



Research Article

Physicochemical and anti-nutrient composition of banana leaves (*Musa paradisiaca*) ensiled with watermelon juice (*Citrullus lanatus*)

Odeyinka Simisola Mercy¹ , Abegunde Taye Olurotimi¹ , Ayandiran Samuel Kola² ,
Adunola Funbi Peter¹  and Nwaokolo Stephen Awele¹ 

1. Department of Animal Sciences, Obafemi Awolowo University, Ile Ife. Osun State Nigeria.
2. Department of Animal Science, Osun State University Osogbo. Osun State. Nigeria.

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Prof. Dr. Gian Carlo Tenore

Corresponding Author

Prof. Dr. Odeyinka Simisola
Mercy
E-mail:
smodeyinka@yahoo.co.uk
Tel: +2348037252130

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Abstract

This study investigated the physicochemical properties, proximate composition, and anti-nutritional factors of banana leaves ensiled with varying levels of watermelon juice by a completely randomized design. Banana leaves were harvested from banana plantations and watermelon fruits were procured from local markets. Five silage diets were prepared: T1 (100% banana leaves), T2 (90% banana leaves + 10% watermelon juice), T3 (80% banana leaves + 20% watermelon juice), T4 (70% banana leaves + 30% watermelon juice) and T5 (60% banana leaves + 40% watermelon juice). The silages were compacted and sealed in airtight polyethylene bags for 21 days. The colour of the silages indicated that T1 and T3 had brownish green, T2 and T4 had olive green, while T5 had dark brown greenish. The T1, T2, T3, and T5 silages had pleasant odour, whereas T4 had a fruity smell. T1, T2 and T3 were moderately moist and T4 was slightly moist while T5 was moist. The crude protein content was significantly highest ($p < 0.05$) in T3 (10.21), followed by T3 (9.34), T4 (9.34), T2 (8.95), T1 (8.27) and T5 (8.01). The T1 silage had significantly higher ($p < 0.05$) dry matter, crude fibre and nitrogen free extract content than the other silages. The tannin and oxalate contents significantly ($p < 0.05$) increased ($p < 0.05$) with higher levels of watermelon juice, while saponin content significantly decreased ($p < 0.05$). It could be concluded that banana leaves ensiled with watermelon juice produced silages with attractive attributes, improved crude protein, reduced fibre content and acceptable tannin and oxalate levels for ruminant animals.

1. Introduction

Feed costs and market instability continue to hinder ruminant production, especially in resource-limited regions, driving the search for non-conventional forages and agricultural by-products that are both abundant and cost-effective. Banana (*Musa* spp.) leaves, readily available in tropical and subtropical regions, have shown potential as a sustainable feed ingredient due to their moderate crude protein, high fibre, and essential micronutrient content [1].

However, their practical use in monogastric nutrition, such as animal feed, is constrained by the presence of anti-nutritional factors (ANFs), including tannins, oxalates, saponins, and phytates, which can reduce nutrient digestibility, interfere with mineral absorption, and impair overall growth performance [2]. Ensiling, an anaerobic fermentation process mediated primarily by lactic acid bacteria (LAB) is a proven method for preserving green forage while

potentially reducing ANF concentrations. During ensiling, LAB utilize soluble carbohydrates to produce organic acids, lowering the pH, inhibiting spoilage microorganisms, and hydrolyzing certain phenolic and oxalate compounds, thereby improving feed safety and palatability [3]. Banana leaves and pseudo stems possess adequate water-soluble carbohydrate levels (> 5% DM) and naturally occurring LAB populations (> 10⁵ cfu/g), making them highly suitable for silage production [2]. Recent studies have demonstrated that ensiling banana biomass with carbohydrate-rich additives, such as molasses, beet pulp, or fruit juices, enhances fermentation quality, increases lactic acid yield, and reduces tannin and oxalate concentrations [4]. Watermelon (*Citrullus lanatus*) juice is an underutilized silage additive that provides fermentable sugars and several bioactive compounds, including lycopene, flavonoids, phenolics, and vitamins with antioxidant properties, which may contribute to improved silage stability and nutrient utilization [5]. Integrating watermelon juice into banana leaf silage for rabbit feed, may therefore, offer a dual advantage by mitigating anti-nutritional factors while enhancing the energy density and overall nutritive value of the diet. This study evaluated the impact of watermelon juice on the physicochemical properties, chemical composition, anti-nutrient profile, specifically tannins, oxalates, and saponins of banana leaf silage, with the aim of improving its suitability as a low-cost, nutritionally balanced feed ingredient for ruminant production in resource-constrained systems. Objective of the study was to determine the physicochemical properties, proximate and anti-nutrient parameters of banana leaves ensiled with watermelon juice.

2. Materials and methods

2.1. Experimental location

The experiment was conducted at the Obafemi Awolowo University Teaching and Research Farm, in Ile-Ife, Osun State, Nigeria. Fresh banana leaves (*Musa paradisiaca*) were harvested from various banana plantations located at the Obafemi Awolowo University campus, Ile-Ife, Nigeria. Broken or rejected watermelon fruits (*Citrullus lanatus*), comprising the pulp, rind, and seeds, were also procured from local

fruit stalls in Ile-Ife. The entire fruit (including the rind, flesh, and seeds) was blended into a homogeneous slurry using a heavy-duty mechanical blender (Qasa QBL-1861 Blender).

2.2. Sample preparation

The harvested banana leaves were left to wilt under shade for 4 h to lower the moisture content and facilitate chopping. Following wilting, the leaves were mechanically chopped into smaller pieces of approximately 2–3 cm using a specialized chopper machine (Newhai 9ZP-0.4 Chaff Cutter). The chopped leaves were filled rapidly into thick black polythene bags and compacted at regular intervals to prevent infiltration of air and swift establishment of anaerobic conditions to enhance proper and prompt fermentation with the addition of blended watermelon at varying inclusion levels. The sealed bags were then stored at ambient room temperature (approximately 25 to 30 °C) for a fermentation period of 28 days. Five distinct silage diets were prepared with specific proportions of watermelon juice and conventional feed served as the control. Treatment 1(control) was free of watermelon juice (100% banana leaves) while treatments 2, 3, 4 and 5 contained leaf: watermelon mixtures of 90:10, 80:20, 70:30 and 60:40, respectively. The silages were tightly sealed to prevent air penetration. The experiment was arranged in a completely randomized design with four replicates per treatment (Table 1).

Table 1. Varying proportions of chopped banana leaves and watermelon juice on a fresh weight basis for ensiling.

| Treatment | Banana Leaves (%) | Watermelon juice (%) |
|-----------|-------------------|----------------------|
| T1 | 100 | 0 |
| T2 | 90 | 10 |
| T3 | 80 | 20 |
| T4 | 70 | 30 |
| T5 | 60 | 40 |

T1= 100% Banana leaves + 0% watermelon juice, T2= 90% Banana leaves + 10% watermelon juice inclusion, T3= 80% Banana leaves + 20% watermelon juice inclusion, T4= 70% Banana leaves + 30% watermelon juice inclusion, T5= 60% Banana leaves + 40% watermelon juice inclusion.

2.3. Physicochemical experiments

The Silage was opened after 28 days to determine the physical parameters, such as the colour, smell, texture,

temperature and pH. The appearance was determined by sight, the smell was determined by perceiving it with the nose, the texture was determined by hand feeling, the temperature was determined using a thermometer, and the pH was determined using a pH meter. The temperature was measured by deep insertion of the thermometer into the silages and allowed to stand for 120 s, after which the reading was taken. Silage colour was determined using standard colour chart as described by Kung et al. [6]. For reliable and accurate physical examination of the silage, a group of five trained silage experts was used to evaluate odour and texture. This is essential due to the nominal rather than an ordinal scale was adopted for the physical attributes of the silage [7]. The pH was determined in accordance with the procedure described by [8]. A portion of the ensiled sample (25 g) was taken from each treatment. Exactly 100 mL of distilled water was added to the sample in a beaker and mixed. The mixture was left for 1 h and then shaken. Subsequently, an electric pH meter glass electrode was dipped into the contents of the beaker for 10 s and the pH of each sample was measured. The proximate components (crude protein, crude fibre, ether extract, ash, ether and nitrogen free extracts) of silage samples were determined according to the standard procedure [9].

2.4. Anti-nutritional composition

Anti-nutritional factors such as tannins, saponins and oxalates were determined according to the earlier procedures [10, 11].

2.5. Data analysis

Data were subjected to one-way analysis of variance (ANOVA) using a statistical software package [12]. Significant differences ($P < 0.05$) among treatment means were detected using Duncan's Multiple Range Test.

3. Results and discussion

3.1. Physicochemical parameters of banana leaf ensiled with watermelon juice

Table 2 shows the effects of adding varying quantities of watermelon juice on the appearance, smell/odour, and overall quality of banana leaf silage. These parameters, namely color, odor, pH, temperature, and texture, are essential indicators required to evaluate

the effective silage fermentation and its suitability for animal feeding. The colour of the silages were indicated T1 (brownish green), T3 (brownish green), T2 (olive green), T4 (olive green) and T5 (dark greenish brown). The T1, T2, T3, and T5 silages had pleasant odours, whereas T4 had a fruity smell. The T1, T2 and T3 were moderately moist, T4 was slightly moist, while T5 was moist. The physicochemical attributes of silage appearance, odour, pH, temperature, and texture are critical determinants of its preservation efficiency and animal acceptability. These studies provide insights into fermentation quality, stability, and potential impact on feed intake [13]. The olive-green to brownish-green colour observed in the silages suggests effective preservation, as good quality silage typically retains a greenish hue due to minimal chlorophyll degradation [14]. Slight darkening, as observed in some treatments, may occur naturally during fermentation due to Maillard reactions, without indicating spoilage [15]. This colour stability supports the idea that watermelon juice inclusion did not cause detrimental oxidative changes but maintained the visual appeal necessary for encouraging animal consumption of the feed [16]. The pleasant aroma noted across treatments was a positive indicator of dominant lactic acid fermentation, as opposed to the undesirable butyric acid or ammonia odour associated with clostridial spoilage [17]. Fruity or sweet smells often result from the presence of esters and aldehydes formed during the fermentation of plant sugars, an effect enhanced by sugar-rich additives such as watermelon juice [18]. Pleasant-smelling silage has been shown to increase feed intake in rabbits and other small herbivores, linking fermentation quality directly to the performance outcomes [19].

The recorded pH values of T1, T2 and T5 fell within or close to the optimal range (3.8–4.5) for stable silage, where microbial spoilage is suppressed [16]. The lower pH values in treatments with higher juice inclusion align with the findings of Bureenok *et al.* [16], who reported that fruit-derived additives accelerate lactic acid production by providing fermentable sugars. Rapid acidification is critical during the early stages of ensiling to inhibit undesirable microbes and preserve nutritional value [13].

Table 2. Physicochemical parameters of banana leaf ensiled with water melon juice.

| Parameters | T1 | T2 | T3 | T4 | T5 |
|---------------------|------|------|------|------|-------|
| Appearance (Colour) | BG | OG | BG | OG | DBG |
| Odour | PS | PS | PS | FS | PS |
| pH | 4.40 | 4.12 | 4.61 | 5.45 | 3.79 |
| Temperature(°C) | 29.3 | 29.2 | 29.3 | 28.6 | 29.1 |
| Texture | MM | MM | MM | SM | Moist |

Note: BG; Brownish green, OG; Olive green, DBG; Dark brownish green, PL; Pleasant smell, FS; Fruity smell, MM: Moderately moist, SM; Slightly moist. T1= 100% Banana leaves + 0% watermelon juice, T2= 90% Banana leaves + 10% watermelon juice inclusion, T3= 80% Banana leaves + 20% watermelon juice inclusion, T4= 70% Banana leaves + 30% watermelon juice inclusion, T5= 60% Banana leaves + 40% watermelon juice inclusion.

Table 3. Proximate composition of silages.

| Parameters (%) | T1 | T2 | T3 | T4 | T5 | SEM |
|-----------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------|
| Dry matter | 78.88 ^a | 77.52 ^b | 75.32 ^c | 73.86 ^d | 72.44 ^e | 0.03 |
| Crude protein | 8.27 ^d | 8.95 ^c | 10.21 ^a | 9.34 ^b | 8.01 ^e | 0.05 |
| Ether extract | 1.95 ^e | 2.01 ^d | 2.36 ^b | 2.67 ^a | 2.22 ^c | 0.04 |
| Ash content | 5.92 ^e | 6.72 ^d | 6.85 ^c | 6.94 ^b | 7.11 ^a | 0.022 |
| Crude fibre | 15.01 ^a | 14.98 ^b | 14.79 ^c | 14.72 ^d | 14.58 ^e | 0.008 |
| Nitrogen free extract | 68.78 ^a | 67.29 ^b | 65.68 ^d | 66.29 ^c | 67.28 ^b | 0.02 |

^{a, b, c, d}: Means on the same row with different superscripts are significantly different ($P < 0.05$). T1= 100% Banana leaves + 0% watermelon juice, T2= 90% Banana leaves + 10% watermelon juice inclusion, T3= 80% Banana leaves + 20% watermelon juice inclusion, T4= 70% Banana leaves + 30% watermelon juice inclusion, T5= 60% Banana leaves + 40% watermelon juice inclusion.

Maintaining silage temperature below 40 °C is essential for limiting proteolysis and nutrient loss [14]. The moderate temperatures (28.6 – 29.3) recorded here indicate successful anaerobiosis and minimal aerobic spoilage, consistent with well-packed and adequately sealed silages. This agrees with previous observations that optimal fermentation conditions prevent excessive heating, which can damage proteins and reduce digestibility [17].

An appropriate moisture balance, as reflected in silage texture, is crucial for compaction and microbial activity [18]. The moisture contributed by watermelon juice may have enhanced compaction and promoted the growth of lactic acid bacteria, while avoiding excessive wetness that could encourage effluent loss or secondary fermentation [20]. Slight increases in moisture content in feed or silage, when properly managed, can improve texture and handling characteristics, and may enhance palatability and ease of ingestion in rabbits, provided the material remains within safe dry matter limits to prevent spoilage [21]. The combination of desirable colour, pleasant aroma, favourable pH, controlled temperature, and suitable

texture demonstrates that banana leaf silage with watermelon juice underwent efficient fermentation and preserved its sensory qualities. These results are consistent with those of studies showing that natural fruit additives can improve silage fermentation, extend shelf life, and enhance feed palatability [16].

3.2. Chemical composition of the silage treatments

The proximate composition of the ensiled banana leaves is shown in Table 3. The analysis revealed significant differences ($P < 0.05$) across all measured parameters. Dry matter, crude protein, ether extract, ash, crude fiber, and nitrogen-free extract indicated that the inclusion of watermelon juice significantly altered ($P < 0.05$) the nutritional profile of the ensiled product. As the proportion of watermelon juice increased from T1 (0% juice) to T5 (40% juice), the dry matter content of the ensiled diets decreased progressively. This consistent decrease was expected because watermelon juice has a very high moisture content, and its inclusion dilutes the dry matter of the banana leaves. This trend highlights the direct impact of the additive on the moisture level of the final silage, which is consistent with general silage principles [21].

Table 4. Anti-nutrient profile of banana leaf silage.

| Parameter (mg/100g) | T1 | T2 | T3 | T4 | T5 | SEM | P-value |
|---------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------|---------|
| Tannin | 30.00 ^e | 34.58 ^d | 46.73 ^c | 52.69 ^b | 68.49 ^a | 3.681 | <.0001 |
| Saponin | 55.00 ^a | 48.29 ^b | 34.51 ^c | 28.24 ^d | 22.96 ^e | 2.854 | <.0001 |
| Oxalate | 3.50 ^e | 4.21 ^d | 5.92 ^c | 7.48 ^b | 8.72 ^a | 0.51 | <.0001 |

^{a, b, c, d, e}: Means on the same row with different superscripts are significantly different ($P < 0.05$) T1= 100% Banana leaves, T2= 90% Banana leaves + 10% watermelon juice slurry; T3= 80% Banana leaves + 20% watermelon juice slurry; T4= 70% Banana leaves + 30% watermelon juice slurry; T5= 60% Banana leaves + 40% watermelon juice slurry.

The crude protein content exhibited an interesting trend. T3 (10.21%) had the highest crude protein content, which was significantly higher than that of all other treatments. Crude protein increased significantly ($P < 0.05$) from T1 (8.27%) to T3 (10.21), but then decreased in T4 (9.34%) and T5 (8.01%). The initial increase may be attributed to improved fermentation dynamics and reduced proteolysis under optimal inclusion levels of fermentable sugar sources such as watermelon juice, which can enhance nitrogen preservation during ensiling. This agrees with reports that supplementation with readily fermentable carbohydrates improves silage fermentation quality and crude protein retention [22]. However, higher levels of watermelon juice (T4 and T5) might lead to an overly rapid or less stable fermentation, potentially increasing protein degradation or leaching, resulting in a lower CP compared to T3. Ether extract, which represents the fat content, generally increased significantly ($P < 0.05$) with higher levels of watermelon juice. T4 (2.67%) recorded the highest EE, followed by T3 (2.36%) and T5 (2.22%). Sample T1 (1.95%) had the lowest. This increase in fat content with increasing watermelon juice inclusion could be attributed to the fat content of the watermelon seeds, which were blended with the fruit. The ash content, which indicates the mineral concentration, consistently increased with higher proportions of watermelon juice. Sample T5 (7.11%) showed significantly ($P < 0.05$) highest ash content, whereas, T1 (5.92%) had the lowest. This suggests that watermelon juice contributes a notable amount of minerals to the ensiled product, thereby enriching its mineral profile. In contrast the crude fiber content decreased as the proportion of watermelon juice increased. The T1 (15.01%) had significantly ($P < 0.05$) higher crude fiber content, compared to banana leaves ensiled with graded levels of watermelon. This

reduction was primarily due to the diluting effect of adding a low-fiber material (watermelon juice) to high-fiber banana leaves. Furthermore, the fermentation process itself may lead to some degradation of complex carbohydrates, contributing to a slight reduction in crude fiber, which is a common occurrence in well-fermented silages. The nitrogen-free extract, which primarily represents soluble carbohydrates, showed a variable trend. The NFE was significantly ($P < 0.05$) highest in T1 (68.78), suggesting a high carbohydrate content in the diet with banana leaves ensiled without watermelon juice. NFE then decreased significantly ($P < 0.05$) to T3 (65.68%) but then slightly increased in T4 (66.29%) and T5 (67.28%) groups. The initial decrease might be due to the utilization of soluble carbohydrates by lactic acid bacteria during fermentation, as sugars are converted to organic acids. The subsequent increase at higher watermelon juice levels (T4 and T5) could be attributed to the high sugar content of the watermelon juice, which contributes significantly to the NFE fraction despite microbial activity.

3.3. Anti-nutritional profile of banana leaf silage

The anti-nutrient profiles of the ensiled banana leaf samples are presented in Table 4. The treatments containing watermelon juice (T2, T3, T4 and T5) had significantly higher ($P < 0.05$) tannin and oxalate contents than the control (T1). Notably, the tannin and oxalate contents significantly increased ($P < 0.05$) with increasing watermelon juice level. However, the T1 (55.00) had significantly lowest ($P < 0.05$) saponin content followed by T2 (48.29), T3 (34.51), T4 (28.24) and T5 (22.96). This finding contrasts with the general expectation that ensiling may reduce anti-nutritional factors such as tannins through microbial and enzymatic activity during fermentation. However, the extent of tannin reduction is highly variable and depends on forage type, fermentation conditions, and

additive composition [20]. It is therefore possible that increasing levels of watermelon juice altered fermentation conditions in a way that limited tannin degradation, or introduced additional phenolic compounds that contributed to total tannin levels. Further investigation into the specific type of tannins present and their interaction with fermentation conditions is required. In contrast to tannins, the inclusion of watermelon juice significantly decreased ($P < 0.05$) the saponin content as the levels increased. T1 (55.00 mg/100g) had the highest saponin content, whereas T5 (22.96 mg/100g) had the lowest. This suggests that higher levels of watermelon juice addition and the resulting fermentation conditions may have contributed to a reduction in detectable saponin levels in banana leaf silage, although the extent of saponin reduction during ensiling can vary depending on plant type and fermentation environment. This is beneficial because saponins are anti-nutritional factors known to impair nutrient absorption and reduce palatability in animals [23]. The oxalate content significantly ($p < 0.05$) increased with higher levels of watermelon juice. T2 (4.21 mg/100g) had the lowest oxalate content, whereas T5 (8.72 mg/100g) had the highest.

This suggests that watermelon juice either contributes oxalate to the mixture or that the ensiling conditions do not effectively degrade oxalates and the increase is due to concentration effects as other components are consumed or diluted differently. However, the anti-nutritional factors observed in this study were generally lower than values commonly reported for plant-based feed resources such as leaves, legumes, and agro-industrial by-products. These compounds, including tannins, saponins, and oxalates, are naturally present in many forage materials and can vary widely depending on plant species, maturity, and processing methods [13].

4. Conclusions

It could be concluded that banana leaves ensiled with watermelon juice produced silages with attractive attributes, improved crude protein, reduced fibre content and acceptable tannin, saponin and oxalate contents for ruminant animals. Based on the findings, it is recommended that banana leaves ensiled with

watermelon juice be adopted as a viable alternative feed resource for ruminant animals, particularly during the dry season when forages are scarce in Nigeria and even those available are limiting in essential nutrients. Furthermore, farmers and livestock producers should consider integrating this silage formulation into feeding systems to improve animal performance and feed efficiency, especially during the dry season.

Disclaimer (artificial intelligence)

Author(s) hereby state that no generative AI tools such as Large Language Models (ChatGPT, Copilot, etc.) and text-to-image generators were utilized in the preparation or editing of this manuscript.

Authors' contributions

Conceptualization; supervision; fund acquisition and original draft preparation, S.M.O.; methodology; validation; fund acquisition; formal analysis; software and project administration, T.O.A.; data curation; writing; review and editing and resources, S.K.A.; investigation; methodology; validation and investigation, F.P.A.; investigation; resources; investigation; fund acquisition and project administration, S.A.N.

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Availability of data and materials

All data will be made available on request according to the journal policy.

Conflicts of interest

The authors declare no conflict of interest.

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