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Research Article

Development and evaluation of *Moringa stenopetala*-based functional beverage blended with watermelon and beetroot

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Abstract

The present study aimed to develop a consumer-acceptable beverage from the extract of moringa leaves, watermelon, and beetroot juices for improving consumer acceptance. Juices of moringa, watermelon, and beetroot were blended in nine (9) different ratios, designed using Mini-tab statistical software (v.19.1, USA). The beverages were bottled, stored at room temperatures, and evaluated for Total Soluble Solids (TSS), pH, total bacterial & fungal count, presence of pathogenic microorganisms (*Staphylococcus aureus* and *Escherichia coli*), and 5 sensory parameters during storage for a period of 300 days at intervals of 150 days, using standard procedures. The beverages with higher initial total soluble solids (TSS) maintained relatively stable TSS during storage. There was a significant difference ($p < 0.05$) in pH of different treatments, but no changes ($p > 0.05$) during storage were observed. The beverages observed variations in total bacterial count among different treatments. The total bacterial counts ranged from Not Detected (ND) to 9.5×10^3 cfu/ml, while total fungal growth remained undetectable across all treatments. The microbial quality of all treatments was within acceptable safety limits. Pathogenic organisms (*S. aureus* and *E. coli*) were absent in all the treatments. Beverage having 42.5% moringa, 33.75% watermelon, and 23.75% beetroot consistently obtained significantly higher score ($p<0.05$), ranging from 7.0±0.4 to 7.5±0.5 using 9-point hedonic scale for all sensory parameters throughout storage, indicating strong consumer acceptability and product stability. The pH and TSS of this blended beverage ranged from 5.1±0.05 to 5.2±0.05 and 8.5±0.1 to 8.6±0.1, respectively, during storage. The bacterial count ranged from non-detectable levels to 1×10^3, whereas no fungal and pathogenic microorganisms were detected over 300 days of storage.

Keywords: Beetroot; Beverages; Consumer acceptable; Moringa leaves; Watermelon

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1. Introduction

The genus moringa (family *Moringaceae*) includes about 13 species distributed across tropical and subtropical zones of Africa and Asia. Among them, *Moringa oleifera*, native to the north-western Himalayan foothills of India, is the most widely cultivated and researched species (Abdul Karim et al., 2005; Seifu & Teketay, 2020). In contrast, *Moringa stenopetala* is native to East Africa, particularly Ethiopia, Kenya, and Sudan, where the Konso region of southern Ethiopia is considered a center of its domestication (Assefa et al., 2015).

Despite its potential, *M. stenopetala* remains underutilized compared to *M. oleifera* in most countries. Both species have been recognized globally for their contributions to food security, traditional medicine, and agricultural sustainability. However, the African species *(M. stenopetala*) possesses distinctive morphological and nutritional attributes that makes it particularly valuable in addressing regional nutritional deficiencies (Assefa et al., 2015). Moringa leaves are a rich source of proteins, vitamins (A, B3, C, and E), and essential minerals such as calcium, potassium, iron, and magnesium (Mulyaningsih et al., 2018; El Sohaimy et al., 2015). Comparative nutrient profiling has shown that moringa leaves surpass many conventional foods—for example, higher vitamin C than oranges, greater vitamin A than carrots, more calcium than milk, more potassium than bananas, and significantly more iron than spinach (Rockwood et al., 2013). In addition to macronutrients and micronutrients, the leaves contain bioactive phytochemicals, including flavonoids, phenolic compounds, alkaloids, and saponins, which have been linked to antimicrobial properties (Ajayi et al., 2015; Vieira et al., 2010; Kalpana et al., 2013).

In Ethiopia, malnutrition continues to be a major public health challenge, especially among children, where stunting and wasting contribute to impaired immunity, developmental delays, and elevated mortality risks. Access to animal-derived and fortified foods is often limited due to economic constraints, making locally available, nutrient-dense crops like moringa an attractive alternative. Successful incorporation of moringa into acceptable food products could, therefore, play a significant role in combating malnutrition in resource-constrained communities.

In traditional Ethiopian diets, particularly in Konso, *M. stenopetala* leaves are already incorporated into local foods such as damaa and kurkufaa. The leaves are also dried and powdered for use in teas, biscuits, cereals, and dairy substitutes. Research has demonstrated their value when integrated into bakery and complementary food formulations (Alam et al., 2014; Chinma et al., 2014). Furthermore, moringa leaves have been identified as galactagogues, promoting breast milk production and thereby supporting maternal and child nutrition in food-insecure regions (Melesse et al., 2009; Tetteh, 2008).

Despite these nutritional advantages, moringa's inherent bitterness and grassy taste, particularly in liquid extracts, reduce consumer acceptability. Previous efforts to incorporate moringa into cookies or other fortified products have enhanced nutritional value but have not matched the sensory acceptability of products without moringa (Emelike et al., 2015). Developing moringa-based beverages blended with more palatable fruits, therefore, offers a promising approach to mask undesirable flavors while delivering nutritional benefits.

Fruit juices, especially from sweet and colorful fruits, are widely consumed and highly accepted. Thus, blending moringa extracts with compatible fruits such as watermelon and beetroot, both locally available and inexpensive, have the potential to produce a nutrient-rich beverage that is not only more palatable but also more marketable. The present study was therefore undertaken to formulate and evaluate moringa-based multi-fruit beverages to enhance sensory acceptability, microbial safety, and overall stability during storage.

2. Materials and Methods

2.1 Raw materials

Fresh moringa (*Moringa stenopetala*) leaves were harvested from mature trees located on the campus of the College of Agricultural Sciences, Arba Minch University, Ethiopia. Fresh beetroot (*Beta vulgaris*) and watermelon (*Citrullus lanatus*) were procured from the local market in Arba Minch.

2.2 Juice extraction procedures

2.2.1 Moringa juice

The moringa leaves were thoroughly washed, weighed, and chopped using a stainless-steel knife. Water was added in a 1:1 (w/v) ratio, and the mixture was boiled for 10–15 minutes. The cooked material was then processed using a laboratory juice extractor to obtain the primary extract. The laboratory juice extractor used in the present studies has an in-built mechanism of separating the coarse particles and thus partially filtering the extract. The residue was reprocessed to obtain a secondary extract. Both extracts were combined, and the total juice yield was recorded.

2.2.2 Beetroot juice

Beetroots were washed, peeled, and chopped, followed by the addition of water at a 1:1 (w/v) ratio. The mixture was boiled for 10–15 minutes, and juice was extracted using the same laboratory juicer employed for moringa juice. In the case of beetroot also the residue was reprocessed to obtain a secondary extract, as was done in moringa. Both extracts were combined, and the total juice yield was recorded.

2.2.3 Watermelon juice

Watermelons were washed, sliced, and the rinds removed. The pulp was chopped into small pieces and processed directly using a laboratory juice extractor to obtain the juice.

2.3 Experimental design

The extracted juices (moringa, watermelon, and beetroot) were blended under a simplex mixture design model using Minitab software (v. 19.1, USA). Nine different formulations (shown in Table 1), having the range of moringa juice constituted 40-50% of the total volume, and beetroot and watermelon juices varied between 10-40% each. The treatments of formulation were named T-1, T-2 …… T-9, as reflected in Table 1. The triplicate experiments were undertaken for each formulation.

2.4 Blending and processing of juices

Each formulation was mixed thoroughly, and 4% table sugar was added uniformly across treatments. The mixtures were filtered through muslin cloth, heated to 80-85^{o}C, and hot-filled into sterilized glass bottles. The bottles were sealed with crown caps and pasteurized in boiling water for 25-30 minutes. After pasteurization, bottles were immediately cooled to room temperature, dried, labeled, and stored under ambient conditions for storage analysis.

2.5 Storage and analytical evaluation

Storage studies were conducted at intervals of 150 days for a total period of 300 days. Oliveira et al. (2011) conducted long-term storage of acerola fruit puree and tabulated storage changes for 0, 150, and 300 days. In the present study also the changes in the beverages have been presented for 0, 150, and 300 days. The following parameters were analyzed. Total soluble solids were measured using a hand refractometer (Erma, Japan) and expressed in °Brix. Procedures as reflected in AOAC, 932.12 (2016) were followed. The pH was determined using a calibrated digital pH meter following the AOAC, 981.12 standard methods (2016).

2.6 Sensory evaluation

Sensory acceptability of the beverages was evaluated using a nine-point hedonic scale (Stone & Sidel, 1985; Everitt, 2009), assessing attributes such as color, flavor, taste, mouth feel, and overall acceptability. The 9-point hedonic scale, such as 1, 2, 3, 4, 5, 6, 7, 8, and 9, depicted dislike extremely, dislike very much, dislike moderately, dislike slightly, neither like nor dislike, like slightly, like moderately, like very much, and like extremely, respectively. Each evaluation was conducted by at least twenty-five (25) semi-trained panelists, falling in the age group of 16 to 65 years of age, and at least 30% of them were females.

2.7 Microbial analysis

Microbiological analysis*:* Microbial safety was assessed by determining total bacterial count (TBC), total fungal count (TFC), and the presence of *Escherichia coli* and *Staphylococcus aureus*. Procedures as adopted by Chauhan et al. (2020) were followed for microbial examinations.

Each beverage sample (1 mL) was aseptically transferred into 9 mL of sterile distilled water and homogenized using a vortex shaker. Serial ten-fold dilutions (10^{-1} to 10^{-6}) were prepared. From appropriate dilutions, 1 mL aliquots were pour-plated in duplicate on the recommended media. Enumeration of total fungal count was done on Potato Dextrose Agar (PDA) with 0.01 g/L chloramphenicol after incubation at 25 °C for 3–5 days. Plate Count Agar (PCA) was used for the enumeration of total bacterial count after incubation at 32 °C for 24–48 hours.

Growth of total fungal and bacterial counts was determined by counting colonies on the respective medium using a digital colony counter (Staffordshire, ST15 OSA, UK) and expressed as colony-forming units per mL (cfu/mL). For the detection of pathogens, the microorganism *E. coli*, Mac Conkey agar was used, and for *Staphylococcus aureus*, Mannitol Salt Agar (MSA) was used. For both *E. coli* and *S. aureus* incubation time of 24 hours was adopted after incubating at 44^{o}C and 37^{o}C, respectively, being the selective temperatures for these pathogenic microorganisms for ascertaining their presence/growth.

2.8 Statistical analysis

Sensory data were subjected to analysis of variance (ANOVA) to determine the significance of treatment and storage effects. Results were expressed as mean ± standard deviation (SD), and means followed by different superscript letters within the same column indicate a significant difference (Steel et al., 1997). Mean comparisons were carried out using Duncan's multiple range test at a 5% significance level ($p < 0.05$) to separate the treatment means.

3. Results and Discussions

In the current study, the juice/aqueous extract from *Moringa stenopetala* leaves was subjected to sensory evaluation. Initial sensory evaluation of the aqueous extract from *Moringa stenopetala* leaves showed a very low acceptability score of 2.5 on the 9-point Hedonic scale. This places consumer response between "dislike very much" and "dislike moderately." Such rejection can be attributed to the combination of low total soluble solids (TSS; 2.5 °Brix) and the characteristic bitterness and grassy notes of moringa juice. While developing a commercial beverage from moringa, Rodrigues et al. (2023) during sensory evaluation observed that green, grassy and herbal flavors, as well as sour, bitter taste and presence of precipitate in the moringa beverage were considered unpleasant attributes by the panelists. Similar outcomes have been reported in other studies, where inclusion of moringa enhanced nutritional value but compromised sensory quality (Ajayi et al., 2015; Melesse et al., 2009; Chinma et al., 2014).

To improve sensory appeal, moringa juice was blended with watermelon and beetroot juices in nine formulations (T1–T9) in different ratios as reflected in Table 1. Both beetroot and moringa juices had low initial TSS (2.5 °Brix), whereas watermelon contained higher soluble solids (7.5 °Brix). Consequently, blended products exhibited TSS values between 3.0 °Brix and 4.5 °Brix before sugar addition. After the uniform addition of 4% sucrose, the TSS of blends increased to 7.0–8.5 °Brix, improving sweetness and consumer appeal. Watermelon and beetroot were chosen not only for their complementary flavor and vibrant color but also for their wide availability in the region, making them ideal for commercial blending and value addition.

As depicted in Table 1, treatments T-1, T-3, T-5, and T-7 had significantly higher initial TSS (4.5 °Brix) compared to T-2, T-4, and T-6 (3.5 °Brix). T-8 showed intermediate TSS (4.0 °Brix), not significantly different from either group. T-9 had the lowest TSS (3 °Brix). A similar pattern was observed after the addition of an equal quantity of sugar to different blends. These differences will reflect the initial juice composition and blending ratios used in each treatment.

The blended beverages without the addition of sugar were subjected to sensory evaluation. Initial evaluation of these unsweetened blends showed a slight improvement in acceptability compared to pure moringa juice, but the overall acceptability scores ranged from 3.0 to 4.5, indicating levels between “dislike moderately” and “neither like nor dislike.” While blending effectively reduced the intensity of the undesirable moringa flavor, the products still fell short of consumer expectations for pleasant taste.

To further enhance sensory appeal and mask residual bitterness, 4% sugar was added uniformly to all blended formulations. The TSS of the sweetened blends increased accordingly, ranging between 7.0°Brix and 8.5°Brix, as shown in Table 1. These sweetened blends were then subjected to sensory evaluation, the results of which are discussed in this paper.

This strategic blending approach not only aimed to improve taste and color but also served as a value addition method for locally grown fruits. The potential for commercialization of such functional beverages is promising, especially when nutritional richness is matched with acceptable sensory quality.

Table 1. Total soluble solids of moringa-watermelon-beetroot blended beverages

Sample code	Beverage blending ratio (mL/100 mL)			TSS (°Brix)	TSS (°Brix) after adding 4% sugar
	Moringa	Watermelon	Beetroot		
T-1	47.5	33.75	18.75	4.5^{a}	8.5^{a}
T-2	40.0	20.00	40.00	3.5^{b}	7.5^{b}
T-3	50.0	40.00	10.00	4.5^{a}	8.5^{a}
T-4	47.5	18.75	33.75	3.5^{b}	7.5^{b}
T-5	42.5	33.75	23.75	4.5^{a}	8.5^{a}
T-6	42.5	23.75	33.75	3.5^{b}	7.5^{b}
T-7	40.0	40.00	20.00	4.5^{a}	8.5^{a}
T-8	45.0	27.50	27.50	4.0^{ab}	8.0^{ab}
T-9	50.0	10.00	40.00	3.0^{c}	7.0^{c}

Superscripts indicate significant differences ($p < 0.05$) among treatments in a column. Treatments sharing the same letter within a column are not significantly different.

Total soluble solids (TSS) and pH are very important factors in any fruit beverage. The TSS contributes to consumer acceptance, and pH plays a role in microbial population. The changes in these parameters were studied during storage and are presented in Table 2. During 300 days of storage, treatments with higher initial TSS (T1, T3, T5, T7) retained relatively stable soluble solid levels. T9 consistently showed the lowest TSS, though it slightly increased by the end of storage. The pH values across treatments exhibited a gradual, statistically significant decline over time. This mild acidification likely reflects natural biochemical changes during storage. Noaman et al. (2022) reported pH values comparable to the present findings in the moringa beverages blended with different fruit juices.

Microbiological evaluations (Table 3) at 0, 150, and 300 days confirmed that all beverages remained within acceptable safety limits. Total bacterial counts ranged from "not detected" at baseline to a maximum of 9.5×10^3 cfu/ml after extended storage in T3. Fungal growth was absent in all treatments, and neither *Staphylococcus aureus* nor *Escherichia coli* were detected at any stage. Although bacterial presence increased slightly during storage in some formulations, but all values remained well below international safety thresholds ($<10^5$ cfu/ml) as defined by Food Standards Australia New Zealand (2001) and the World Health Organization (WHO, 2021). Treatments such as T4, T5, and T8 showed minimal or no bacterial growth even after 300 days, further confirming their safety.

Earlier researchers (El-Shawaf et al., 2017) also observed that moringa juice blended with other fruit juices (strawberry, cantaloupe, guava, and pomegranate) had initially no viable bacterial count, but with the advancement of the storage period, the microbial count was observed in different blends, and the total count varied from blend to blend. Present results also indicate similar trends. In a study conducted by Boniface et al. (2020), it was observed that the addition of 10% *Moringa oleifera* leaf juice to pasteurized sugarcane juice had helped to have lower yeast/mould and *Leuconostoc sp.* counts compared to the juice without moringa leaf juice.

Table 2. Effect of storage period on total soluble solids and pH of moringa-based beverages

Treatment	Total soluble solids, ^{o}B in storage			pH		
	0-day	150-days	300-days	0-days	150-days	300-days
T-1	8.5± 0.10^{a}	8.8± 0.10^{a}	8.8± 0.10^{a}	5.2± 0.05^{a}	5.1± 0.05^{a}	5.0± 0.05^{a}
T-2	7.5± 0.10^{b}	7.6± 0.10^{b}	7.7± 0.10^{b}	4.9± 0.05^{b}	5.1± 0.05^{a}	5.1± 0.05^{a}
T-3	8.5± 0.10^{a}	8.7± 0.10^{a}	8.6± 0.10^{ab}	5.2± 0.05^{a}	5.1± 0.05^{a}	5.1± 0.05^{a}
T-4	7.5± 0.10^{b}	7.7± 0.10^{b}	7.7± 0.10^{b}	5.2± 0.05^{a}	5.1± 0.05^{a}	5.1± 0.05^{a}
T-5	8.5± 0.10^{a}	8.5± .10^{ab}	8.6± 0.10^{ab}	5.2± 0.05^{a}	5.1± 0.05^{a}	5.1± 0.05^{a}
T-6	7.5± 0.10^{b}	7.5± 0.10^{b}	7.8± 0.10^{b}	5.1± .05^{ab}	5.0± 0.05^{a}	5.0± 0.05^{a}
T-7	8.5± 0.10^{a}	8.8± 0.10^{a}	8.8± 0.10^{a}	5.0± 0.05^{b}	5.0± 0.05^{a}	5.0± 0.05^{a}
T-8	8.0± 0.10^{c}	7.9± 0.10^{b}	8.4± 0.10^{ab}	5.0± 0.05^{b}	4.9± 0.05^{b}	4.9± 0.05^{b}
T-9	7.0± 0.10^{d}	6.9± 0.10^{c}	7.5± 0.10^{c}	5.1± .05^{ab}	5.1± 0.05^{a}	5.1± 0.05^{a}

Superscripts indicate significant differences ($p < 0.05$). Treatments sharing the same letter are not significantly different.

Table 3. Microbial count of moringa-based multi-fruit beverages during storage

Treatments	Total bacteria (cfu /mL)			Fungi (cfu /mL)			Pathogenic bacteria		
	0-day	150-days	300-days	0-day	150-days	300-days	0-day	150-days	300-days
T-1	ND^{a}	0.5x0^{-4a}	1×10^{3a}	ND	ND	ND	ND	ND	ND
T-2	ND^{a}	1x0^{-4ab}	2×10^{3ab}	ND	ND	ND	ND	ND	ND
T-3	ND^{a}	9.5 x0^{-4b}	9.5×10^{3b}	ND	ND	ND	ND	ND	ND
T-4	ND^{a}	ND^{a}	ND ^{a}	ND	ND	ND	ND	ND	ND
T-5	ND^{a}	0.5x0^{-4a}	1×10^{3a}	ND	ND	ND	ND	ND	ND
T-6	ND^{a}	4.0x0^{-4c}	4×10^{3c}	ND	ND	ND	ND	ND	ND
T-7	ND^{a}	2.0x0^{-4ab}	2×10^{3ab}	ND	ND	ND	ND	ND	ND
T-8	ND^{a}	ND^{a}	ND^{a}	ND	ND	ND	ND	ND	ND
T-9	ND^{a}	0.5x0^{-4a}	1×10^{3a}	ND	ND	ND	ND	ND	ND

ND=Not Detected; Values with different superscripts within a column differ significantly ($p < 0.05$). Shared superscripts (e.g., nif values are statistically similar).

Pathogenic bacteria like *S. aureus* and *E. coli*, reported to be among the major causes of food-borne diseases, were absent in all the treatments in the present studies, thus establishing the safety for consumers. So, it can be concluded that the beverages remained safe for consumption even up to 300 days of storage at ambient temperatures.

The sensory attributes of color, appearance, mouth feel, taste, and overall acceptability were tracked over 0, 150, and 300 days of storage and are presented in Figures 1 to 5. Each score represents the average rating from the panelists, assessing the five attributes. Color and appearance score of all treatments (Figure 1 & 2) ranged from 6.0 to 7.5 during storage, except the initial scores of 8.0 scored by T-2 for both color and appearance attributes. The initial high score of 8.0 scored for color and appearance by T-2 blend (containing a higher beetroot proportion) is due to the strong natural pigmentation. However, despite the high initial values of color and appearance of T2 treatment, the product exhibited a decline in both these attributes as well as in taste and overall acceptability during 300 days of storage. The color scores in most treatments remained stable throughout storage, particularly in T4, T5, T6, and T9.

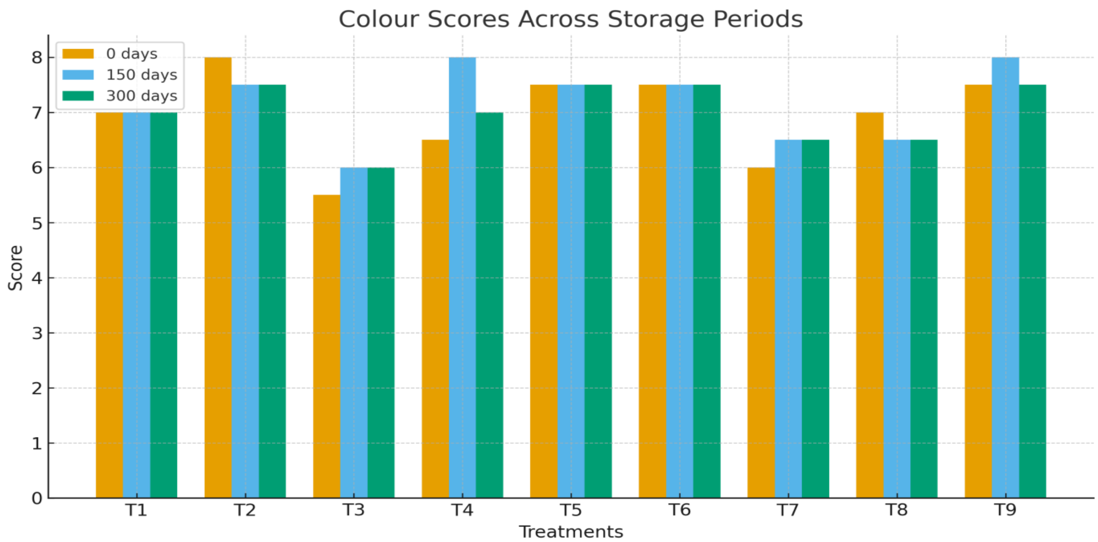

Figure 1. Color scores of moringa beverages during storage

Scores for mouth feel (Figure 3) of beverages ranged from 4.5 to 7.5. Beverage with 50% moringa, 10% watermelon and 40% beetroot (T-9) had the lowest score for this attribute, ranging from 4.5 to 6.0. The best performance in respect of mouth feel was demonstrated by T-5, recording a score of 7.0 to 7.5 during a 300-day storage period.

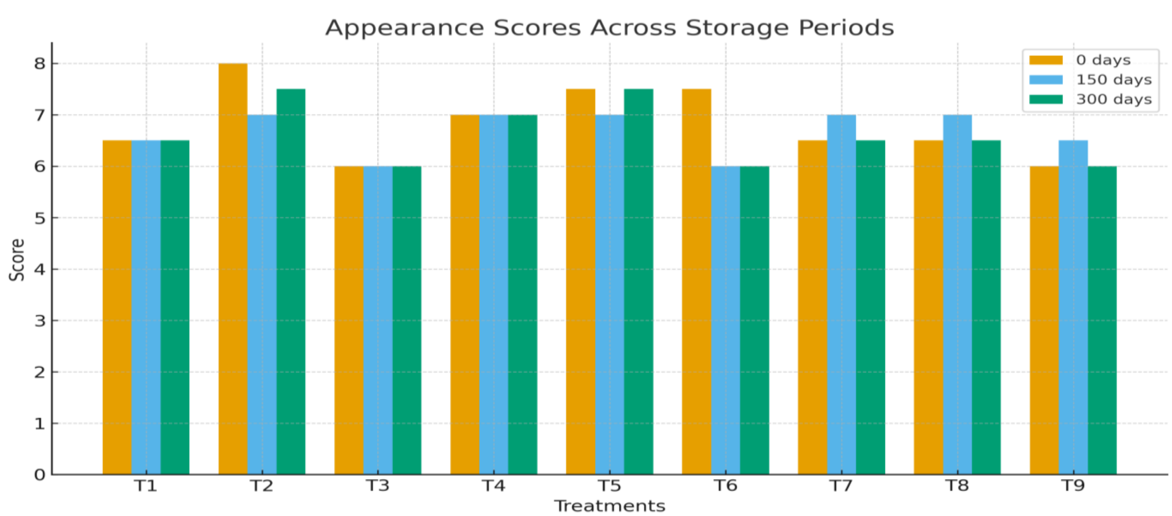

Figure 2. Appearance scores of moringa beverages during storage

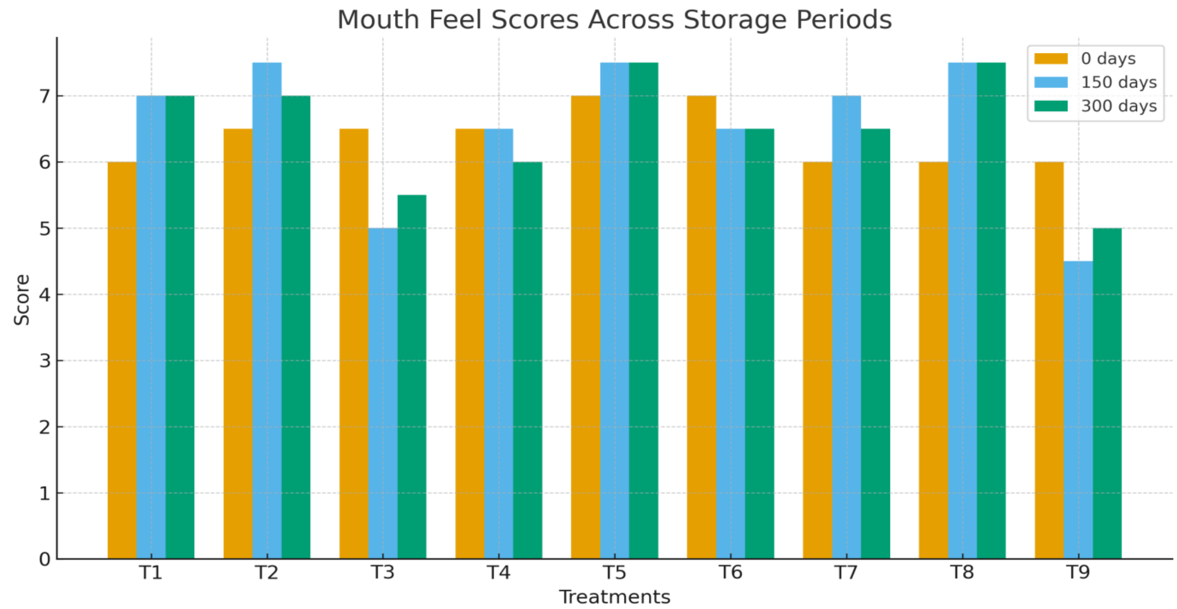

Figure 3. Mouth feel scores of moringa beverages during storage

Both “Taste” and “Overall acceptability” scores ranged from 5.5 to 7.5 (Figures 4 & 5) during storage studies. Treatment T-5 retained its superiority over other treatments in respect of both taste and overall acceptability by maintaining score values of 7.0 to 7.5 for both attributes during the entire storage period. Treatments T3 and T9 had comparatively lower scores for the taste attribute, likely due to higher proportions (50%) of moringa or less effective masking of its bitter flavor.

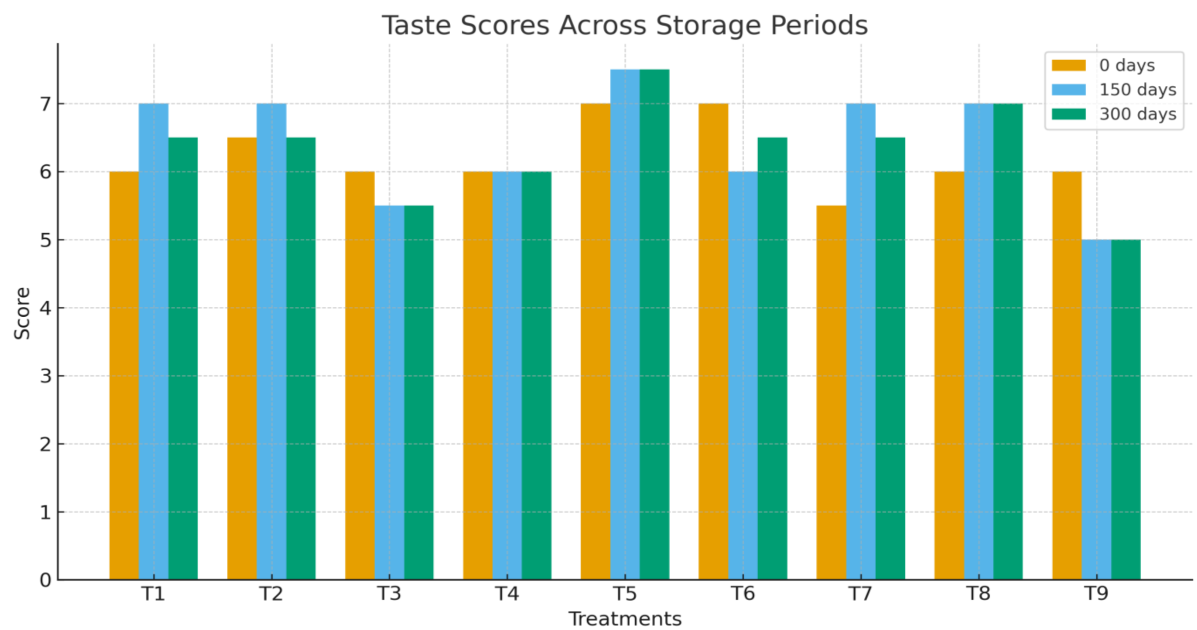

Figure 4. Taste scores of moringa beverages during storage

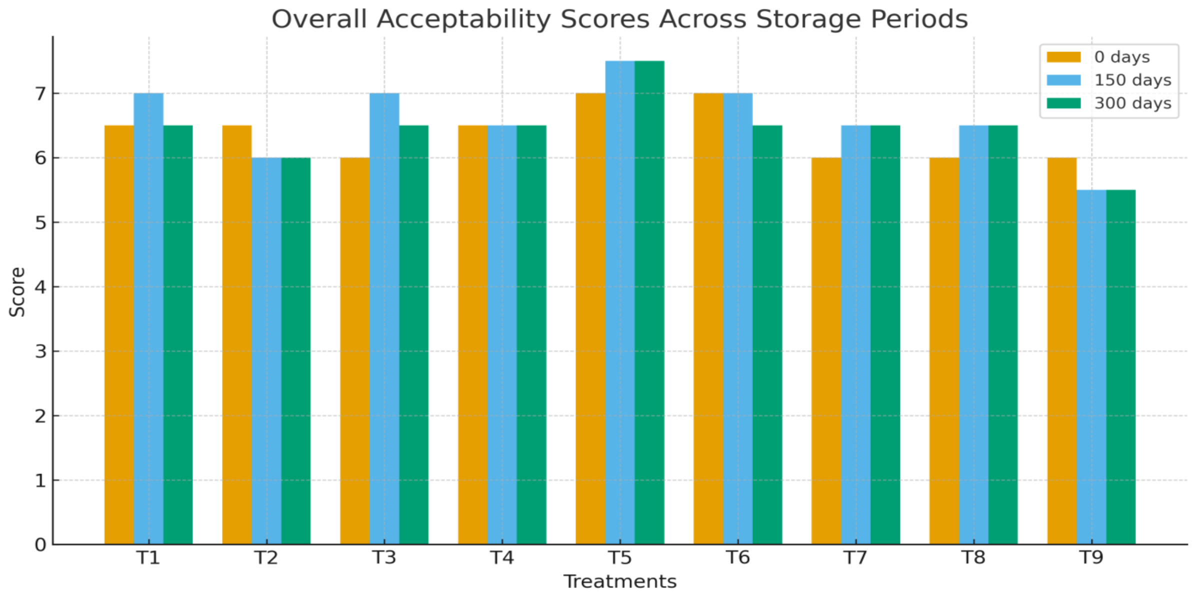

Figure 5. Overall acceptability scores of moringa beverages during storage

The data show that, in general, most of the attributes showed minor fluctuations, possibly due to biochemical changes in the beverage matrix. Notably, the addition of watermelon and beetroot appears to enhance both visual and organoleptic quality. This highlights the importance of strategic blending in improving the marketability of nutrient-dense but less palatable ingredients such as *Moringa stenopetala* leaf juice. Treatment T5 (42.5% moringa, 33.75% watermelon, 23.75% beetroot) achieved the most balanced flavor profile, maintaining scores 7.0 and above across all intervals. This treatment scored high across for all parameters throughout storage, indicating strong consumer acceptability and product stability.

4. Conclusions

This study demonstrated that although *Moringa stenopetala* leaf extract is highly nutritious, its direct use as a beverage is limited by low soluble solids and an inherently bitter flavor that compromises sensory acceptance. Strategic blending with watermelon and beetroot juices, along with the addition of sucrose, markedly improved the sensory properties and overall consumer preference.

Across the nine formulations developed, the blend containing 42.5% moringa, 33.75% watermelon, and 23.75% beetroot (T5) consistently achieved the highest scores for taste, mouth feel, and overall acceptability throughout 300 days of storage. This formulation also maintained stable TSS, pH levels, and microbial counts well within internationally accepted standards, confirming both quality and safety during long-term storage.

The findings highlight that locally available fruits can be effectively combined with moringa to mask undesirable flavors and produce a highly acceptable, nutrient-dense beverage. Such products can support nutrition security in Ethiopia and similar regions by offering affordable, functional food derived from underutilized crops. Furthermore, the demonstrated storage stability and consumer acceptability suggest strong potential for the commercialization of moringa-based blended beverages, particularly in markets seeking natural and health-promoting alternatives.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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