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EVALUATION OF THE EFFECTS OF PASTEURIZATION TEMPERATURE AND HOLDING TIME ON THE QUALITY OF RED-FLESH DRAGON FRUIT (*Hylocereus polyrhizus*) - STRAWBERRY (*Fragaria × ananassa*) JUICE

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Abstract

This study evaluated the effects of pasteurization temperature and holding time on the quality of red-flesh dragon fruit (Hylocereus polyrhizus) - strawberry (Fragaria × ananassa) juice. The juice was blended at a ratio of 7:3 (v/v), treated with pectinase enzyme, supplemented with sugar and ascorbic acid, and subsequently pasteurized at three temperature levels (80, 85, and 90 °C) for corresponding holding times (3, 5, and 7 minutes). The evaluated parameters included pasteurization unit (PU), inhibition efficiency against aerobic bacteria, yeasts, and molds, betacyanin and vitamin C content, as well as sensory quality. The results demonstrated that both pasteurization temperature and holding time had significant impacts on all examined criteria. Among the tested conditions, pasteurization at 85 °C for 5 minutes achieved a PU ≥ 5, ensured microbiological safety, and preserved the characteristic color, natural aroma, and high nutritional value of the product. Therefore, this condition was identified as optimal for producing red-flesh dragon fruit - strawberry juice with desirable sensory properties, high nutritional retention, and appropriate microbiological stability. This study provides scientific and practical basis for processing red-flesh dragon fruit - strawberry juice at industrial scale.

Keywords: *Betacyanin, microbial safety, pasteurization, red-flesh dragon fruit, sensory quality, strawberry, vitamin C.*

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ĐÁNH GIÁ ẢNH HƯỞNG CỦA NHIỆT ĐỘ VÀ THỜI GIAN GIỮ NHIỆT TRONG THANH TRÙNG ĐẾN CHẤT LƯỢNG NƯỚC ÉP THANH LONG RUỘT ĐỎ (*Hylocereus polyrhizus*) - DÂU TÂY (*Fragaria × ananassa*)

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Tóm tắt

Nghiên cứu này được thực hiện nhằm đánh giá ảnh hưởng của nhiệt độ và thời gian giữ nhiệt trong quá trình thanh trùng đến chất lượng của nước ép thanh long ruột đỏ (Hylocereus polyrhizus) - dâu tây (Fragaria × ananassa). Hỗn hợp nước ép được phối trộn theo tỷ lệ 7:3 (v/v) được xử lý enzyme pectinase, bổ sung đường và acid ascorbic, sau đó được thanh trùng ở ba mức nhiệt độ (80, 85 và 90 °C) với các thời gian giữ nhiệt tương ứng (3, 5 và 7 phút). Các chỉ tiêu được đánh giá bao gồm giá trị thanh trùng (PU), hiệu quả ức chế vi sinh vật hiếu khí, nấm men và nấm mốc, hàm lượng betacyanin, vitamin C và chất lượng cảm quan. Kết quả cho thấy nhiệt độ và thời gian thanh trùng có ảnh hưởng rõ rệt đến tất cả các chỉ tiêu khảo sát. Trong đó, điều kiện thanh trùng ở 85 °C trong 5 phút đạt giá trị PU ≥ 5, đảm bảo an toàn vi sinh, đồng thời duy trì được màu sắc đặc trưng, mùi thơm tự nhiên và hàm lượng chất dinh dưỡng cao. Do đó, đây được xác định là điều kiện tối ưu để sản xuất nước ép thanh long ruột đỏ - dâu tây có chất lượng cảm quan tốt, giá trị dinh dưỡng cao và độ ổn định vi sinh phù hợp. Nghiên cứu cung cấp cơ sở khoa học và thực tiễn cho sản xuất nước ép thanh long ruột đỏ - dâu tây ở quy mô công nghiệp.

Từ khóa: *An toàn vi sinh, betacyanin, dâu tây, giá trị cảm quan, thanh long ruột đỏ, thanh trùng, vitamin C.*

1. Introduction

Vietnam possesses a diverse tropical climate that is highly suitable for the cultivation of a wide range of fruits and vegetables with distinctive nutritional profiles and strong potential for processing. However, during peak harvest periods, several fruit varieties, especially red flesh dragon fruit, often face market oversupply due to limited consumption capacity. This surplus results in significant price volatility and adversely affects the income of fruit growers. Currently, the majority of red flesh dragon fruit is exported in fresh form to the Chinese market at highly unstable prices. A substantial portion of the harvested fruit does not meet export standards due to inadequate size (less than 350 grams) or suboptimal appearance, leading to low economic value and domestic distribution at reduced prices (Tran, 2017).

Processing surplus or substandard fruit into juice offers a practical strategy to improve raw material utilization, increase product diversity, extend shelf life, and enhance economic returns. Red-flesh dragon fruit (*Hylocereus polyrhizus*) is rich in water, vitamins, and minerals. Also, it shown high betacyanin content which is a strong antioxidant compound supported cardiovascular health (Liaotrakoon, 2013). Its vivid color also enhances consumer appeal, making it suitable for juice production, though it lacks a distinctive aroma. In addition, many studies reported that strawberry is an excellent source of vitamin C, potassium, folic acid, and dietary fiber (Patras et al., 2009; Husaini & Neri, 2016). Therefore, combining dragon fruit and strawberry for making drinking fruit might improve both sensory qualities and nutritional value of the final product.

Besides, pasteurization has been widely studied in single-fruit juices and some blends, for example, red dragon fruit juice (Thanasegaran and Mahror, 2025), dragon fruit - aloe vera (Tran, 2017), dragon fruit - passion fruit (Le et al., 2024), no systematic study has yet optimized processing conditions for red-flesh dragon fruit - strawberry juice. Pasteurization is a critical step in juice production, ensuring microbial safety and enzyme inactivation, but it may also negatively affect sensory attributes and degrade heat-sensitive compounds such as vitamin C and betacyanin. Therefore, this study investigates the effects of pasteurization conditions on the sensory and nutritional quality of dragon fruit - strawberry juice, with the aim of identifying optimal parameters that balance microbial safety with product quality.

2. Materials and research methods

2.1 Materials and chemicals

Red-flesh dragon fruits (*Hylocereus polyrhizus*) were procured from local markets in Can Tho City. Selected fruits were fresh, firm, intact, undamaged, and physiologically ripe, with approximately 75% of the peel turning dark red and bracts remaining green. Strawberries were purchased from The Go Can Tho supermarket and selected based on ripeness, uniform bright red color, firm texture, and absence of bruising.

Additives included high-purity saccharose (99.8%) supplied by Bien Hoa Sugar Joint Stock Company and food-grade ascorbic acid produced domestically. Pectinase enzyme (ICIFOOD Company) was used to hydrolyze pectin in the fruit matrix, thereby improving juice extraction yield. The enzyme exhibited optimal activity at pH 5.0 and 50 °C.

The microbiological culture medium used for total aerobic mesophilic bacterial count analysis was Plate Count Agar (PCA), imported from India and compliant with international standards. For yeast and mold count analysis, Yeast Extract Glucose Chloramphenicol Agar (YGC, also known as YBD) was used, ensuring selectivity and accuracy in detecting fungal growth.

2.2. Juice processing method for red-flesh dragon fruit and strawberry

Red-flesh dragon fruits were washed, peeled, chopped, and finely ground, then diluted with water at a 1:1 ratio (v/v). Strawberries were similarly pre-treated and blended into a puree to obtain strawberry juice. The two types of fruit juices were blended at a 7:3 ratio (v/v), corresponding to 70% dragon fruit juice and 30% strawberry juice. The mixture was supplemented with pectinase enzyme at a concentration of 0.2% (w/v) and incubated at 50 °C for 120 minutes to hydrolyze pectin, thereby promoting clarification and improving juice yield (Le et al., 2024). The enzyme-treated juice was filtered through fine cloth to remove pulp residues.

The filtrate was adjusted with 12% sucrose and 0.4% ascorbic acid (w/v). These concentrations were determined from preliminary trials (data not shown). The mixture was heated to 90 °C for 5 minutes (Doan et al., 2025), hot-filled into 200 mL glass bottles, and pasteurized under the designated temperature - time conditions arranged in the experimental design. Pasteurization was performed in a thermostatic waterbath, with the initial product temperature maintained at approximately 40 °C. The core temperature was monitored and recorded throughout the process. After pasteurization, the samples were rapidly cooled under continuous running water until their internal temperature returned to the initial state and were stored at 4 ± 2 °C. The overall processing steps are summarized in the flow diagram (Figure 1).

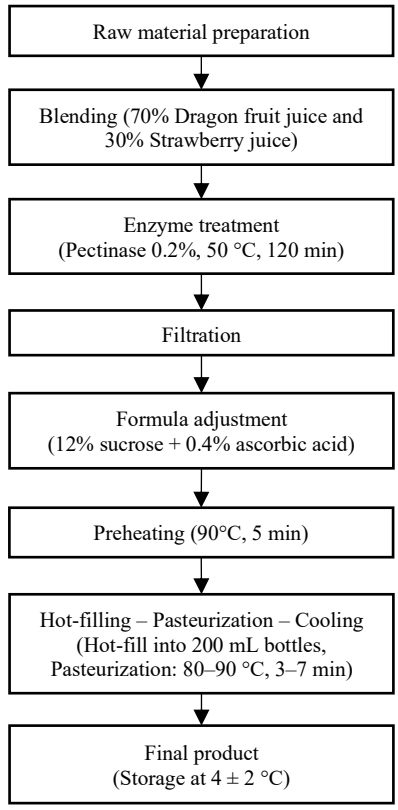

Figure 1. Flow diagram of red-flesh dragon fruit - strawberry juice processing

2.3. Experimental design

The experiment was conducted to determine the optimal pasteurization condition that effectively inactivated microorganisms, extended shelf life, and maintained the sensory and nutritional quality of the juice product. A completely randomized design was applied with two main factors: pasteurization temperature and holding time. Each treatment was performed in triplicate. The juice processing was carried out as described in Section 2.2.

Pasteurization was conducted at three temperature levels: 80 °C, 85 °C, and 90 °C, with corresponding holding times of 3, 5, and 7 minutes. After pasteurization, the samples were fully cooled, followed by sensory evaluation, and determination of vitamin C (mg/100mL) and betacyanin content (mg/L). Additionally, the pasteurization unit (PU, in minutes) was calculated, and the total aerobic plate count, yeast, and mold counts (CFU/mL) were assessed to evaluate microbial inactivation and product quality.

2.4 Analytical methods

All analytical procedures were conducted to assess the effects of pasteurization conditions on the quality of the juice. The methods included the determination of total betacyanin, vitamin C content, sensory evaluation, microbiological analysis, and the calculation of pasteurization unit.

2.4.1. Determination of total betacyanin content

The total betacyanin content was determined according to the method of Wong and Siow (2015), with slight modifications. The juice sample was diluted with McIlvaine buffer, prepared from 30 mL of 0.1 M citric acid and 70 mL of 0.2 M disodium phosphate (pH 6.5), until the absorbance was within the optimal range.

Absorbance was measured using a UV-Vis spectrophotometer at 537 nm and corrected by subtracting the absorbance at 600 nm. The total betacyanin concentration (BC, mg/L) was calculated as:

$$BC = \frac{(A_{537} - A_{600}) \times F \times MW \times 1000}{\varepsilon \times l}$$

Where: A_{537}: absorbance at 537 nm, A_{600}: absorbance at 600 nm, F: dilution factor, MW: molecular weight of betacyanin (550 g/mol), ε: molar extinction coefficient (60,000 L/mol.cm), l: path length of the cuvette (1 cm).

2.4.2. Determination of Vitamin C Content

Vitamin C was determined using iodometric titration as described by Nhan and Diep (2014). A volume of 20 mL juice sample was mixed with 5 mL of 1% HCl solution in a 50 mL Erlenmeyer flask. The mixture was titrated with 0.01 N iodine in the presence of 1% starch indicator until a persistent blue color was observed. Titration was repeated in triplicate.

2.4.3. Sensory Evaluation

Sensory quality was assessed following the Vietnamese National Standard TCVN 3215-79. A panel of 15 trained individuals, aged between 20 and 30 years, evaluated the juice samples for color, aroma, taste, and texture.

2.4.4. Microbiological Analysis

Microbial quality was assessed by determining the total aerobic mesophilic bacterial count and the yeast–mold count. Enumeration was performed using the pour plate technique according to Wise (2006). Plate Count Agar (PCA, India) was used for the analysis of total aerobic mesophilic bacteria, while Yeast Extract Glucose Chloramphenicol Agar (YGC, also known as YBD) was employed for the selective enumeration of yeasts and molds. Results were expressed as colony forming units per milliliter (CFU/mL).

2.4.5. Calculation of Pasteurization Unit (PU)

The pasteurization unit (PU) was calculated based on the integrated thermal lethality approach, which quantified the microbial inactivation effect over time during thermal processing. The PU was determined using the following equation:

$$PU = \int_0^{\infty} 10^{\frac{T-Tref}{z}} . dt$$

Where:

T_{ref}: the reference temperature for the thermal treatment (°C)

T: the actual processing temperature (°C)

z: the temperature range required for the "decimal reduction time" curve to complete one logarithmic cycle (Holdsworth & Simpson, 2016).

2.5. Data processing method

Statistical analysis was performed using Statgraphics Centurion XVIII (ANOVA, $p < 0.05$; Duncan's test for mean separation). Results are presented as mean ± standard deviation (SD) of triplicate determinations. Microsoft Excel (2019) was used only for plotting.

3. Results and discussion

3.1. Effect of pasteurization temperature and holding time on PU value

The red-flesh dragon fruit and strawberry juice, that had an average pH of 3.8 ± 0.1, was classified as a high-acid product. According to Holdsworth and Simpson (2016), products within a pH range of 3.7 to 4.2 are suitable for pasteurization at 85 °C with a z-value of 8.3 °C, and a minimum reference pasteurization unit (PU_0) of 5 minutes is required to ensure microbial safety.

Based on this reference, the study employed three pasteurization temperatures: 80 °C, 85 °C, and 90 °C, each combined with holding times of 3, 5, and 7 minutes, to evaluate their impact on thermal lethality.

The temperature at the geometric center of the product, referred to as core temperature, plays a critical role in microbial inactivation. Sufficient heat penetration and retention at the target temperature are essential. Insufficient thermal input may result in microbial survival, while excessive heating can cause nutrient degradation and adverse changes in sensory attributes (Holdsworth & Simpson, 2016).

As illustrated in Figure 2, all treatments followed the typical thermal processing stages: heating, holding, and cooling. Higher temperatures and prolonged holding times extended and stabilized the holding phase, thereby increasing the accumulated pasteurization unit (PU), which indicated microbial lethality. At 90 °C, the juice maintained the target temperature for the longest duration, and the cooling phase occurred more gradually, reflecting the highest thermal load.

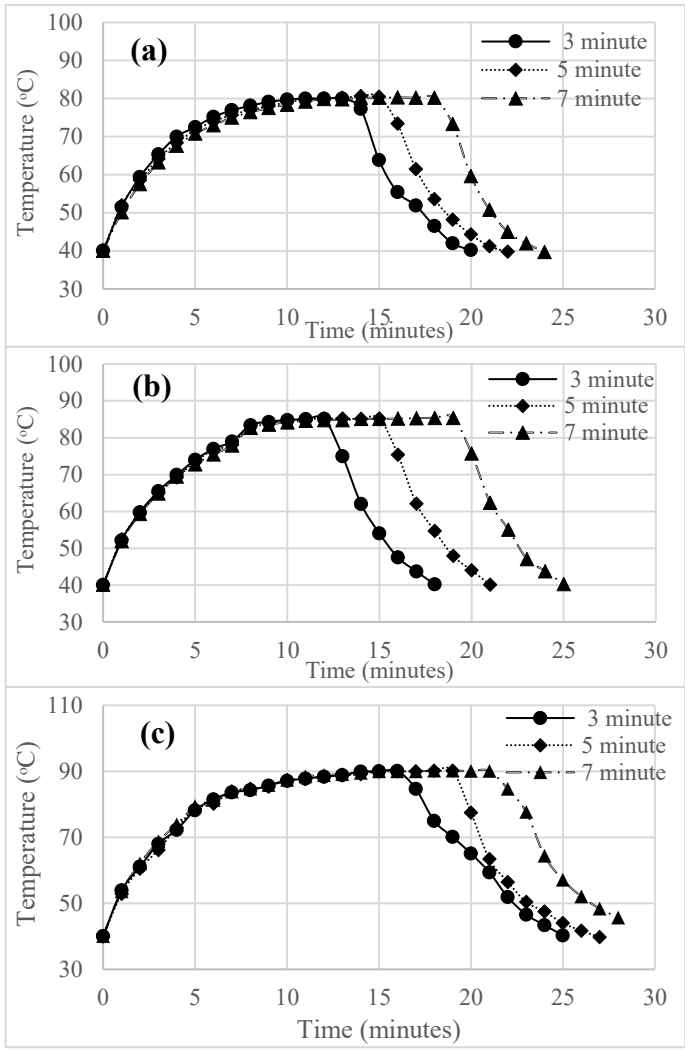

Figure 2. Changes in core temperature of the juice product during pasteurization at (a) 80 °C, (b) 85 °C, and (c) 90 °C

The calculated PU values, shown in Table 1, confirmed this trend. At 80 °C, a holding time of 7 minutes yielded a PU of only 2.55 minutes, which fell below the required threshold. At 85 °C, PU values of 7.91 and 10.45 minutes were achieved with 5 and 7 minute holding times, respectively, indicating sufficient lethality. The most efficient condition was observed at 90 °C, where a 3-minute holding time produced a PU of 25.79 minutes.

These results suggested that higher temperatures significantly enhance pasteurization efficiency. However, it remained essential to optimize processing conditions to achieve effective microbial inactivation while minimizing thermal damage and preserving product quality.

Table 1. Pasteurization unit (PU) values of the product under different temperature and holding time conditions

Temperature (°C)	Holding time (min)	PU value (min)
	3	1.67

80	5	1.97
	7	2.55
	3	4.87
85	5	7.91
	7	10.45
	3	25.79
90	5	36.41
	7	47.46

Note: Data are presented as the mean values of three replications.

3.2. Effect of pasteurization temperature and holding time on total aerobic microorganisms and yeast - mold spores

After pasteurization, red-flesh dragon fruit - strawberry juice samples were stored at 4 ± 2 °C for 15 days to evaluate the microbiological stability under refrigerated conditions. Total aerobic viable counts (TVC) and the counts of yeast and mold spores were assessed on days 0, 5, 10, and 15 (Table 2).

Table 2. Total aerobic microorganisms and yeast - mold spore counts at different pasteurization temperatures and holding times

Temperature (°C)	Holding time (min)	Total aerobic count (CFU/mL)				Yeast - mold spores (CFU/mL)			
		Day 0	Day 5	Day 10	Day 15	Day 0	Day 5	Day 10	Day 15
Unpasteurized	-	< 1	5.6×10^{1}	2.8×10^{3}	7.1×10^{5}	< 1	< 1	< 1	< 1
80	3	< 1	< 1	2.7×10^{1}	3.8×10^{2}	< 1	< 1	< 1	< 1
	5	< 1	< 1	1.3×10^{1}	2.2×10^{2}	< 1	< 1	< 1	< 1
	7	< 1	< 1	< 1	1.2×10^{2}	< 1	< 1	< 1	< 1
85	3	< 1	< 1	< 1	1.4×10^{2}	< 1	< 1	< 1	< 1
	5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	7	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
90	3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	7	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1

Note: *Data are expressed as mean values from three replicates. The symbol "<1 CFU/mL" means that the microbial count was below the detection limit of the method used, not that microorganisms were entirely absent.*

At the initial time point (day 0), all samples, including the untreated control, showed undetectable microbial levels (<1 CFU/mL). However, only certain pasteurization treatments were able to maintain this condition through day 15. This finding indicated that the long-term microbial stability of the product was strongly influenced by the initial heat treatment applied.

The original microbial population was likely reduced to below detectable levels by a preliminary heating step at 90 °C for 5 minutes. Despite this, microbial growth became evident in the untreated control sample starting on day 5, reaching 2.8×10^{3} CFU/mL by day 10 and peaking at 7.1×10^{5} CFU/mL on day 15.

In samples treated at 80 °C for 3 and 5 minutes, aerobic bacteria were first detected on day 10, with values of 2.7×10^1 and 1.3×10^1 CFU/mL, respectively. By day 15, these values exceeded the safety threshold of 10^2 CFU/mL. Likewise, microbial counts in the samples treated at 80 °C for 7 minutes and at 85 °C for 3 minutes also surpassed this limit on day 15, recording 1.2×10^2 and 1.4×10^2 CFU/mL, respectively. According to Vietnam National Standard QCVN 6-2:2010/BYT, the acceptable limit for total aerobic mesophilic bacteria in pasteurized beverages is 100 CFU/mL. Any sample that exceeds this limit after storage is deemed unsafe in terms of microbiological quality.

By contrast, no aerobic microorganisms were detected at any time during the 15 day storage in samples processed at 85 °C for 5 and 7 minutes, or in any of the samples treated at 90 °C. These conditions effectively ensured microbial safety throughout the storage period.

For yeast and mold spores, no growth was observed in any sample across all tested time points. This consistent absence was likely due to the acidic nature of the juice, which had a mean pH of 3.8 ± 0.1. When combined with thermal treatment, this low pH environment inhibits the survival of acid-sensitive microorganisms. In acidic matrices, organisms such as yeasts, molds, and spore-forming bacteria generally display lower thermal resistance (Pahalagedara et al., 2024). Therefore, the combination of acid conditions and pasteurization proved effective in eliminating these microbial groups.

3.3. Effect of pasteurization temperature and holding time on betacyanin and vitamin C content

Pasteurization aims not only to inactivate microorganisms but also to preserve the nutritional value of the product. Therefore, in addition to ensuring microbiological safety, thermal treatment can significantly affect key nutritional compounds such as betacyanin and vitamin C, which directly influence the overall quality of the juice.

Table 3. Betacyanin and vitamin C content in the juice under different pasteurization temperatures and holding times

Temperature (°C)	Holding Time (min)	Betacyanin (mg/L)	Vitamin C (mg/100mL)
80	3	7.65 ± 0.14^{a}	45.48 ± 0.54^{a}
	5	7.20 ± 0.13^{b}	43.42 ± 0.63^{b}
	7	6.85 ± 0.24^{c}	41.35 ± 0.44^{c}
85	3	7.15 ± 0.36^{b}	38.02 ± 0.36^{d}
	5	6.68 ± 0.14^{d}	36.70 ± 0.54^{e}
	7	6.46 ± 0.18^{f}	35.58 ± 0.48^{f}
90	3	6.61 ± 0.27^{e}	30.42 ± 0.37^{g}
	5	6.57 ± 0.23^{e}	28.44 ± 0.53^{h}
	7	6.06 ± 0.34^{g}	26.44 ± 0.44^{i}
		$P < 0.05$	$P < 0.05$

Note: Values are means of three replicates. Different superscript letters within a column indicate statistically significant differences at $P < 0.05$.

A significant decrease in betacyanin content was observed with increasing pasteurization temperature and holding time, reflecting the thermolabile nature of betalain pigments. The highest concentration of betacyanin (7.65 mg/L) was retained at 80 °C for 3 minutes, whereas the lowest (6.06 mg/L) occurred at 90 °C for 7 minutes. These differences were statistically significant ($p < 0.05$). Betacyanins are known to degrade through

isomerization, oxidation, decarboxylation, and hydrolysis when exposed to heat, with longer exposure accelerating pigment loss and color fading. This finding was consistent with the studies of Wong and Siow (2015) and Tran (2017), which demonstrated that both temperature and heating duration strongly influenced the degradation rate of betacyanins. Additionally, Reshmi et al. (2012) reported that increasing temperature can alter betacyanin levels due to polymerization, decarboxylation, or breakdown of the molecular structure. A recent study by Pham et al. (2024) also observed similar degradation patterns.

A similar trend was observed for vitamin C, a heat-labile compound highly sensitive to thermal processing. In this study, vitamin C content declined from 45.48 mg/100 mL at 80 °C for 3 minutes to 26.44 mg/100 mL at 90 °C for 7 minutes. The degradation mechanism is primarily attributed to thermal oxidation of ascorbic acid, which undergoes conversion to dehydroascorbic acid and subsequently to secondary products such as furfural, 2-furoic acid, and 3-hydroxy-2-pyrone. Among these, furfural may react with amino acids, contributing to browning in ascorbic acid-containing juices (Yin et al., 2022). The process is further accelerated by the presence of dissolved oxygen, trace metal ions, and prolonged exposure to elevated temperatures. Consistent with these findings, Thanasegaran and Mahror (2025) reported significant vitamin C degradation in red dragon fruit (*Hylocereus costaricensis)* juice as pasteurization temperatures increased from 60 °C to 80 °C, while extended holding times at the same temperature exacerbated the losses. Similarly, Ding (2020) confirmed the progressive reduction of vitamin C with increasing temperature and processing duration.

3.4. Effect of pasteurization temperature and holding time on the sensory attributes of the product

Sensory evaluation is an important criterion for selecting appropriate pasteurization conditions for the product. The results showed that temperature and holding time had a significant effect on color and aroma, while texture and flavor did not differ significantly among the samples ($P < 0.05$) (Figure 3). Specifically, samples treated at 85 °C for 7 minutes and at 90 °C for 3, 5, and 7 minutes had lower sensory scores for color and aroma compared to the other treatments. Notably, the sample pasteurized at 90 °C for 7 minutes recorded the lowest scores for both attributes.

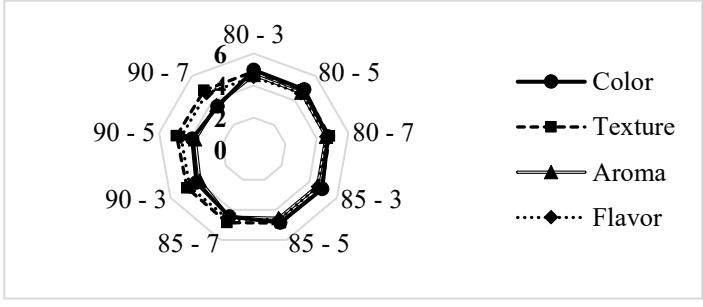

Figure 3. Sensory scores of the product at different pasteurization temperatures and holding times

The primary cause was believed to be the degradation of betacyanin, the characteristic pigment was responsible for the color of dragon fruit, when exposed to high temperatures for an extended period. As a result, the product's color shifted from bright purplish-red to pale red, losing its distinctive purplish hue. In addition, prolonged thermal treatment led to the evaporation of volatile aromatic compounds, resulting in a marked reduction in the characteristic strawberry-like aroma. Loss of aroma was likely due to volatilization of

strawberry compounds with low molecular weight during prolonged heating (Patras et al., 2009) (Table 4).

Table 4. Qualitative sensory description of the product under different pasteurization conditions

Temperature (°C)	Holding Time (min)	Color	Texture	Aroma	Flavor
80	3	Bright red with distinct purplish hue	Uniform	Clear, characteristic strawberry aroma	Balanced sweet-sour
	5	Bright red with distinct purplish hue	Uniform	Clear, characteristic strawberry aroma	Balanced sweet-sour
	7	Bright red with slightly lighter purplish hue	Uniform	Mild strawberry aroma	Balanced sweet-sour
85	3	Bright red with distinct purplish hue	Uniform	Clear, characteristic strawberry aroma	Balanced sweet-sour
	5	Bright red with distinct purplish hue	Uniform	Clear, characteristic strawberry aroma	Balanced sweet-sour
	7	Bright red with slightly lighter purplish hue	Uniform	Mild strawberry aroma	Balanced sweet-sour
90	3	Bright red with distinct purplish hue	Uniform	Clear, characteristic strawberry aroma	Balanced sweet-sour
	5	Bright red with slightly faded purplish hue	Uniform	Mild strawberry aroma	Balanced sweet-sour
	7	Pale red, purplish hue barely visible	Uniform	Very faint strawberry aroma	Balanced sweet-sour

Note: Sensory descriptions were compiled based on evaluations by a panel group (n = 15).

In summary, among the tested pasteurization conditions, the product treated at 85 °C for 5 minutes showed favorable sensory qualities and retained relatively high levels of betacyanin and vitamin C. Moreover, after 15 days of storage for monitoring microbiological stability, no aerobic bacteria, yeasts, or molds were detected. With a pasteurization unit (PU) value greater than 5 minutes, the treatment was sufficient to ensure microbial safety. These findings are particularly relevant for juice processors in Vietnam, where seasonal dragon fruit surpluses frequently occur.

4. Conclusion

Betacyanin and vitamin C contents showed a marked decreasing trend as pasteurization temperature increased and holding time was prolonged. Among the tested conditions, pasteurization at 85 °C for 5 minutes was identified as the optimal treatment for red-flesh dragon fruit-strawberry juice, achieving a pasteurization unit (PU) of 7.91 minutes, which exceeded the required PU_0 threshold. This result provides a solid scientific basis for selecting appropriate processing conditions to produce juice with high nutritional value and stable quality.

Limitations and Future Work

This study was limited to a 15-day observation period under refrigerated storage and to fixed levels of sucrose and ascorbic acid supplementation. Future research should investigate longer storage durations to evaluate extended shelf life, examine the influence of different packaging materials with varying barrier properties, and explore alternative or combined preservation technologies (e.g., high-pressure processing, pulsed electric fields) to further enhance the quality and safety of red-flesh dragon fruit - strawberry juice.

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