phenolic compounds, flavonoids, and vitamin C (ascorbic acid) in stevia act as natural antioxidants. The use of stevia as a natural sweetener has been reported in different food and beverage products, including jelly candy, functional okra-ginger beverages, and green tea kombucha (Amelia et al., 2019; Apriyanto et al., 2020; Rukman and Haerussana, 2023). Stevia exhibited higher free-radical-scavenging activity than honey, as indicated by the DPPH assay results (Rukman and Haerussana, 2023). This difference in antioxidant activity among natural sweeteners can be attributed to the presence of steviol glycosides and phenolic compounds in stevia, which may enhance its antioxidant properties (Eliwa and Ahmed, 2025). Peasura and Sinchaipanit (2022) reported that stevia at low concentrations increased antioxidant activity in guava nectar. The addition of 0.05% stevia resulted in the highest free radical-scavenging activity, as measured by the DPPH assay, compared with the other guava nectar formulations. The higher antioxidant activity was attributed to the phenolic and other bioactive compounds present in stevia, which can act as natural antioxidants (Peasura and Sinchaipanit, 2022). Furthermore, the antioxidant activity tended to increase proportionally with increasing honey concentration. The inhibition value increased from 27.33% in 2% honey to 31.42% in 6% honey. This increase demonstrated that honey has potential as a natural antioxidant source in food products. Septiana et al. (2021) indicated that the primary compounds responsible for this protective activity in honey are phenolic and flavonoid compounds. Phenolic and flavonoid compounds are the main compounds acting as antioxidants. These compounds serve as natural antioxidants by donating hydrogen atoms or electrons to unstable molecules (Zeb, 2020). The phenolic content of honey is positively associated with its antioxidant activity, with higher phenolic content corresponding to greater free-radical scavenging activity as determined by the DPPH assay (Abdul, 2021).

Antibacterial activity

The absence of an inhibition zone observed in the honey group could be attributed to the dilution of honey within the milk. This dilution may have reduced the concentration and efficacy of honey antimicrobial activity, thereby weakening its inhibitory activity against the tested bacteria (Luca et al., 2024). Honey contains natural antibacterial components, including the enzyme glucose oxidase, which plays an important role in generating hydrogen peroxide, a key antimicrobial agent in honey. The heating process could diminish the antimicrobial efficacy of honey by impacting the activity of glucose oxidase, the production of hydrogen peroxide, and the content of defensin-1, thereby compromising its antibacterial effects (Bucekova et al., 2018; Mat Ramlan et al., 2021). The reduced antimicrobial activity observed in the present study may be attributable to the availability of nutrients in the milk, including protein, lactose, and fat, which can support the growth of *E. coli* and *S. aureus*. The observed reduction in antibacterial activity in the present study was consistent with the findings of Rababah et al. (2024), who reported that heating can affect the physicochemical properties and biological activity of honey. Although stevia exhibited greater thermal stability than honey, the incorporation of stevia in the current antibacterial assay did not produce an inhibition zone. Stevia contains bioactive compounds such as flavonoids, alkaloids, and tannins, which may compromise the integrity of microbial cell membranes (Singh et al., 2024a). However, the stevia concentrations used in the present study (0.05%, 0.1%, 0.15%) may not have reached the minimum inhibitory concentration required to effectively suppress bacterial growth. The absence of an inhibition zone indicated that, although steviol glycosides are heat-stable and can remain stable within the applied thermal treatment range (Singh et al., 2024b), their concentration was inadequate to effectively suppress bacterial metabolism in milk media. Ahmed et al. (2025) reported that the antimicrobial activity of *Stevia rebaudiana* leaf extract was concentration-dependent, with higher concentrations of bioactive compounds producing stronger inhibitory effects against bacteria. The concentration-dependent antimicrobial activity reported by Ahmed et al. (2025) is relevant to the present study, as the relatively low stevia concentrations used (0.05%, 0.1%, and 0.15%) may have resulted in an insufficient concentration of bioactive compounds to produce a detectable inhibition zone.

Degree of acidity

Stevia supplementation resulted in relatively stable pH values, ranging from 6.44 to 6.58. The pH values of the stevia treatments did not differ from that of the control group (pH 6.45), indicating that the addition of stevia did not notably alter the pH of the final product. The stability of stevia pH values could be attributed to the low concentration of

stevia used as a non-nutritive sweetener, while its major compounds, stevioside and rebaudioside, remained stable across different pH levels and temperatures. The high stability of steviol glycosides across different pH levels and temperature conditions has been documented by [Chughtai et al. \(2025\)](#), suggesting that stevia is unlikely to notably alter the chemical properties of food products. The high thermal stability of steviol glycosides prevents heat reactions from generating organic acid byproducts; therefore, the inclusion of stevia in goat milk supplemented with lontar fruit maintained the milk pH as stable and within the normal range of fresh milk. In contrast to stevia, honey supplementation exhibited a decline in pH value with increasing concentration, from 6.24 at 2% to 6.05 at 4%, then to 5.99 at 6% honey inclusion level. Honey has a naturally acidic pH, typically ranging from 3.2 to 4.5, and its incorporation can increase the final product's acidity ([Gadge et al., 2024](#); [Inaudi et al., 2025](#)). The acidic nature of honey is consistent with the present results, as the increasing honey concentration progressively decreased the pH of the product from 6.24 to 5.99. The greater amount of acidic honey added to the product likely contributed to the increased acidity and consequently the lower pH observed at higher honey concentrations. The reduction in pH value might be due to the natural organic acid content of honey, particularly gluconic acid, formed by the oxidation of glucose by the enzyme glucose oxidase. Goat's milk exhibits strong resistance to pH changes due to its protein, particularly casein, phosphate, and mineral components, all of which remarkably enhance its buffering capacity ([Zakaria et al., 2020](#)). Despite exposure to high-temperature heating, the pH of the product remained relatively stable, which could be attributed to the high buffering capacity of goat's milk.

Viscosity

The higher viscosity observed in the honey treatment groups might be attributed to the high content of simple sugars, particularly fructose and glucose, which are important contributors to honey's rheological properties ([Oroian et al., 2014](#); [Faustino and Pinheiro, 2021](#)). Fructose and glucose are the predominant sugars in honey and contribute substantially to its total soluble solids content. Higher sugar concentrations typically increase viscosity, as elevated dissolved sugar levels can impede molecular motion and reduce fluid flow. [Faustino and Pinheiro \(2021\)](#) reported that the rheological properties of honey are strongly influenced by its glucose and fructose contents. The high concentrations of these sugars can increase the viscosity of honey by increasing the concentration of dissolved solids and restricting the mobility of water molecules, thereby reducing fluid flow. This mechanism is consistent with the present study, in which increasing honey concentration resulted in a progressive increase in viscosity from 7.09 cP at 2% honey to 7.80 cP at 4% and 8.27 cP at 6% honey. Similarly, [Anwar et al. \(2021\)](#) reported that increasing honey concentration in kefir increased viscosity, attributed to honey's high carbohydrate content and its ability to bind water. A similar pattern was observed in the present study, where increasing honey concentration resulted in a progressive increase in viscosity from 7.09 cP at 2% honey to 7.80 cP at 4% and 8.27 cP at 6% honey. Greater water binding by carbohydrates can reduce the mobility of water molecules, thereby increasing product viscosity. Stevia is a non-nutritive sweetener characterized by a very high level of sweetness and is therefore used at very low concentrations in the present study. Consequently, the incorporation of stevia did not impact the product's viscosity as much as honey or table sugar, which have high sugar content. [Astuti et al. \(2021\)](#) indicated that stevia, particularly the extract from *Stevia rebaudiana* leaves, did not contain high concentrations of simple sugars such as glucose, sucrose, maltose, or fructose, and therefore did not affect the total dissolved solids of the product. The low contribution of simple sugars from stevia is consistent with the limited change in viscosity observed in the present study, where viscosity remained nearly unchanged at 6.23, 6.23, and 6.19 cP with the addition of 0.05%, 0.10%, and 0.15% stevia, respectively. The low concentration of stevia and its limited contribution to dissolved solids may therefore account for its minimal effect on product viscosity.

L* Color

The addition of honey tended to decrease the L* value as its concentration increased. The L* values decreased from 78.92 at 2% honey to 76.29 at 4% honey and 74.54 at 6% honey, indicating a gradual reduction in lightness. The decrease in L* value may be attributed to the natural yellow-to-brown color of honey and the formation of brown pigments through Maillard reactions, which could contribute to darker product coloration during heating ([Starowicz et al., 2021](#)). The observed decrease in L* value was consistent with the findings of [Anwar et al. \(2025\)](#), who reported that increasing honey concentration tended to decrease L*. In addition, [Mercan and Akin \(2017\)](#) reported that adding honey increased total phenolic content and reduced L* values, resulting in darker yogurt coloration, which is consistent with the present findings. Conversely, the addition of stevia resulted in higher L* values than the addition of honey and the 5% commercial granulated sucrose, indicating a lighter product color. The lighter color might be due to the absence of reducing sugars in steviol glycosides, which limited the potential for non-enzymatic browning reactions during heating. Consequently, stevia was less likely to induce browning through Maillard reactions or caramelization of sugars than sweeteners containing glucose and fructose. The current findings were consistent with those of [Sulistyawati et al. \(2024\)](#),

who reported that stevia had a lower potential to participate in Maillard reactions than sucrose-based sweeteners. The lower potential of stevia to participate in Maillard reactions may have contributed to the higher L^* values observed in the stevia treatments in the present study by limiting brown pigment formation during heating. Similarly, [Shahu et al. \(2023\)](#) discovered that stevia leaf extract in water notably reduced the formation of Maillard reaction products, supporting the lighter color observed in the stevia treatments compared with the honey and sucrose treatments in the present study. However, as the stevia concentration increased, the L^* value decreased. This finding was consistent with that of [Rungraeng et al. \(2022\)](#), who reported that the lightness value decreased with increasing levels of steviol bioside (the main component of stevia). The decrease in L^* with increasing stevia concentration was further supported by the findings of [Buniowska et al. \(2020\)](#) and [Roy et al. \(2025\)](#), who indicated that the coloration of stevia extract was derived from natural pigments, including tannins and phenolic compounds, and that increasing the concentration of the extract could reduce clarity and increase turbidity, consequently leading to a reduction in the lightness value (L^*).

a^* Color

All treatments exhibited negative a^* values, indicating that the product color was predominantly within the green spectrum. The stevia treatment groups exhibited lower (more negative) a^* values than the other treatment groups, indicating a greater intensity of greenish color in the product. The change to a greener hue might result from natural compounds in stevia extract, such as chlorophyll, polyphenols, and flavonoids, which can contribute to the product's greenish appearance. The current findings are consistent with [Maharika et al. \(2024\)](#), who reported that increasing the concentration of stevia leaves resulted in progressively darker green coloration. This color alteration might be attributed to non-sugar compounds in stevia leaf extract, particularly chlorophyll, the primary contributor to the green color, and flavonoids, which may influence the resulting greenish-to-brownish coloration. Conversely, in the honey treatment, the a^* value increased from -3.65 and -3.23 to -2.44, indicating that the product color became less green and shifted toward red as the honey concentration increased. This color shift toward red could be attributed to the natural pigments in honey and to the formation of reddish-brown compounds from the Maillard reaction during heating. The increase in the a^* value was consistent with the findings of [Anwar et al. \(2025\)](#), who investigated probiotic yogurt beverages produced from different milk sources with varying honey concentrations and reported an increase in redness (a^*) with increasing honey concentration.

b^* Color

The b^* values increased with higher stevia concentrations; however, the b^* values in stevia treatment groups remained comparatively low compared to other treatment groups, resulting in a less yellow product color. [Maharika et al. \(2024\)](#) reported that the substitution of stevia leaf powder in aloe vera dodol increased the b^* value, which might be related to the presence of β -carotene and carotenoids in stevia leaves that contribute to red, orange, and yellow coloration. A similar increase in b^* value was observed in the present study as the stevia concentration increased, although the b^* values remained relatively low compared with the honey and control treatments. The increase in b^* value may be associated with the contribution of pigments present in stevia leaves, including β -carotene and carotenoids. In addition, quercetin 3- β -rutinoside, a flavonoid glycoside found in stevia, may contribute to the yellow coloration. The relatively low b^* values observed in the stevia treatment groups, compared with those in the honey and control treatment groups, may be attributed to the predominance of chlorophyll pigments in the stevia extract. Chlorophyll pigments impart a green coloration, which may diminish the true intensity of yellow. Phenolic and flavonoid compounds present in stevia may also influence light absorption, resulting in less pronounced color intensity. [Habsari et al. \(2026\)](#) reported that the predominance of chlorophyll can mask yellow coloration, thereby leading to lower b^* values. The relatively low b^* values observed in the stevia treatments in the present study are consistent with the reported effect of chlorophyll, as the green pigment may have masked the yellow coloration. Furthermore, [Indiarto et al. \(2024\)](#) reported that phenolic and flavonoid compounds can influence light absorption, thereby reducing color brightness and producing a darker or more subdued appearance. The presence of these compounds in stevia may also have contributed to the relatively low b^* values observed in the present study. The honey treatment groups exhibited higher b^* values than the other treatment groups. The b^* value increased from 7.71 to 8.49 and 9.89 as the honey concentration increased, indicating a progressively more yellow product color. The increase in b^* value may be attributed to natural pigments in honey, including carotenoids, as well as the formation of yellow to brown compounds through non-enzymatic browning reactions, such as the Maillard reaction, during heating. The observed color changes in the present study were consistent with the findings of [Brudzynski \(2023\)](#), who stated that the concentration of pigmented compounds in honey, such as flavonoids, quinones, carotenoids, and Maillard reaction products, plays an important role in the formation of honey color, which can range from yellow, orange, and red to brown. Additionally, chemical reactions involving phenolic

compounds may contribute to color changes, particularly through the oxidation of polyphenols to semiquinones and quinones, which can produce yellow-to-brown coloration.

CONCLUSION

The present study demonstrated that incorporating natural sweeteners, particularly stevia at 0.15%, significantly enhanced the functional properties of goat milk supplemented with lontar fruit by increasing the antioxidant activity and maintaining favorable physicochemical characteristics, including pH. Although neither honey nor stevia exhibited antibacterial effects in the present study, stevia at 0.15% demonstrated potential as a natural sweetener to increase the antioxidant activity of goat milk supplemented with lontar fruit puree. Further studies should investigate a wider range of stevia concentrations and processing conditions and evaluate the physicochemical, antioxidant, microbiological, and sensory stability of goat milk supplemented with lontar fruit puree during storage.

DECLARATIONS

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Authors' contributions

Hilma Hamimah contributed to the methodology, data collection, data analysis, data interpretation, and manuscript preparation. Fatma Maruddin was responsible for study design, data interpretation, and manuscript review and editing. Ambo Ako contributed to manuscript review and editing. All authors have read and approved the final edition of the manuscript.

Availability of data and materials

All data obtained and analyzed in this study are included in the manuscript. No supplementary materials are available for this article. Further data may be requested from the corresponding author upon reasonable request.

Competing interests

The authors declare no conflicts of interest.

Ethical considerations

The authors confirm that the present study is original, has not been submitted elsewhere, and has been examined for misconduct and plagiarism prior to submission to the present journal. The authors accept full responsibility for the originality and integrity of this study before and after submission and publication. No artificial intelligence tools were used in conducting the study, including research design, data collection, laboratory analyses, or data analysis.

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