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Studies on preparation and qualitative evaluation of grapefruit ready to serve beverage

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Abstract
A preliminary assessment comparing two grapefruit cultivars (NRCC-6 and Imperial) for physicochemical and sensory attributes identified the Imperial cultivar as superior, owing to its higher juice yield (46.8%), higher TSS (10.8 °Brix), lower titratable acidity (0.88%), and elevated sensory scores for taste (8.4) and overall acceptability (8.07). RTS beverages were then formulated using juice of Cv. Imperial. Three TSS levels (14°, 15°, 16°Brix) and three acidity levels (0.30%, 0.35%, 0.40%), and stored under cold storage condition (5±2 °C). During storage, Total Soluble Solids, titratable acidity, total and reducing sugars steadily increased, while non-reducing sugars declined. Sensory evaluation revealed progressive decreases in colour, flavour, taste, and overall acceptability across all treatments. Shelf life defined as the last day the overall acceptability remained at or above the sensory threshold ranged from 32 days for T_1 (14 °Brix + 0.30% acidity) to 63 days for T_8 (16 °Brix & 0.35% acidity) and T_9 (16 °Brix & 0.40% acidity). Among all formulations, treatment T_9 (16°Brix & 0.40% acidity) consistently maintained the highest physicochemical stability and sensory quality, achieving a shelf life of 63 days. These results demonstrate that a higher TSS combined with higher acidity is critical for extending the shelf life stability and enhancing the consumer acceptability of grapefruit RTS beverages.

Keywords: Acidity, storage, grapefruit, beverage, levels, treatment, citrus, sugar

Introduction

Citrus fruits rank among the world's most widely cultivated crops, prized for their nutritious content and versatility in human diets. Major commercial species include oranges, lemons, limes, grapefruits and tangerines, which thrive in tropical and subtropical zones between 35° N and 35° S. Over 140 countries grow citrus, but production is concentrated in China (22.9 Mt), Brazil (22.7 Mt), the United States (10.4 Mt) and India (10.48 Mt). China and Brazil together account for nearly 40% of global output, reflecting their advanced infrastructure and favorable climates.

In India, citrus ranks third among fruit crops, covering 1.23 M ha in 2024-25 and yielding 15.7 Mt at 13.08 t ha^{-1}. The principal cultivars are Mandarin (38% of area), Acid lime (35%) and Sweet orange (19%), with minor plantings of Pummelo, Grapefruit and Citron. Major producing states include Andhra Pradesh, Maharashtra, Assam, Meghalaya, Karnataka, Punjab and Rajasthan. Citrus cultivation supports rural livelihoods, contributes to food security, and underpins India's export earnings. Grapefruit (*Citrus paradisi* Macf.) the fourth most important citrus species worldwide is a relatively recent hybrid of Sweet Orange and Pummelo, first described in Barbados less than 300 years ago. It favors subtropical climates (13-35 °C, sea level to 1 800 m) and sandy, moderately fertile soils, with trees reaching 4.5-6 m in height. Global production (including Pummelo) reached 9.8 Mt in 2022, led by China (53%), Mexico and Vietnam; India ranks fourth, with 16.27 thousand ha yielding 390.5 thousand t at 24 t ha^{-1}.

Nutritionally, grapefruit delivers ~88 g water, 10.7 g carbohydrates, 1.6 g fiber and 31.2 mg vitamin C per 100 g edible portion (USDA, 2018). It also supplies B-vitamins, minerals (K, Ca, P), flavonoids, limonoids, carotenoids and other phytochemicals with antioxidant and health-promoting properties (Uckoo *et al.*, 2011; Zou *et al.*, 2016) [19, 22]. Yet its inherent bitterness and tartness limit fresh consumption, despite documented benefits against cardiovascular disease, certain cancers and metabolic disorders.

To enhance utilization and reduce post-harvest losses, this study focuses on developing a carbonated ready-to-serve (RTS) grapefruit beverage that balances flavor, nutritional quality and storage stability. By optimizing TSS, acidity and carbonation, and evaluating physico-chemical and sensory changes during storage, we aim to create a palatable functional drink that valorizes under-appreciated grapefruit cultivars and offers a model for value-addition of other citrus fruits.

Experimental materials
The present investigation entitled "Studies on Preparation and Qualitative Evaluation of Grapefruit Ready-to-Serve Beverage" was conducted during 2024-2025 at the Post-Harvest Technology Laboratory, Department of Horticulture, Mahatma Phule Krishi Vidyapeeth, Rahuri.

Grapefruit fruits
For the creation of ready to serve (RTS) beverage, fully ripened, mature, fresh, and sound fruits were acquired from an Grapefruit orchard in MPKV, as well as components such as citric acid and sodium benzoate from the local market. Fruit was washed with tap water, peeled, and utilised in the following process as experimental materials.

RTS preparation
Mature grapefruits were washed, halved, and their juice extracted and filtered through muslin cloth; a 50 °Brix sugar syrup was prepared, then blended with the filtered juice, adjusted to the desired acidity with citric acid, and preserved with 70 ppm Sodium Benzoate. The mixture was thoroughly mixed, pasteurized at 60 °C for 30 minutes, cooled, filled into 200 mL PET bottles, sealed, labeled, and stored under cold (5±2 °C) for subsequent physico-chemical, sensory, and microbial analyses (Figure 1).

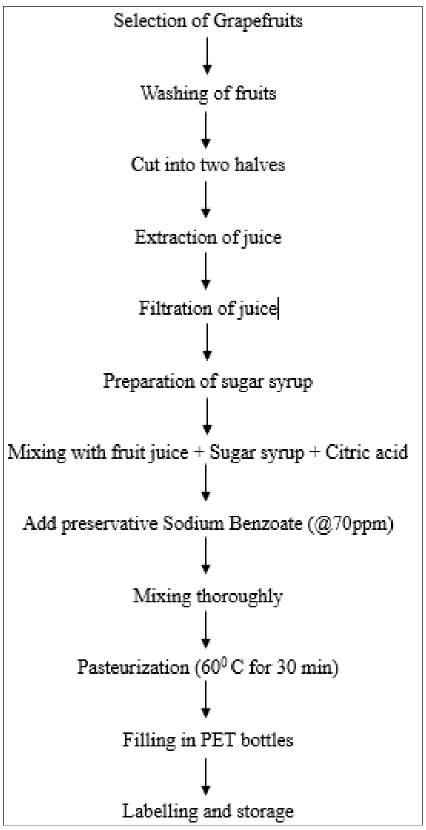

Fig 1: Preparation of ready to serve beverage

Statistical analysis
With three replications, the experiments were planned and carried out using Factorial Completely Randomized Design (FCRD). According to Panse (1985) the data obtained in this study from chemical composition and sensory characteristics were examined for statistical significance.

Results and Discussion
The RTS beverage was prepared in nine treatment combinations (T_1-T_9) by blending filtered grapefruit juice and sugar syrup to achieve TSS levels of 14, 15 and 16 °Brix and acidity levels of 0.30, 0.35 and 0.40% (A_1B_1 through A_3B_3), pasteurizing at 60 °C for 30 min, and filling into 200 mL glass bottles. Samples were stored at 5±2 °C 70 days, with physico-chemical, sensory and microbial analyses conducted at 7 days interval to assess treatment and storage effects on quality and acceptability.

Preliminary assessment
Preliminary assessment comparing two grapefruit cultivars NRCC-6 and Imperial was conducted using fresh juice to evaluate their suitability for RTS beverage production. Physicochemical analysis (Table 1) showed that Imperial juice had higher TSS (10.4 °Brix vs. 9.8), greater total sugars (9.5 g vs. 8.7 g), higher non-reducing sugars (5.42 g vs. 4.95 g), and a larger juice yield (46.8% vs. 41.5%), despite slightly lower acidity (0.90% vs. 1.10%). Sensory evaluation on a 9-point Hedonic scale (Table 2) further confirmed Imperial's superiority, with higher scores for taste (8.4 vs. 6.2), flavour (8.0 vs. 6.5) and overall acceptability (8.07 vs. 6.9). Based on its balanced sweetness, reduced bitterness, and overall better performance, the Imperial cultivar was selected for subsequent formulation and quality evaluation of the grapefruit RTS beverage.

Chemical composition of Grapefruit ready to serve beverage during storage
The data for changes in chemical composition of ready to serve beverage from Grapefruit subjected to different TSS and acid levels are given and discussed below.

Total soluble solids (T.S.S.), (˚B)
From the data given in table 2, it was observed that TSS content increased during storage period, which might be due to reduction of moisture content, conversion of insoluble carbohydrates into soluble sugars and increasing total sugar content of carbonated RTS Beverage during storage.TSS content of ready to serve beverage was statistically significantt. The TSS of carbonated ready to serve beverage ranged from 14,00 to 17.08 ˚B in different treatments. The highest TSS observed in T_9 (17.08 ˚B) while lowest increase in TSS in T_1. Numerous studies have similarly reported increases in TSS during storage of fruit beverages, including jamun-based RTS (Das, 2009) [7], Aonla syrup (Mandal *et al*., 2014) [10], kinnow and mandarin juices.

Acidity (%)
The results presented in table 2 showed that there was significant difference in acidity of ready to serve beverage during the 70 days of storage. During storage, increase in acidity of carbonated ready to serve beverage from grapefruit was observed which might be due to decrease in pH. The highest value of acidity was observed in treatment

T_9 as 0.562 per cent and the lowest value was observed in treatment T_1 as 0.338 per cent. Das (2009) [7], Mandal *et al*. (2014) [10], Byanna & Doreyappa Gowda (2012) [4] and Birari (2004) [3] all reported increasing acidity during storage of various RTS beverages.

Total sugars (%)

The results showed that, there was significant effect of total sugars of RTS beverage from Grapefruit during advancement of storage period. The total sugars during storage period were increased might be due to loss of moisture in RTS beverage from Grapefruit or due to conversion of starch and carbohydrates into sugars. Statistically significant increase in total sugars content were observed in all treatments with the increase in storage period. The maximum value of total sugars content of RTS beverage was observed in treatment T_9 (14.89%) and the lowest value of total sugars content of RTS beverage was observed in treatment T_1 (12.03%). Similar results were also reported by [16] in carbonated RTS of guava. Similar storage-induced trends were observed by Birari (2004) [3] for Aonla drinks, Pandurnikar (2004) in Jamun RTS, Masalkar (2005) [11] in Pomegranate-Ginger blends, and Teli (2008) [18] in Kokum-Lime-Pineapple beverages.

Reducing sugars (%)

The data revealed that, there was increase in reducing sugars content during storage. During storage, the reducing sugars were increased which might be due to hydrolysis of non-reducing sugars to reducing sugars. The maximum value of reducing sugars content of RTS beverage from Grapefruit was observed in treatment T_9 as 7.46 per cent and minimum value of reducing sugar content was observed in treatment T_1 as 5.15 per cent. Similar storage-induced trends were observed by Birari (2004) [3] for aonla carbonated drinks, Pandurnikar (2004) in jamun RTS, Masalkar (2005) [11] in pomegranate-ginger blends, and Teli (2008) [18] in kokum-lime-pineapple beverages.

Non reducing sugars (%)

The data revealed that, there was a decrease in reducing sugars content during storage. During storage, the reducing sugars were decreased which might be due to hydrolysis of non-reducing sugars to reducing sugars. The maximum value of non-reducing sugars content of RTS beverage from Grapefruit was observed in treatment T_7 as 8.23 per cent and minimum value of reducing sugar content was observed in treatment T_3 as 6.61 per cent. These observations align with findings by Byanna & Doreyappa Gowda (2012) [4], and Teli (2008) [18], supported by earlier research (Echeverria, 1991) linking slower sucrose inversion to lower acidity in fruit beverages.

Sensory evaluation of Grapefruit ready to serve beverage

Colour

Colour is the main quality parameter for RTS beverages. The data on changes in colour of RTS beverage from Grapefruit during storage is presented in Table 3. All treatments had statistically significant effect on colour. The data indicates that the scores for colour and appearance decreased continuously during storage. The highest scores for colour of RTS beverage was observed for treatment T_3 (7.43) while the lowest scores were observed for treatment T_8 (5.77) during storage. Lee & Nagy (1988), and Saura *et al*. (2017) collectively highlighted that pigment breakdown, sugar and vitamin C degradation, and non-enzymatic browning contribute to color loss in juices, while increased acidity helps minimize such deterioration.

Flavour

The results regarding the flavour score of beverage from Grapefruit is presented in Table 3. All the treatments had statistically significant effect on flavour score. The score of flavor in all treatments of RTS beverage was decreased with increase of storage period. From statistical point of view, treatment T_8 (6.96) was found to be best over the all other treatments having highest score of flavor. The lowest flavor score was found in treatment T_1 (5.21). Similar results were also reported by [23] in mandarin juice. Obenland *et al*. (2011) [12] reported that flavour quality in citrus RTS beverages declines over time due to sugar and volatile degradation, but a balanced sugar-acid ratio and higher TSS help preserve taste during storage.

Taste

The data regarding taste score of carbonated RTS beverage from Nagpur mandarin during storage is presented in table 3. All the treatments had statistically significant effect on taste scores. From table it is observed that, the scores of RTS decreases gradually for storage period. From statistical point of view, treatment T_8 was found to be best over the other treatments having highest score of taste and the lowest taste score was found in treatment T_1.Similar results were also reported by [8] in Kinnow mandarin juice. A consistent decline in taste during storage, likely due to bitterness and volatile changes, aligns with earlier findings by Obenland *et al*. (2011) [12], Chatha *et al*. (2008) [6] in mandarin-based beverages.

Overall acceptability

The data on changes in overall acceptability as influenced by storage period are presented in Table 3. The scores for overall acceptability of RTS beverage decreased gradually during storage period. Statistically, treatment T_9 was found to be the best over the other treatments having highest score of overall acceptability and the lowest score was observed for treatment T_1 A gradual decline in overall acceptability during storage, likely due to oxidative reactions and volatile degradation, was similarly reported by Chatha *et al*. (2008) [6] and Obenland *et al*. (2011) [12] in mandarin-based beverages.

Shelf life

Sensory evaluation showed a gradual decline in overall acceptability of grapefruit RTS beverages during storage, with shelf life determined by the day the score is just greater than or equal to sensory thresold. T_8 (A3B2) and T_9 (A3B3) had the longest shelf life (63 days), followed by T_7 (A3B1) and T_5 (A2B2) at 56 days, while T_1 (A1B1) had the shortest (35 days). Treatments with higher TSS (16 °Brix) and acidity retained better flavor, indicating their effectiveness in maintaining sensory quality. The decline in acceptability was likely due to loss of volatiles, bitterness, and oxidative changes, as also noted by Chatha *et al*. (2008) [6] and Obenland *et al*. (2011) [12]. This confirms that higher TSS with balanced acidity improves flavor stability and extends shelf life.

Table 1: Treatments details, A=Total soluble solids, B=Acidity

Treatment No.	Treatment Combinations		
		TSS (°Brix)	Acidity (%)
T_1	A1B1	14	0.30
T_2	A1B2	14	0.35
T_3	A1B3	14	0.40
T_4	A2B1	15	0.30
T_5	A2B2	15	0.35
T_6	A2B3	15	0.40
T_7	A3B1	16	0.30
T_8	A3B2	16	0.35
T_9	A3B3	16	0.40

Table 2: Effect of TSS and acidity levels on physicochemical properties of Grapefruit Ready to serve beverage along with their treatment combinations

Storage period days	Treatment combinations										
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	S.E ±	C.D. at 5%
Total soluble solids (⁰B)											
0	14.01	14.02	14.00	15.01	15.00	15.03	16.02	16.00	16.00	0.02	NS
7	14.10	14.11	14.14	15.11	15.12	15.15	16.10	16.12	16.15	0.01	0.04
14	14.21	14.23	14.28	15.20	15.22	15.24	16.22	16.24	16.26	0.02	0.05
21	14.32	14.34	14.37	15.33	15.36	15.40	16.30	16.33	16.38	0.02	0.05
28	14.38	14.41	14.44	15.38	15.40	15.43	16.40	16.44	16.48	0.02	0.06
35	14.48	14.50	14.54	15.47	15.49	15.54	16.51	16.56	16.59	0.02	0.06
42	14.57	14.62	14.67	15.60	15.63	15.69	16.57	16.65	16.73	0.02	0.07
49	14.68	14.72	14.79	15.72	15.75	15.78	16.73	16.78	16.82	0.03	0.07
56	14.77	14.82	14.88	15.83	15.85	15.87	16.84	16.89	16.94	0.03	0.08
63	14.87	14.92	14.97	15.93	15.96	15.97	16.95	17.01	17.08	0.03	0.09
70	14.95	14.98	15.02	16.02	16.04	16.09	17.07	17.12	17.20	0.03	0.10
Acidity (%)											
0	0.301	0.350	0.402	0.302	0.351	0.403	0.304	0.352	0.405	0.010	0.029
7	0.312	0.362	0.409	0.311	0.362	0.418	0.319	0.375	0.425	0.006	0.017
14	0.318	0.368	0.416	0.328	0.378	0.430	0.343	0.395	0.447	0.012	0.036
21	0.324	0.375	0.423	0.343	0.395	0.446	0.350	0.408	0.457	0.014	0.042
28	0.330	0.386	0.435	0.353	0.407	0.460	0.359	0.422	0.472	0.015	0.045
35	0.338	0.395	0.447	0.365	0.422	0.478	0.375	0.439	0.490	0.017	0.050
42	0.346	0.405	0.459	0.377	0.437	0.494	0.390	0.460	0.508	0.018	0.053
49	0.353	0.413	0.472	0.389	0.450	0.511	0.406	0.477	0.527	0.019	0.057
56	0.360	0.421	0.486	0.401	0.463	0.528	0.422	0.494	0.545	0.021	0.061
63	0.368	0.430	0.497	0.414	0.477	0.543	0.436	0.510	0.562	0.021	0.062
70	0.376	0.439	0.509	0.427	0.491	0.558	0.450	0.526	0.579	0.022	0.066
Total sugars (%)											
0	11.67	11.74	11.85	12.73	12.81	12.92	13.78	13.83	13.98	0.05	0.15
7	11.75	11.82	11.93	12.81	12.90	13.01	13.87	13.92	14.08	0.05	0.15
14	11.82	11.90	12.02	12.89	12.98	13.10	13.96	14.01	14.18	0.05	0.16
21	11.89	11.98	12.10	12.97	13.07	13.20	14.06	14.10	14.29	0.06	0.17
28	11.96	12.05	12.18	13.05	13.15	13.28	14.15	14.19	14.39	0.06	0.18
35	12.03	12.13	12.25	13.12	13.24	13.38	14.24	14.27	14.49	0.06	0.18
42	12.12	12.21	12.35	13.21	13.32	13.47	14.33	14.37	14.58	0.06	0.19
49	12.19	12.28	12.43	13.29	13.41	13.56	14.41	14.46	14.68	0.07	0.19
56	12.27	12.36	12.51	13.37	13.48	13.65	14.49	14.55	14.78	0.07	0.20
63	12.35	12.44	12.60	13.46	13.56	13.74	14.58	14.63	14.89	0.07	0.20
70	12.43	12.52	12.68	13.54	13.63	13.83	14.66	14.72	14.97	0.07	0.21
Reducing sugars (%)											
0	3.96	4.04	4.17	4.03	4.13	4.26	4.10	4.18	4.36	0.01	0.03
7	4.20	4.29	4.43	4.28	4.41	4.56	4.37	4.48	4.69	0.02	0.05
14	4.44	4.54	4.69	4.53	4.69	4.86	4.65	4.78	5.04	0.02	0.06
21	4.67	4.79	4.96	4.80	4.97	5.16	4.93	5.08	5.40	0.02	0.07
28	4.91	5.03	5.21	5.06	5.25	5.44	5.21	5.38	5.74	0.03	0.08
35	5.15	5.28	5.47	5.30	5.53	5.75	5.47	5.66	6.07	0.03	0.09
42	5.40	5.50	5.74	5.55	5.80	6.05	5.74	5.98	6.42	0.03	0.10
49	5.63	5.78	6.00	5.79	6.09	6.36	6.00	6.28	6.76	0.04	0.11
56	5.86	6.05	6.25	6.03	6.36	6.65	6.26	6.57	7.11	0.04	0.11
63	6.09	6.30	6.50	6.28	6.63	6.94	6.52	6.86	7.46	0.04	0.13
70	6.32	6.56	6.76	6.52	6.90	7.24	6.78	7.15	7.79	0.05	0.15
Non reducing sugar (%)											

0	7.71	7.70	7.68	8.70	8.68	8.66	9.68	9.65	9.62	0.01	0.04
7	7.55	7.53	7.50	8.53	8.49	8.45	9.50	9.44	9.38	0.02	0.05
14	7.38	7.36	7.32	8.35	8.30	8.24	9.31	9.23	9.14	0.02	0.06
21	7.22	7.19	7.14	8.17	8.10	8.04	9.13	9.02	8.89	0.02	0.07
28	7.05	7.02	6.97	7.99	7.90	7.84	8.94	8.81	8.65	0.03	0.08
35	6.88	6.85	6.79	7.82	7.71	7.63	8.77	8.61	8.42	0.03	0.09
42	6.72	6.67	6.61	7.66	7.52	7.41	8.59	8.39	8.17	0.03	0.09
49	6.56	6.49	6.43	7.50	7.32	7.20	8.41	8.18	7.92	0.03	0.10
56	6.41	6.31	6.26	7.34	7.12	7.00	8.23	7.98	7.67	0.03	0.10
63	6.26	6.14	6.09	7.18	6.93	6.79	8.06	7.78	7.43	0.04	0.11
70	6.10	5.96	5.92	7.02	6.73	6.59	7.88	7.57	7.18	0.04	0.11

Note: Underlined treatments have surpassed their validated shelf life and are included only to maintain the 3×3 factorial ANOVA structure; they are not considered in biological interpretation.

Table 3: Effect of TSS and acidity levels on sensory properties of grapefruit ready to serve beverage along with their treatment combinations

Storage period days	Treatment combinations										
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	S.E ±	C.D. at 5%
Colour											
0	7.62	8.00	8.41	7.62	7.80	8.30	7.20	7.40	7.90	0.06	0.17
7	7.52	7.88	8.25	7.48	7.67	8.15	7.04	7.20	7.75	0.06	0.18
14	7.40	7.77	8.08	7.34	7.55	7.99	6.88	7.02	7.63	0.07	0.19
21	7.35	7.70	7.94	7.26	7.47	7.88	6.79	6.91	7.51	0.07	0.21
28	7.18	7.54	7.75	7.05	7.30	7.70	6.56	6.66	7.31	0.07	0.21
35	7.08	7.43	7.60	6.91	7.17	7.55	6.41	6.47	7.16	0.08	0.23
42	6.97	7.31	7.43	6.78	7.04	7.38	6.23	6.28	7.00	0.08	0.24
49	6.87	7.19	7.26	6.63	6.92	7.21	6.05	6.06	6.82	0.09	0.26
56	6.80	7.07	7.11	6.49	6.79	7.09	5.89	5.87	6.70	0.09	0.27
63	6.71	6.98	6.97	6.35	6.69	6.92	5.72	5.77	6.53	0.09	0.28
70	6.58	6.87	6.81	6.22	6.57	6.78	5.56	5.68	6.37	0.10	0.30
Flavour											
0	5.52	6.03	6.51	6.11	6.54	6.70	7.51	8.01	7.92	0.07	0.20
7	5.45	5.93	6.36	6.03	6.44	6.58	7.42	7.89	7.79	0.07	0.22
14	5.40	5.85	6.20	5.94	6.35	6.46	7.33	7.76	7.63	0.08	0.24
21	5.31	5.75	6.04	5.82	6.25	6.30	7.21	7.60	7.49	0.08	0.23
28	5.28	5.69	5.89	5.77	6.17	6.19	7.16	7.51	7.38	0.09	0.27
35	5.21	5.59	5.73	5.69	6.10	6.06	7.05	7.38	7.23	0.09	0.26
42	5.14	5.51	5.59	5.63	6.02	5.92	6.98	7.25	7.11	0.09	0.27
49	5.12	5.44	5.47	5.57	5.96	5.80	6.91	7.13	7.00	0.09	0.26
56	5.10	5.35	5.33	5.49	5.88	5.69	6.81	6.99	6.93	0.10	0.29
63	5.06	5.30	5.20	5.41	5.83	5.55	6.73	6.96	6.80	0.09	0.28
70	4.98	5.23	5.06	5.35	5.76	5.43	6.66	6.65	6.67	0.11	NS
Taste											
0	11.67	11.74	11.85	12.73	12.81	12.92	13.78	13.83	13.98	0.05	0.15
7	11.75	11.82	11.93	12.81	12.90	13.01	13.87	13.92	14.08	0.05	0.15
14	11.82	11.90	12.02	12.89	12.98	13.10	13.96	14.01	14.18	0.05	0.16
21	11.89	11.98	12.10	12.97	13.07	13.20	14.06	14.10	14.29	0.06	0.17
28	11.96	12.05	12.18	13.05	13.15	13.28	14.15	14.19	14.39	0.06	0.18
35	12.03	12.13	12.25	13.12	13.24	13.38	14.24	14.27	14.49	0.06	0.18
42	12.12	12.21	12.35	13.21	13.32	13.47	14.33	14.37	14.58	0.06	0.19
49	12.19	12.28	12.43	13.29	13.41	13.56	14.41	14.46	14.68	0.07	0.19
56	12.27	12.36	12.51	13.37	13.48	13.65	14.49	14.55	14.78	0.07	0.20
63	12.35	12.44	12.60	13.46	13.56	13.74	14.58	14.63	14.89	0.07	0.20
70	12.43	12.52	12.68	13.54	13.63	13.83	14.66	14.72	14.97	0.07	0.21
Overall acceptability											
0	6.49	6.95	7.14	6.86	7.22	7.40	7.46	7.91	7.94	0.04	0.13
7	6.41	6.83	6.97	6.73	7.08	7.22	7.30	7.71	7.75	0.05	0.16
14	6.32	6.70	6.80	6.59	6.94	7.04	7.13	7.50	7.55	0.06	0.18
21	6.24	6.58	6.63	6.46	6.81	6.86	6.97	7.30	7.36	0.06	0.19
28	6.15	6.46	6.46	6.32	6.67	6.68	6.80	7.09	7.16	0.06	0.19
35	6.07	6.34	6.29	6.19	6.53	6.50	6.64	6.89	6.97	0.07	0.22
42	5.98	6.21	6.11	6.05	6.39	6.32	6.47	6.68	6.77	0.08	0.24
49	5.90	6.09	5.94	5.92	6.25	6.14	6.31	6.48	6.58	0.08	0.25
56	5.81	5.97	5.77	5.79	6.12	5.96	6.14	6.27	6.38	0.06	0.19
63	5.73	5.84	5.60	5.65	5.98	5.78	5.98	6.07	6.19	0.07	0.21
70	5.64	5.72	5.43	5.52	5.84	5.60	5.81	5.86	5.99	0.07	0.22

Note: Underlined treatments have surpassed their validated shelf life and are included only to maintain the 3×3 factorial ANOVA structure; they are not considered in biological interpretation.

Summary and Conclusion

The study demonstrated that grapefruit RTS beverages formulated with varying TSS (14-16 °Brix) and acidity levels (0.30-0.40%) showed significant changes in physicochemical and sensory attributes for 70 days of cold storage. Among the nine treatment combinations, T_8 (A3B2) and T_9 (A3B3) exhibited the best overall quality and longest shelf life (63 days), attributed to higher sugar content and balanced acidity, which helped preserve flavour, colour, and acceptability. TSS, total and reducing sugars increased significantly during storage, while non-reducing sugars declined, and acidity also rose. Sensory parameters like taste, flavour, and colour decreased over time due to oxidative and chemical changes, consistent with trends reported in earlier citrus-based RTS studies. Overall, higher TSS with moderate to high acidity proved most effective in extending the shelf life and maintaining the sensory and chemical quality of grapefruit RTS beverage.

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