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Effects of Blanching Pretreatment on the Quality Attributes of Freeze-Dried Red Dragon Fruit (Hylocereus costaricensis)

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ABSTRACT

Freeze drying is an effective method for preserving heat-sensitive fruits such as dragon fruit (Hylocereus costaricensis) by removing moisture through sublimation. This study aimed to evaluate the effect of blanching pretreatment on the quality attributes of freeze-dried dragon fruit, including moisture content, color, total dissolved solids (TDS), and texture. A completely randomized design with two treatments (blanched at 90°C for 3 minutes and unblanched) and three replications was employed. Samples were cut into 1 mm and 3 mm thicknesses and freeze-dried at –50°C and 20 Pa for 24 hours. Results showed that blanching significantly reduced moisture content (final difference ≈1%), but also led to greater color degradation (lower L∗ and a∗ values, higher ΔE) and softer texture compared to unblanched samples. TDS values were lower in blanched samples. In conclusion, blanching enhances drying efficiency but compromises color, texture, and soluble solids retention in freeze-dried dragon fruit.

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1. INTRODUCTION

Indonesia is an agricultural country with a tropical climate that supports the growth of various fruit trees, including dragon fruit (Hylocereus costaricensis). Dragon fruit is a horticultural plant that thrives in tropical and subtropical regions at altitudes of 200–800 m above sea level. Known for its striking appearance, pleasant taste, and health benefits, dragon fruit is classified as a non-climacteric fruit, meaning that it reaches optimal ripeness on the plant and does not undergo significant post-harvest respiratory increases. However, its high moisture content (approximately 80–90%) makes it highly perishable, necessitating proper post-harvest handling or processing to extend its shelf life (Budhathoki et al., 2023; Ghorband et al., 2023; Khalili et al., 2006; Usmandoyo, 2017)

Drying is one of the oldest and most effective methods for food preservation. By reducing the water content, drying inhibits microbial growth and enzymatic activity, thereby maintaining product quality. Various drying techniques are available, including sun drying, cabinet drying, and freeze-drying. Among these, freeze-drying (lyophilization) is particularly suitable for heat-sensitive materials such as fruits, as it preserves nutritional, sensory, and structural properties through the sublimation of ice under low temperature and pressure (Liliana et al., 2015; Nowak & Jakubczyk, 2020; Pawestri & Syahbanu, 2023; Prosapio & Lopez-Quiroga, 2020).

The principle of freeze-drying involves the direct transition of water from the solid to vapor phase without passing through the liquid state, a process known as sublimation. This occurs when the temperature and pressure are maintained below the triple point of water. By avoiding liquid phase formation, freeze-drying minimizes structural collapse, color degradation, and nutrient loss, making it ideal for high-value products such as dragon fruit (Ellab, 2020; Martin Christ, 2021; Nowak & Jakubczyk, 2020).

Pretreatments, such as blanching, are often applied before drying to inactivate enzymes, reduce microbial load, and modify tissue structure, thereby improving drying efficiency and product quality (Deng et al., 2019). However, the effects of blanching on freeze-dried dragon fruits remain underexplored (Dadhaneeya et al., 2023; Mawilai et al., 2017; Wei et al., 2021). Previous studies have focused mainly on conventional drying methods, with limited attention paid to the combined impact of blanching and freeze-drying on the physicochemical attributes of dragon fruit (Ariani et al., 2019; Rosidi et al., 2021).

This study sought to assess the final quality of freeze-dried dragon fruit by examining its color, moisture content, total soluble solids, and texture. Additionally, the influence of the blanching pretreatment on these quality parameters throughout the freeze-drying process was investigated.

2. MATERIALS AND METHODS

2.1 Materials and Equipment

The materials used in this study included fresh red dragon fruit (Hylocereus costeriencis) harvested 30–50 days after flowering and obtained from local farmers in Bone Regency, South Sulawesi, Indonesia. The fruits were selected based on their uniform size, deep red flesh color, and absence of physical damage or signs of decay.

The equipment used in this study consisted of a freeze dryer (Model LBFD-D10), colorimeter (Model KW0520388), texture analyzer (Ametek Brookfield), digital refractometer (ATC), analytical balance, chiller, water bath, beakers, molds, mortar and pestle, stopwatch, and digital camera.

2.2. Research Design

This study utilized a Completely Randomized Design (CRD) incorporating two treatment factors: (1) blanching treatment, which included both blanched and unblanched conditions, and (2) sample thickness, specifically 1 mm and 3 mm.

Each treatment combination was replicated three times. The treatments were defined as follows:

- A1: Dragon fruit slices (4 × 4 cm, 1 mm thickness) with blanching at 90°C for 3 min.
- A2: Dragon fruit slices (4 × 4 cm, 1 mm thickness) without blanching.

2.3. Sample Preparation

Fresh dragon fruit was washed, peeled, and cut into 4 × 4 cm slices with thicknesses of 1 and 3 mm using a stainless-steel mold. For the blanching treatment, slices were immersed in a water bath maintained at 90°C for 3 min, followed by immediate cooling in ice water to halt thermal processing. All samples were then drained, packed in Ziplock bags, and stored in a refrigerator at 4°C for 24 h prior to freeze drying.

2.4. Freeze-Drying Process

Samples were pre-frozen at –20°C for 24 h to promote uniform ice crystal formation. Freeze drying was conducted using a laboratory freeze dryer at –50°C and 20 Pa for 24 h. During drying, samples were periodically removed at 8, 16, and 24 h for quality parameter analysis.

2.5. Quality Parameter Analysis

2.5.1. Moisture Content

The moisture content was determined gravimetrically using the wet basis (MC_{wb}) and dry basis (MC_{db}) formulas:

$$MC_{wb}\ (\%) = \frac{Wt - Wd}{Wt} \times 100\% \quad (1)$$

$$MC_{db}\ (\%) = \frac{Wt - Wd}{Wd} \times 100\% \quad (2)$$

where is the W_t = initial weight (g) and W_d= dry weight (g).

2.5.2. Color Measurement

Color was measured using a colorimeter in the CIE $L^*a^*b^*$ system. The total color difference (ΔE) was calculated as follows:

$$\Delta E = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2} \quad (3)$$

where L_0^*, a_0^*, b_0^* are the initial values, and L^*, a^*, b^* are the values after treatment.

2.5.3. Texture Analysis

Hardness was measured using a texture analyzer with a 2 mm cylindrical probe at a penetration speed of 20 mm/s.

2.5.4 Total Dissolved Solids (TDS)

To quantify the total dissolved solids (TDS) in dragon fruit, a refractometer was utilized. The procedure commences with crushing the fruit sample using a mortar and pestle to extract the juice. This extracted liquid was subsequently applied to the refractometer's glass plate, allowing the TDS value to be determined from the display.

2.6. Data Analysis

The data were analyzed descriptively and presented graphically. Qualitative changes in color, texture, moisture, and TDS were discussed in relation to blanching pretreatment and drying time.

3. RESULTS AND DISCUSSION

3.1 Moisture Content

Moisture content is a key indicator of the success of freeze-drying dragon fruits. Fresh dragon fruit has a high moisture content of approximately 80–90%; therefore, it needs to be reduced to <5% for safe long-term storage. In freeze-drying, water is removed in two stages: ice sublimation (primary drying) and removal of bound water (secondary drying). Dry basis moisture content indicates the amount of water in each unit of dry material mass, whereas wet basis moisture content indicates the water content relative to the total weight of the material.

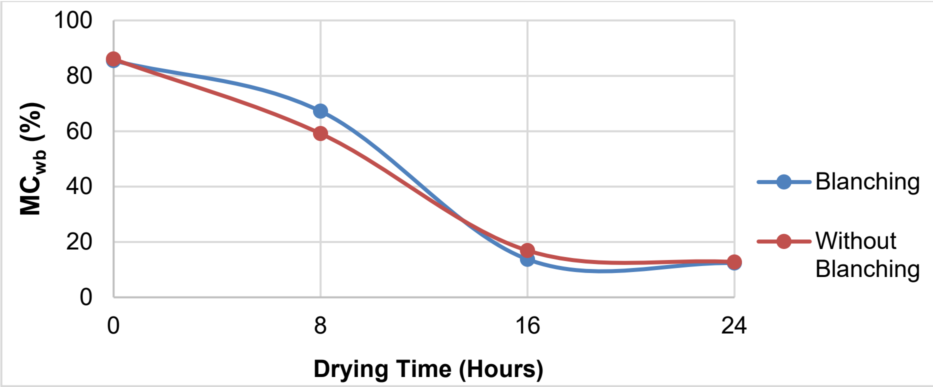

Figure 1. MC_{wb} Graph of Blanched and Unblanched Samples Based on.

The graph above illustrates a comparison of changes in the water content of dragon fruit subjected to blanching and those not blanched during the drying process over time. At the onset of drying (extrapolated from the initial data point), the water content in dragon fruit was notably high, estimated at around 86% for blanched fruit and 84% for unblanched fruit. At this juncture, the primary factor influencing water content is the inherently high water content of dragon fruit. The slight initial difference may be attributed to sample variability and the impact of blanching on the samples. Between hours 0 and 8, there was a marked reduction in water content in both samples. By the 8-hour mark, the water content of blanched dragon fruit had decreased to approximately 67%, while that of unblanched dragon fruit had dropped to about 59%. The drying rate at this early stage was rapid due to the significant difference in water vapor pressure between the fruit's wet surface and the drying air. Blanching began to show its effect by slightly accelerating the initial release of water. This was due to the pretreatment process, which opened the pores of the fruit, making the drying process more significant. It has been reported that blanching causes air in the tissue to escape and water movement is not hindered, thus accelerating the drying process (Pawestri & Syahbanu, 2023). The water content continued to decrease but at a slower rate. At 16 and 24 h, the water content of blanched dragon fruit reached approximately 14%, whereas of that unblanched fruit was approximately 16%. The slowing of the drying rate is caused by a decrease in the free water content of the fruit, such that the water that must be evaporated comes from deeper layers and requires diffusion to the surface. The structure of the fruit tissue and changes that occur during drying begin to become limiting factors (Ariani et al., 2019).

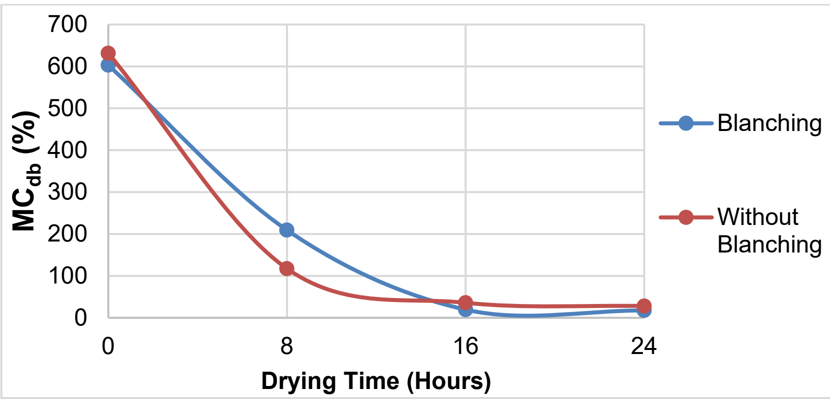

Figure 2. MC_{db} Graph of Blanched and Unblanched Samples.

The graph above shows how water is removed from dragon fruit during drying, comparing blanched fruit and fruit that have not undergone the blanching process. At the beginning of drying, from the start to approximately the first eight hours, dragon fruit that has not been blanched appears to lose water more quickly. This occurs because, at this early stage, the cell structure and cell membranes of the fruit are still intact and unchanged. Consequently, free water between cells or on the surface of the fruit can evaporate or sublimate very quickly. This type of water is not strongly bound and is very easily released from the fruit, as if the cell doors are still wide open for easily accessible water, which explains the higher drying rate of the unblanched fruit at the beginning. However, after passing the eight-hour mark and onwards until the fruit was completely dry, the situation was reversed.

Dragon fruit that was previously blanched actually reaches optimal dryness first when the water content is very low and stable. This change was caused by the blanching process itself, which involved exposure to heat. This heat causes changes in membrane permeability. Dragon fruit cells. Although initially, this change may slightly inhibit the release of free water due to other modifications in the structure of dragon fruit that make water slightly more difficult to escape compared to the highly free water in samples without blanching, the impact is very beneficial in the final stage of drying. Cells whose walls are slightly "damaged" or whose membranes become more permeable because of blanching will facilitate the diffusion of water that is strongly bound within the cells, which is much more difficult to remove because it is trapped in the cellular matrix. With this "open" structure due to blanching, water that is difficult to release can move more easily and quickly, so that the blanched fruit achieves a stable low water content. The Changes in the micro and macro structure of materials during the freezing and freeze-drying process can affect the water vapor diffusion pathway, which contributes to a decrease in the drying rate (Nowak & Jakubczyk, 2020).

3.2 Color Change

Color is the most easily observable physical characteristic of food, and in fruits dried using a freeze dryer, changes typically occur because of the loss of pigments and water. Color intensity is also influenced by the freezing rate, as rapid freezing forms smaller pores that increase light scattering compared to large pores.

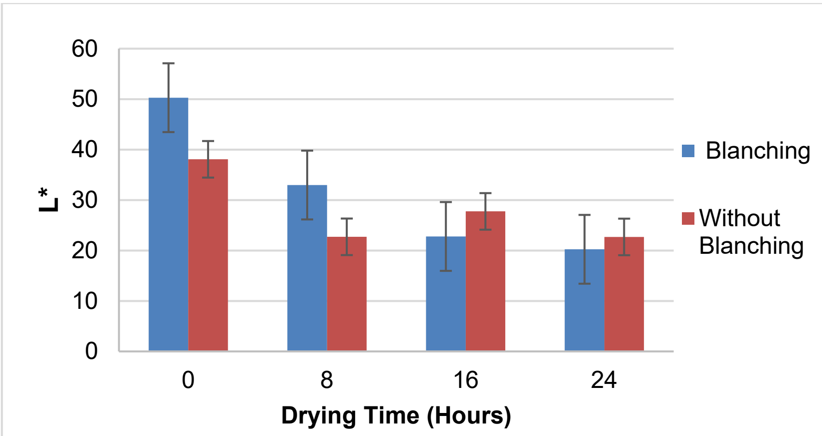

Figure 3. Color values (L*) of blanched and unblanched samples.

Based on the bar graph above, this graph compares the average color values (L*) between samples A1 and A2 at various times (0, 8, 16, and 24) with two treatments, namely blanching and without blanching. The L* value represents the brightness level of an object, where a higher value indicates a brighter color. The effect of blanching is evident at almost all time points except at 16 h, when the L* value in samples treated with blanching tends to be lower than that in samples without blanching. This indicates that the blanching process can cause a decrease in color brightness in samples owing to pigment damage caused by suboptimal blanching. L* values tended to decrease over time, although there was a slight increase between 8 and 16 h. This decrease shows that the blanched samples become darker over time. The L* value also decreased over time, but the decrease was not always consistent. There was a significant decrease from time 0 to 8, then a slight increase at time 16, and a decrease again at time 24. For samples that did not undergo blanching at time 0, the graph shows a higher L* value than that of the blanched samples. This means that in the initial condition without the blanching process, the samples retained their original color brightness. This higher L* value became the benchmark or initial condition before any treatment. Changes in L* values at subsequent time points (8, 16, and 24 h) in samples without blanching show how the natural color brightness of the samples changes over time without blanching intervention. The decrease in L* values at subsequent times indicates natural darkening of color over time, which is likely caused by factors such as pigment oxidation or internal chemical reactions in the sample. Fruits that have been dried using a freeze dryer generally undergo color changes because, during the drying process, there is a loss of color pigments in the fruit along with water content, for example, a reduction in color pigments (Habibi et al., 2019).

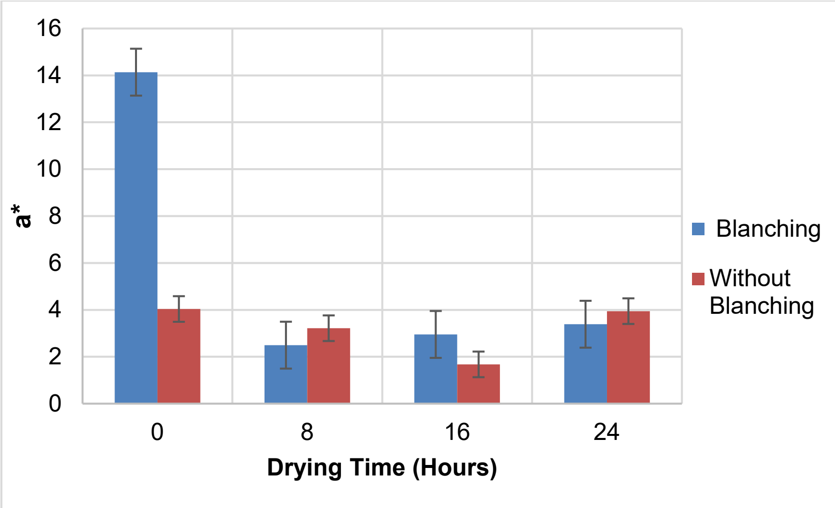

Figure 4. Color values (b*) in the blanched and unblanched samples.

This bar graph shows the average color value (a*) for samples A1 and A2 at various times (0, 8, 16, and 24 h) with two treatments, namely blanching and without blanching. The a* value in the color system represents the level of redness or greenness of an object. Positive values indicate a redder color, whereas negative values indicate a greener color. At the initial time (0 h), the blanched sample showed a much higher a* value (more red) compared to the unblanched sample. However, over time, the a* value in the blanched sample decreased dramatically. Meanwhile, the a* value in the unblanched sample tended to be more stable and even showed a slight increase at 8 and 24 h. There was a significant decrease in the a* value after blanching, and this decrease continued over time, despite a slight increase at 24 h. This indicates that the redness of the blanched samples decreased significantly after treatment and continued to fade over time. The blanching process, which causes a decrease in the L* brightness, is also accompanied by a decrease in the a * redness over time. This may indicate that the red pigments in the sample become unstable owing to the blanching heat treatment, causing degradation that results in a darker and less red color over time. Meanwhile, the a* value in the process without blanching is relatively lower at the beginning but tends to be more stable or even increase slightly over time. Samples that were not blanched retained their natural color pigments without the heat stress of the blanching process. These pigments may be more stable in their original state than after heat exposure. This is in line that this decrease is thought to occur because the drying process relies on heat, causing heat discoloration and nutrient loss in the resulting product (Mujumdar & Law, 2010).

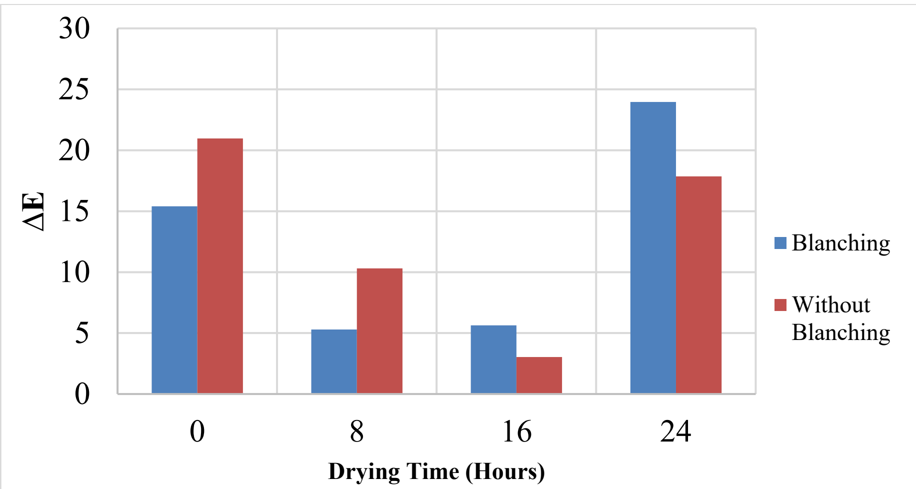

Figure 5. Total color change in the blanched and unblanched samples.

Figure 5 shows the total color change (ΔE) for the blanched and unblanched samples at various times (0, 8, 16, and 24 h). The total color change (ΔE) is a single value that calculates the difference between two colors in a specific color space. A higher ΔE value indicates a greater color difference. This chart compares the colors of the samples at each time point with their initial colors (at time 0). At the initial measurement, the total color change for blanching was significantly high, whereas for non-blanching, it was comparatively low. This indicates that at the start of observation (which may be the condition after initial treatment such as blanching, although not explicitly stated in this chart), the color of the blanched sample had already undergone a significant change from its reference color, whereas the color of the unblanched sample had relatively little change. At 8 h, the total color change for both samples decreased dramatically compared to time 0. This shows that after the initial large change in blanching, the subsequent color change in the 0 to 8-hour period is relatively small. The color change in the non-blanching sample was also small during this period. The total color change for both samples shows a slight increase from 8 to 16 h. This indicates that there was a slight color change in both samples during this time period (Rosidi et al., 2021).

The changes in the unblanched samples appear to be slightly greater than those in the blanched samples. The total color change of dragon fruit between 16 and 24 h during freeze-drying shows opposite trends between blanched and unblanched conditions. At 16 h, blanching showed a color change value of 2.55, which then decreased to 2.24 at 24 h. This small decrease indicates color stabilization or the dominance of mechanisms that inhibit further color change in the final phase of drying of the blanched samples. In contrast, unblanched samples showed good color stability at 16 h with the lowest color change value of 1.69, but experienced a significant jump to 8.09 at 24 h. This dramatic increase implies that after a longer freeze-drying process, the color degradation mechanism becomes very active under non-blanching conditions. Factors that may underlie these differences in trends include differences in residual moisture content, the potential for more intense non-enzymatic reactions, such as pigment oxidation under non-blanching conditions during extended drying times, or differences in pigment sensitivity to drying conditions in the final phase. The contrasting color change behavior between the two conditions over this time frame emphasizes the importance of considering the freeze-drying duration in relation to the initial treatment to achieve optimal final product color quality. Various research journals on freeze-drying fruits and vegetables show that optimizing duration (Ariani et al., 2019).

3.3. Total Dissolved Solids

Total Dissolved Solids is a parameter used to measure the amount of dissolved substances in a liquid, especially sugar, organic acids, vitamins, and minerals. TDS is generally expressed in degrees Brix (°Brix), which describes the sugar concentration in a solution and is often used to assess the sweetness and ripeness of fruits.

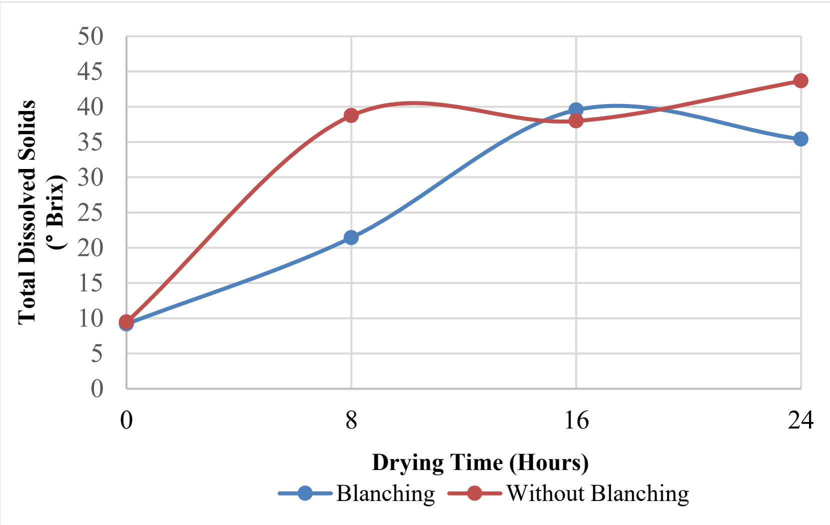

Figure 6. Total dissolved solids with and without blanching.

Based on Figure 6, it can be understood that the total dissolved solids (mainly natural sugars in dragon fruit) increase as water is lost during freeze-drying. The difference between the curves with and without blanching indicates that blanching has a significant effect on changes in the TDS of dragon fruit during freeze-drying. Under both conditions, there was a tendency for the total dissolved solids to increase as the freeze-drying process progressed. This is reasonable because the freeze-drying process aims to remove water from the material. As water evaporates, the concentration of dissolved substances (such as sugars, acids, and other compounds) in the remaining material increases, thereby increasing the °Brix value. At the beginning of the process, TDS increases rapidly, peaking at approximately 8-10 hours, and then tends to stabilize or even decrease slightly thereafter. This decrease may be due to several factors, such as possible structural changes during drying that affect solubility or the detection of dissolved solids. The increase in TDS in the blanched samples tended to be slower in the early stages. However, after approximately 15 h, TDS continued to increase and even exceeded the TDS value in the sample without blanching at the end of the drying process observed. Blanching may cause reactions that alter the soluble solid components during drying. In addition, blanching can break down cellular structures, facilitating the release and measurement of dissolved solids. This blanching can damage the cell structure, facilitate the release of dissolved solids during drying, and inactivate enzymes that can break down dissolved solid components (Paramita et al., 2023) .

3.4. Texture

Texture is an important quality parameter in dragon fruit freeze-drying. The freeze-drying process has the advantage of preserving the physical structure of the fruit because it involves low temperatures and vacuum pressure, which allows the water in the fruit tissue to evaporate directly in the form of vapor through the process of sublimation. This results in a dry product that is light, porous, and brittle, with a shape close to the original. The texture of dried dragon fruit is generally crispy owing to its open pore structure caused by ice sublimation.

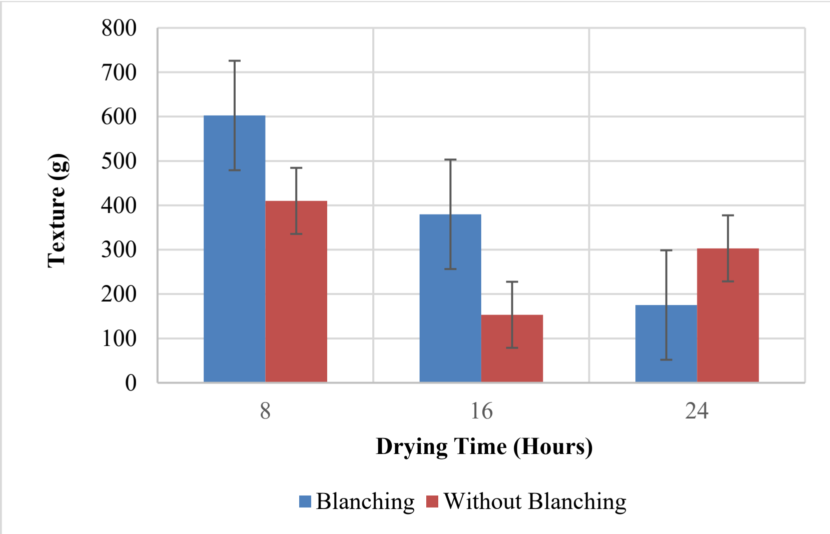

Figure 7. Textures with and without blanching.

The graph above indicates that at the initial measurement point for texture, specifically at 8 h, both blanched and unblanched dragon fruit exhibited very low and similar texture values, each falling below 10,000 g. This indicates that the freeze-drying process had just begun, and the frozen water content in the fruit was still dominant; therefore, the texture had not yet hardened significantly. After the next 8 h (a total of 16 h of drying), there was a significant increase in texture values in both groups. This indicates that more frozen water has sublimated and the fruit structure has begun to become denser. Dragon fruit that was not blanched showed a much higher texture value (around 155,000 g) compared to fruit that was blanched (around 68,000 g), indicating that fruit that was not blanched lost water more quickly or underwent structural changes that resulted in a harder texture during the same drying time. Dragon fruit that was freeze-dried for 24 h without blanching reached a very high texture value of approximately 305,000 g, significantly higher than blanched fruit at approximately 175,000 g. Heating during blanching can damage the cell membranes and cell walls of the fruit and cause a loss of structural integrity in the tissue. As a result, when water is removed during freeze-drying, the damaged cell structure is unable to maintain the same hardness as the fruit. These fruit chips undergo structural collapse owing to increased porosity caused by a decrease in water content during the process. This results in a decrease in volume and an increase in density, resulting in fruit chips with a harder texture than that of fresh fruit (Mujumdar & Law, 2010; Usmandoyo, 2017).

The results of the four parameters analyzed (moisture content, color, TDS, and texture) show that blanching improves drying efficiency (faster moisture reduction and slightly lower final moisture content), but compromises in final quality appear in color (decrease in L*, a*, and increase in ΔE), TDS (lower), and texture (softer). These findings are consistent with the literature on high-moisture horticulture, where thermal pretreatment accelerates drying but alters the sorption properties and tissue structure, thereby reducing sensory quality. Therefore, the decision to use blanching must be tailored to the product's objectives. If the primary goal is efficiency/moisture reduction, blanching is beneficial; if color preservation, TDS, and crispness are prioritized, non-blanching is more appropriate (Putri Sejagat et al., 2023; Selpiah et al., 2023).

4. CONCLUSION

Based on the results of the research that has been carried out, it can be concluded that

1. Blanching pretreatment significantly affects the quality attributes of freeze-dried dragon fruit, particularly by accelerating moisture removal. However, the final difference in moisture content between the blanched and unblanched samples was relatively small (approximately 1%).
2. Color degradation was more pronounced in the blanched samples, as indicated by lower L∗ (lightness) and a∗ (redness) values, along with a higher total color difference (ΔE). This suggests that blanching may not be suitable if color preservation is a priority.
3. The total dissolved solids (TDS) content was lower in the blanched samples, indicating the potential leaching of soluble components during the blanching process.
4. Texture analysis revealed that unblanched samples were significantly harder after freeze-drying, suggesting that blanching softens the fruit tissue, likely due to cellular structure disruption.
5. Overall, blanching can be recommended when the primary goal is to enhance drying efficiency and moisture reduction, but it should be avoided if the aim is to preserve the natural color, texture, and soluble solid content in freeze-dried dragon fruit.

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