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Journal of Agroalimentary Processes and Technologies 2026, 32 (2), 218-227

Journal of Agroalimentary Processes and Technologies

Quality and Antioxidant Evaluation of Tomato Juice with Plant Extracts

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Received 30 April 2026; Revised 13 May 2026, Published 26 May 2026

Abstract
The present study focuses on the development and evaluation of tomato juice assortments flavored with medicinal and aromatic plants, aiming to enhance their functional and sensory properties. Two variants were formulated: tomato juice enriched with mint extract, intended as a refreshing beverage, and tomato juice flavored with thyme extract, designed for culinary applications. The experimental approach included the preparation of samples followed by physicochemical and functional analyses, such as soluble dry matter, total polyphenol content, antioxidant capacity, and pH determination. In addition, sensory evaluation was performed to assess consumer acceptability. The results indicated that the incorporation of plant extracts contributes to an increase in bioactive compounds and antioxidant activity, while maintaining suitable physicochemical characteristics. Differences between variants were observed depending on the type of extract used, influencing both functional properties and sensory perception.
The study demonstrates that the use of medicinal and aromatic plant extracts represents a viable approach for obtaining value-added tomato juice products with improved nutritional quality and consumer appeal.
Keywords: *polyphenols; thyme; mint; functional beverages; plant extracts.*

1. Introduction

In the current context of functional food development, the valorization of plant-based resources represents a major direction in the food industry, aiming to obtain products with enhanced nutritional and functional value [1]. The incorporation of medicinal and aromatic plant extracts into conventional foods is considered an effective strategy to increase the content of bioactive compounds and to diversify food products in line with consumer demand for natural and healthy alternatives [2,3]. Tomatoes (*Solanum lycopersicum L.*) are among the most important agricultural crops worldwide and are widely consumed due to their nutritional value and versatility [4]. They are an important source of bioactive compounds, including carotenoids, polyphenols, and vitamin C, which contribute to reducing oxidative stress and protecting against chronic diseases [5,6]. Additionally, tomatoes contain essential phytonutrients such as β-carotene and lycopene, which play a significant role in the prevention of cardiovascular and metabolic disorders [7]. Both fresh tomatoes and processed tomato-based products are valuable sources of nutrients and biologically active compounds [8]. Lycopene, the predominant carotenoid in tomatoes, is responsible for their characteristic red color and exhibits strong antioxidant activity [9]. Recent studies have highlighted its role in reducing inflammation, preventing cardiovascular diseases, and lowering cancer risk [10,11]. Furthermore, lycopene contributes to metabolic regulation and the reduction of oxidative stress associated with chronic diseases [12]. The bioavailability of bioactive compounds

Citation: Radu A-M, Bădărău C.L., Pădureanu V., Canja C.M.: a review, *Journal of Agroalimentary Processes and Technologies* **2026**, 32 (2), 218-227
DOI:10.59463/JAPT2026.2.10

in tomatoes is significantly influenced by technological processing, including thermal and mechanical treatments. These processes can induce structural changes in bioactive compounds, leading to either an increase or a decrease in their bioavailability depending on processing conditions [8].

From a morphological perspective, the raw material used for tomato juice production consists of epicarp (skin), mesocarp (pulp), placental tissue, seeds, and locules, all of which influence processing yield and final product quality [13]. The chemical composition of tomatoes is complex and variable, being influenced by genetic, environmental, and technological factors [14].

Tomato quality is primarily determined by genetic factors (variety), but it is also significantly affected by cultivation and processing conditions such as fertilization, irrigation, temperature, and humidity. Organoleptic and physicochemical properties are further influenced by ripeness stage, harvesting time, and storage conditions [15]. The freshness and flavor of tomatoes are determined by the balance between organic acids, soluble sugars, and volatile aromatic compounds. Texture and consistency are influenced by the content of pectic substances, proteins, and structural fibers such as cellulose and hemicellulose [15].

Tomato juice is obtained by crushing and filtering fresh tomatoes and is considered a natural product with high nutritional value. In industrial processing, tomatoes with uniform shape, intense red color, and absence of defects are preferred, as they ensure superior product quality and minimal loss of valuable nutrients [14].

The enrichment of tomato juice with extracts from medicinal and aromatic plants, such as mint (*Mentha piperita*) and thyme (*Thymus serpyllum*), represents an innovative approach to developing products with enhanced functional properties [16]. These plants are rich in phenolic compounds, flavonoids, and essential oils, which provide antioxidant, antimicrobial, and anti-inflammatory activities [17,18].

Current consumption trends indicate an increasing demand for natural and functional foods, particularly vegetable-based beverages, due to their health benefits and nutritional profile [19]. In this context, the development of innovative tomato juice products enriched with plant extracts meets consumer expectations and contributes to the expansion of functional food categories [1].

Therefore, the present study investigates the improvement of the quality and antioxidant capacity of tomato juice through the incorporation of mint and thyme extracts, as well as their influence on the physicochemical and sensory properties of the resulting products.

2. Materials and Methods

The experimental study was carried out using tomato juice obtained from two different commercial producers, coded as T and F. These samples were selected in order to evaluate potential differences in quality parameters depending on the source of raw material. Plant extracts used for enrichment included:

- pure mint extract (*Mentha piperita*)(Solaris Plant), obtained through cold extraction from certified organic essential oil;
- thyme extract (*Thymus serpyllum*) (Dacia Plant), prepared as a hydroalcoholic extract using 8% plant material and 96% ethanol.

All samples were prepared using standardized volumes of tomato juice (200 mL) and different concentrations of plant extracts, resulting in a total of ten experimental variants: two control samples (T and F) and eight enriched samples. The coding of experimental samples, together with the corresponding extract volumes and dilutions, is presented in Table 1.

Table 1. Coding of experimental tomato juice samples based on extract type and concentration

Sample Code	Mint Extract (µL)	Dilution (Mint)	Thyme Extract (µL)	Dilution (Thyme)	Tomato Juice (mL)
T	–	–	–	–	200
TM1	100	1:2000	–	–	200
TM2	200	1:1000	–	–	200
TT1	–	–	600	1:333	200
TT2	–	–	1200	1:166	200
F	–	–	–	–	200
FM1	100	1:2000	–	–	200
FM2	200	1:1000	–	–	200
FT1	–	–	600	1:333	200
FT2	–	–	1200	1:166	200

Legend:
T – control sample (producer T);
TM1 – tomato juice (producer T) + mint extract (100 µL, dilution 1:2000);
TM2 – tomato juice (producer T) + mint extract (200 µL, dilution 1:1000);
TT1 – tomato juice (producer T) + thyme extract (600 µL, dilution 1:333);
TT2 – tomato juice (producer T) + thyme extract (1200 µL, dilution 1:166);
F – control sample (producer F);
FM1 – tomato juice (producer F) + mint extract (100 µL, dilution 1:2000);
FM2 – tomato juice (producer F) + mint extract (200 µL, dilution 1:1000);
FT1 – tomato juice (producer F) + thyme extract (600 µL, dilution 1:333);
FT2 – tomato juice (producer F) + thyme extract (1200 µL, dilution 1:166).

2.1. Experimental design

The experimental variants were obtained by adding different volumes of mint and thyme extracts to the tomato juice samples. The concentrations were selected based on preliminary sensory evaluations conducted by a panel of five trained assessors. The most acceptable formulations were selected for further analysis.

All samples were stored under refrigeration conditions (4–8°C) and analyzed at different time intervals: initially (0 days), after 7 days, 14 days, and 21 days, in order to evaluate the effect of plant extracts on quality parameters and storage stability.

3. Results and Discussion

3.1. Results of soluble solid content

The results obtained for soluble solids content (%) (Table 2) showed a gradual increase during the storage period for all analyzed tomato juice samples.

Table 2. Results of soluble solids content (%) in control and plant extract-enriched tomato juice samples during storage

Sample	Initial (0 days)	7 days	14 days	21 days
T	7.39 ± 0.02^{a}	7.51 ± 0.04^{a}	7.57 ± 0.03^{a}	7.63 ± 0.02^{a}
TM1	7.37 ± 0.03^{a}	7.41 ± 0.02^{b}	7.43 ± 0.04^{b}	7.47 ± 0.03^{b}
TM2	7.32 ± 0.04^{b}	7.37 ± 0.03^{b}	7.41 ± 0.02^{b}	7.45 ± 0.04^{b}
TT1	7.21 ± 0.02^{c}	7.25 ± 0.03^{c}	7.31 ± 0.04^{c}	7.36 ± 0.03^{c}
TT2	7.02 ± 0.03^{d}	7.09 ± 0.04^{d}	7.14 ± 0.02^{d}	7.19 ± 0.03^{d}
F	6.58 ± 0.02^{e}	6.74 ± 0.04^{e}	6.81 ± 0.03^{e}	6.87 ± 0.02^{e}
FM1	6.47 ± 0.03^{f}	6.51 ± 0.02^{f}	6.54 ± 0.04^{f}	6.59 ± 0.03^{f}
FM2	6.41 ± 0.04^{f}	6.45 ± 0.03^{f}	6.49 ± 0.02^{f}	6.56 ± 0.04^{f}
FT1	6.36 ± 0.02^{g}	6.39 ± 0.03^{g}	6.45 ± 0.04^{g}	6.49 ± 0.03^{g}
FT2	6.31 ± 0.03^{g}	6.35 ± 0.04^{g}	6.39 ± 0.02^{g}	6.48 ± 0.03^{g}

Values are expressed as mean ± standard deviation (SD), n = 3.
Different superscript letters (a–g) within the same column indicate statistically significant differences between samples ($p < 0.05$), according to one-way ANOVA followed by Tukey's post hoc test. Samples sharing the same letter are not significantly different ($p > 0.05$).

This trend can be attributed to ongoing physico-chemical changes, including concentration effects and transformations of soluble compounds. Similar behavior has been reported in recent studies on tomato juice, where storage conditions influenced the composition and stability of soluble components [25].

Within the group of samples obtained from producer T, the control sample (T) recorded the highest soluble solids values throughout the storage period. The samples enriched with mint extract (TM1 and TM2) showed slightly lower values, while the lowest values were observed in thyme-enriched samples (TC1 and TC2). Statistical analysis confirmed significant differences ($p < 0.05$) between the control and thyme-treated samples. These results suggest that the addition of plant extracts, especially thyme, may lead to a slight dilution effect or interactions with soluble compounds, reducing the overall soluble solids content. Similar effects of plant extract addition on physicochemical properties have been reported in functional beverage studies [19].

A similar pattern was observed for samples obtained from producer F. The control sample (F) presented the highest soluble solids values, followed by mint-treated samples (FM1 and FM2), while thyme-treated samples (FC1 and FC2) exhibited the lowest values. However, the differences between mint- and thyme-enriched samples were less pronounced compared to those observed in samples from producer T. This may indicate that the initial composition of the raw material plays an important role in determining the final product characteristics. According to recent research, soluble solids content is strongly influenced by tomato variety, maturity stage, and processing conditions [26].

When comparing the two producers, it can be observed that all samples from producer T consistently showed higher soluble solids values than those from producer F at all storage times. This difference is most likely due to variations in raw material quality, including sugar content and ripeness of tomatoes. Previous studies have demonstrated that soluble solids content is directly correlated with sugar levels and plays a key role in determining the sensory quality and acceptability of tomato-based products [27].

In addition to physicochemical differences, soluble solids content is closely related to sensory perception, particularly sweetness and overall flavor. Recent studies have highlighted that sensory attributes such as taste, aroma, and overall acceptability are significantly influenced by the chemical composition of tomato juice and its changes during storage [28,29]. In this context, the slightly lower soluble solids values observed in extract-enriched samples may also influence their sensory characteristics.

Overall, although the addition of mint and thyme extracts resulted in slightly lower soluble solids values compared to control samples, the increasing trend during storage was maintained for all variants.

This indicates that storage time has a stronger influence on soluble solids evolution than the addition of plant extracts. These findings are in agreement with recent studies on tomato and fruit-based beverages, where storage conditions were identified as a key factor affecting physicochemical properties and product quality [25].

3.2. Results of total phenol content

The results of total polyphenol content (TPC) in tomato juice samples during storage are presented in Table 3.

Table 3. Result of total phenol content

Sample	Initial (0 days)	7 days	14 days	21 days
T	30.90 ± 0.5^{g}	25.50 ± 0.6^{h}	20.27 ± 0.4^{i}	17.65 ± 0.5^{j}
TM1	43.80 ± 0.7^{f}	35.60 ± 0.5^{g}	34.47 ± 0.6^{g}	32.70 ± 0.5^{h}
TM2	39.20 ± 0.6^{f}	30.90 ± 0.7^{h}	28.75 ± 0.5^{h}	27.68 ± 0.6^{i}
TT1	41.90 ± 0.5^{f}	36.10 ± 0.6^{g}	34.26 ± 0.5^{g}	33.34 ± 0.4^{h}
TT2	46.80 ± 0.6^{e}	40.50 ± 0.7^{f}	39.28 ± 0.6^{f}	38.67 ± 0.5^{g}
F	62.10 ± 0.7^{d}	55.20 ± 0.8^{e}	50.82 ± 0.6^{e}	47.41 ± 0.7^{f}
FM1	63.80 ± 0.6^{d}	57.20 ± 0.7^{e}	52.56 ± 0.8^{e}	51.24 ± 0.6^{e}
FM2	79.80 ± 0.9^{c}	72.85 ± 0.8^{c}	70.26 ± 0.7^{c}	69.17 ± 0.8^{c}
FT1	74.90 ± 0.7^{c}	68.45 ± 0.9^{c}	67.23 ± 0.8^{c}	65.26 ± 0.7^{d}
FT2	87.40 ± 0.8^{a}	79.10 ± 0.9^{a}	78.14 ± 0.7^{a}	78.00 ± 0.8^{a}

Values are expressed as mean ± standard deviation (SD), n = 3.
Different superscript letters (a–j) within the same column indicate statistically significant differences between samples ($p < 0.05$), according to one-way ANOVA followed by Tukey's post hoc test

A general decreasing trend in TPC values was observed for all samples throughout the storage period. For example, the control sample T decreased from 30.90 mg GAE/100 mL initially to 17.65 mg GAE/100 mL after 21 days, while sample F decreased from 62.10 to 47.41 mg GAE/100 mL over the same period. This behavior is consistent with findings reported by Zhao et al. (2024) [25] and Marti et al. (2016) [14], who highlighted the degradation of phenolic compounds during storage due to oxidation and environmental factors.

Within the samples obtained from producer T, the addition of plant extracts led to a significant increase in TPC values compared to the control. For instance, sample TC2 showed an initial value of 46.80 mg GAE/100 mL, which is considerably higher than the control (30.90 mg GAE/100 mL), while TM1 reached 43.80 mg GAE/100 mL. Even after 21 days of storage, enriched samples maintained higher values (TC2: 38.67 mg GAE/100 mL; TM1: 32.70 mg GAE/100 mL) compared to the control (17.65 mg GAE/100 mL). These results confirm the positive effect of plant extracts on the enrichment of polyphenols, in agreement with the findings of Corbo et al. (2014) [19] and Granato *et al.* (2020) [1], who reported increased bioactive compound content in functional beverages enriched with plant-derived ingredients.

A similar trend was observed for samples obtained from producer F, where all enriched variants showed higher TPC values than the control. The highest value was recorded for sample FC2, with 87.40 mg GAE/100 mL initially and 78.00 mg GAE/100 mL after 21 days, followed by FM2 (79.80 → 69.17 mg GAE/100 mL). In contrast, the control sample F showed significantly lower values (62.10 → 47.41 mg GAE/100 mL). These results indicate that higher concentrations of plant extracts lead to a substantial increase in polyphenol content. Similar observations were reported by Nieto (2020) [17] and Miguel (2010) [30], who emphasized the high phenolic content of medicinal and aromatic plants such as thyme and mint.When comparing the two producers, it is evident thatall samples from producer F exhibited higher TPC values than those from producer T. For example, the control sample F (62.10 mg GAE/100 mL) had nearly double the polyphenol content of sample T (30.90 mg GAE/100 mL) at the initial stage. This difference can

be attributed to variations in raw material quality, such as tomato variety and maturity stage, which are known to influence phenolic composition [14].

Despite the beneficial effect of plant extracts, all samples showed a gradual decrease in TPC values during storage. However, enriched samples exhibited a smaller decrease compared to controls. For instance, sample TC2 showed a reduction of only 8.13 mg GAE/100 mL, while the control sample T showed a decrease of 13.25 mg GAE/100 mL. Similarly, FC2 showed a reduction of 9.40 mg GAE/100 mL compared to 14.69 mg GAE/100 mL for sample F. This suggests that plant extracts may have a protective effect against polyphenol degradation, a finding supported by studies indicating that polyphenols from plant sources can enhance oxidative stability in food systems [17].

The results demonstrate that the incorporation of mint and thyme extracts significantly improves the polyphenol content of tomato juice, while also

contributing to better stability during storage. These findings are in agreement with previous studies and confirm the potential of plant extracts as functional ingredients in the development of value-added beverages.

3.3. Results of antioxidant activity

The results of antioxidant activity, expressed as DPPH radical inhibition (%), are presented in Table 4.

Tabel 4. Results of antioxidant activity

Sample	Initial (0 days)	7 days	14 days	21 days
T	52.57 ± 0.6[a]	45.07 ± 0.7[b]	39.84 ± 0.5[c]	37.22 ± 0.6[c]
TM1	49.10 ± 0.5[b]	44.50 ± 0.6[b]	40.96 ± 0.7[c]	39.19 ± 0.5[c]
TM2	39.71 ± 0.7[c]	28.11 ± 0.6[e]	28.11 ± 0.5[e]	28.11 ± 0.6[e]
TT1	42.93 ± 0.6[c]	38.33 ± 0.5[c]	36.49 ± 0.6[c]	35.57 ± 0.5[c]
TT2	45.96 ± 0.5[b]	42.37 ± 0.6[b]	41.15 ± 0.5[b]	40.54 ± 0.6[b]
F	41.47 ± 0.6[c]	37.29 ± 0.7[c]	32.91 ± 0.5[d]	30.72 ± 0.6[d]
FM1	37.66 ± 0.5[d]	32.56 ± 0.6[d]	29.92 ± 0.6[e]	28.60 ± 0.5[e]
FM2	35.53 ± 0.6[d]	34.67 ± 0.5[d]	32.48 ± 0.6[d]	31.39 ± 0.5[d]
FT1	38.56 ± 0.6[d]	35.91 ± 0.6[c]	34.25 ± 0.5[d]	33.42 ± 0.6[d]
FT2	30.49 ± 0.5[e]	29.74 ± 0.6[e]	28.66 ± 0.5[e]	28.12 ± 0.6[e]

Values are expressed as mean ± standard deviation (SD), n = 3. Different superscript letters indicate statistically significant differences between samples ($p < 0.05$), according to one-way ANOVA followed by Tukey's post hoc test.

A gradual decrease in antioxidant capacity was observed for all samples during storage. For instance, the control sample T decreased from 52.57% to 37.22%, while sample F decreased from 41.47% to 30.72% after 21 days. This behavior is consistent with the findings of Joung (2025) [31], who demonstrated that antioxidant activity in tomato extracts is strongly dependent on bioactive compounds but decreases over time due to their instability. Similarly, Narra et al. (2024) [32] reported that processing and storage conditions lead to a reduction in antioxidant capacity in tomato products. These findings are in agreement with the decreasing trend observed in the present study.

Within the samples obtained from producer T, the control sample (T) initially exhibited the highest antioxidant activity (52.57%), followed by TM1 (49.10%) and TC2 (45.96%). However, during storage, samples enriched with plant extracts showed improved stability. For example, TC2 decreased only from 45.96% to 40.54% ($\Delta = 5.42$), whereas the control sample showed a much larger decrease ($\Delta = 15.35$). These results align with those reported by Flaiș & Oroian (2024) [33], who observed high DPPH inhibition values in tomato-derived extracts and emphasized the role of plant bioactive compounds in maintaining antioxidant activity. In contrast, Smorkrović *et al.* (2026) [34] highlighted that processing conditions can lead to a decrease in antioxidant activity, but this reduction is less pronounced when bioactive compounds are present. This supports the improved stability observed in extract-enriched samples in the present study.

A similar trend was observed for samples obtained from producer F. Although the initial antioxidant activity was lower compared to producer T, enriched samples such as FM2 and FC2 exhibited greater stability during storage. For instance, FM2 showed a relatively small decrease (from 35.53% to 31.39%, $\Delta = 4.14$), while FC2 showed the lowest decrease among all samples ($\Delta = 2.37$). In contrast, the control sample F exhibited a higher reduction ($\Delta = 10.75$). These findings are consistent with those reported by Šeregelj et al. (2024) [35], who demonstrated that antioxidant activity in fruit and vegetable juices is closely related to the presence of phenolic compounds and that enriched products tend to maintain higher antioxidant capacity over time.

When comparing the two producers, it is evident that samples from producer T consistently exhibited higher antioxidant activity than those from producer F. For example, the initial value of sample T (52.57%) was significantly higher than that of sample F (41.47%). This observation is supported by Marcu et al. (2025) [36], who reported that antioxidant capacity in tomato products varies depending on the content of bioactive compounds such as lycopene and polyphenols. Therefore, the differences observed between the two producers may be attributed to variations in raw material composition and quality.

Furthermore, a clear relationship between total polyphenol content (TPC) and antioxidant activity can be observed. While Joung et al. (2025) [31] emphasized the role of phenolic compounds and carotenoids in DPPH radical scavenging activity, Šeregelj et al. (2024) [35] reported a strong correlation between phenolic content and antioxidant capacity in juices. These findings are consistent with the present results, where samples with higher TPC values, such as TC2 and FM2, also exhibited improved antioxidant stability during storage.

Taken together, the results indicate that although

antioxidant activity decreases during storage, the addition of plant extracts significantly improves both the initial antioxidant capacity and its stability over time. The present findings are in good agreement with recent literature, confirming that plant-derived compounds play a key role in enhancing and preserving antioxidant activity in tomato-based products.

3.4. Results of pH

The evolution of pH values during storage for tomato juice samples obtained from producers T and F is presented in Figures 1 and 2. In general, all analyzed samples showed a slight decrease in pH throughout the 21-day storage period, indicating a gradual increase in acidity over time. Such behavior is commonly associated with oxidation processes, biochemical reactions, and the release of organic acids during storage. Narra *et al*. (2024) [32] reported that storage significantly affects physicochemical parameters of tomato products, including pH and titratable acidity. Similarly, Rah *et al.* (2016) [37] observed progressive acidification phenomena in processed tomato matrices during storage preservation.

For the samples obtained from producer T (Figure 1), the control sample T exhibited the greatest decrease in pH, declining from approximately 3.50 initially to 3.30 after 21 days. In contrast, samples enriched with plant extracts showed markedly smaller reductions. Sample TM1 decreased from 3.58 to 3.49, TM2 from 3.56 to 3.47, TT1 from 3.55 to 3.46, while TT2 showed the highest stability, decreasing only from 3.54 to 3.47. These results indicate that mint and thyme extracts reduced the rate of acidification during storage. Similar protective effects of plant extracts were reported by Lemoni *et al.* (2025) [38], who showed that edible botanical extracts can delay physicochemical deterioration in food systems, whereas Chen *et al.* (2025) [39] demonstrated that plant-derived preservatives improve postharvest quality retention.

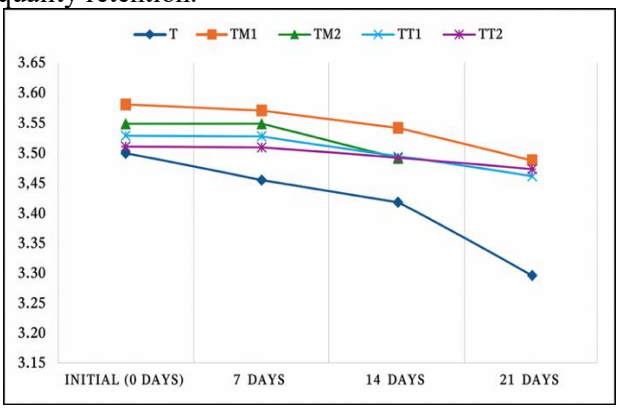

Figure 1. pH evolution of T samples over 21 days

A similar tendency was observed for the samples obtained from producer F (Figure 2). The control sample F decreased from 3.43 initially to 3.24 after 21 days, confirming lower stability compared to enriched variants. Sample FM1 decreased from 3.40 to 3.31, FM2 from 3.42 to 3.37, FT1 from 3.40 to 3.36, while FT2 exhibited the best overall stability, with a decrease of only 0.02 units (from 3.41 to 3.39). Therefore, as in the T group, thyme-enriched samples showed superior resistance to pH decline during storage. This aligns with studies showing that phenolic-rich natural additives may retard acidity changes and maintain quality parameters in tomato products during storage [40].

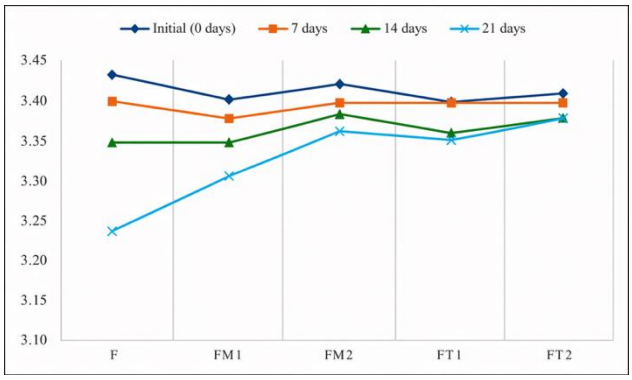

Figure 2. pH evolution of F samples over 21 days

Among all tested variants, FT2 and TT2 showed the smallest pH decreases, followed by FM2 and TM1, indicating that higher concentrations of thyme extract were the most effective in preserving acidity balance. This may be attributed to phenolic compounds and volatile constituents such as thymol and carvacrol. Nieto (2020) [17] reported strong antioxidant and antimicrobial properties of thyme extracts, while Miguel (2010) [30] emphasized the preservative role of aromatic plant extracts in food systems. These observations are consistent with the present results, where thyme-treated samples consistently outperformed controls and most mint-treated variants.

All samples remained within the acidic range typical of tomato juice products (approximately pH 3.2–3.6), which is favorable for microbiological safety. Tomato products are generally considered naturally acidic foods, commonly below pH 4.6, which reduces microbial risk during storage [41].

This results indicate that although a slight decrease in pH occurred in all samples during storage, the addition of mint and thyme extracts significantly improved pH stability compared to the control samples. While Narra et al. (2024) [32] emphasized the natural tendency of tomato matrices to acidify during

storage, Lemoni *et al.* (2025) [38] demonstrated that plant extracts can counteract these changes. The present findings strongly support the latter perspective and confirm the potential of plant-derived compounds to preserve physicochemical quality and extend the shelf life of tomato-based beverages [42].

3.5.Results of sensory analysis

For producer T, the highest-rated samples were TT1 and TT2, with overall mean scores of approximately 8.68 and 8.52, respectively, followed by the control sample T (8.20). These samples showed particularly high ratings for color (9.0), appearance (8.6), and consistency (8.2), suggesting strong consumer appreciation (Figure 3). Similar findings have been reported for high-quality tomato juice, where visual appearance and texture significantly contribute to consumer preference [43].

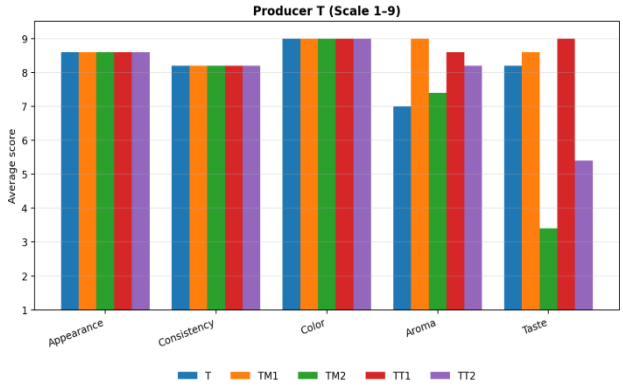

Figure 3. Sensory evaluation of tomato juice samples from producer T

For producer F, samples FT1 and FT2 obtained the best sensory scores, with overall means of approximately 8.52 and 8.36, respectively, followed by the control sample F (8.04). These variants recorded high values for color (8.6), appearance (8.2), and taste (up to 9.0), indicating a balanced and attractive sensory profile (Figure 4).

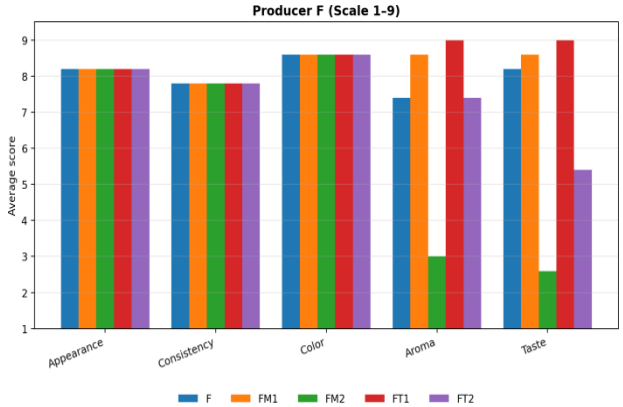

Figure 4. Sensory evaluation of tomato juice samples from producer F

Previous studies on commercial tomato juices also reported that flavor balance, color intensity, and mouthfeel are key quality drivers influencing acceptance [44].

Comparatively, producer T achieved slightly higher scores than producer F, particularly for aroma (8.04 vs. 7.08) and taste (6.92 vs. 6.76), suggesting a more favorable flavor profile [45]. This agrees with studies showing that taste and aroma are the primary determinants of liking in tomato-based beverages, while appearance mainly influences first impression [43].

In conclusion, samples TT1, TT2, FT1 and FT2 demonstrated the highest sensory acceptability, with mean scores above 8.3, whereas control samples Tand F scored 8.20 and 8.04, respectively [46]. These findings confirm that the applied treatments improved the sensory quality of the tomato juice samples.

4. Conclusion

The results of this study clearly demonstrate that the incorporation of mint and thyme extracts into tomato juice improves product quality from both nutritional and technological perspectives. All enriched samples showed higher total polyphenol content than the control variants, confirming that medicinal and aromatic plant extracts are valuable natural sources of bioactive compounds. The highest polyphenol values were recorded for FT2 (87.40 mg GAE/100 mL) and FM2 (79.80 mg GAE/100 mL), while the control samples showed lower values (T: 30.90 mg GAE/100 mL; F: 62.10 mg GAE/100 mL).

Antioxidant activity gradually decreased during storage in all samples; however, extract-enriched variants showed better stability than controls. Samples containing thyme extract, especially TT2 and FT2, retained antioxidant capacity more efficiently during the 21-day storage period, demonstrating the protective effect of phenolic compounds naturally present in thyme.

Regarding physicochemical stability, all juices remained within the normal acidic range for tomato products (pH 3.2–3.6), which is favorable for microbiological safety. In addition, thyme-enriched samples exhibited the smallest pH changes during storage, indicating improved preservation and shelf-life potential.

Sensory analysis confirmed that the addition of plant extracts did not negatively affect consumer acceptance. On the contrary, the highest overall sensory scores were obtained for TT1 (8.68), TT2 (8.52), FT1 (8.52), and FT2 (8.36) on the 9-point

hedonic scale. These results indicate that the selected concentrations of thyme and mint extracts enhanced flavor complexity and overall attractiveness of the juices.

Overall, thyme extract proved to be the most effective additive, particularly at higher concentrations, due to its strong antioxidant and stabilizing effects combined with high sensory acceptability. Therefore, tomato juice enriched with thyme or mint extracts can be considered a promising functional beverage with improved nutritional value, extended storage stability, and high market potential for consumers seeking natural and health-promoting products.

Conflicts of interest / Competing interests: No conflict of interest.

Ethics approval: No ethic situation.

Availability of data and material: The data have been reviewed depending on the literature.

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