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Freshness Identification in Stored Fresh-Cut Cabbage Based on Physicochemical and Sensory Indicators

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Abstract

Fresh-cut cabbages, which are ready to eat, are also popular because of their convenience; however, the cutting process increases metabolism, thereby increasing the loss of quality. In addition, improper storage can result in the loss of quality of fresh-cut cabbages. This study was conducted to determine the respiration rates and quality alterations in fresh-cut cabbages, as well as to examine the effect of temperature on the physicochemical characteristics of fresh-cut cabbage. Fresh-cut cabbages were prepared using a food processor, and the samples were stored at 5, 10, and 20 °C in polypropylene films. During the storage period, respiration rate, color, ascorbic acid content, sensory qualities, and bacterial growth were monitored. The results showed that temperature significantly affected the investigated characteristics. Respiration, loss of color and ascorbic acid, and growth of microflora were higher in samples stored at 20 °C than in those stored at 10 and 5 °C. In contrast, storage at 5 °C reduced bacterial growth and ensured better preservation of quality than at other temperatures. From the sensory point of view, the freshness of cabbage was maintained for five days at 5 °C, four days at 10 °C, and two days at 20 °C. In conclusion, fresh-cut cabbage should be stored at 5 °C for maximum quality retention.

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1. Introduction

The consumption of minimally processed vegetables has markedly increased, primarily due to changes in consumer lifestyles and the demand for healthy food products that are ready to eat (Rico et al., 2007). Cell damage during product processing causes physiological changes, increasing respiration, enzymatic browning, and microbial growth, thus reducing the product's shelf life and quality (Kader, 2002; Barrett et al. 2010; Zainal et al. 2023).

Fresh-cut cabbage is a vegetable product of the species Brassica oleracea var. capitata. This is one of the most consumed fresh-cut vegetables because of the health benefits it offers and the variety of food products that can be prepared using it. However, cutting vegetables increases the rate of

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respiration and ethylene sensitivity, thereby reducing the storage life of the product (Faisal et al., 2025). From empirical evidence, the rate of respiration is doubled or even tripled after cutting the vegetable during the post-harvest stage due to damage to the cells, leading to the release of substances that increase the rate of respiration (Hodges & Toivonen, 2008). The respiration rate is a significant physiological index used to determine the freshness of a product.

In addition to respiration rate, color, and ascorbic acid content, fresh maturity loss is another important predictor of product quality. Discoloration in fresh-cut cabbage occurs due to the degradation of chlorophyll and enzymatic browning caused by the activity of polyphenol oxidase and peroxidase (Toivonen & Brummell, 2008; Zhang et al., 2025). Dullness and discoloration in fresh-cut cabbage products usually lead to negative consumer responses, which are associated with the loss of freshness. However, ascorbic acid content is an important quality attribute of fresh-cut cabbage, as it acts as a natural antioxidant and an indicator of oxidative stress and senescence (Smirnoff, 2017).

Microbial development is an important factor in postharvest losses of produce. Physical damage and surface contamination of produce provide an ideal environment for bacterial growth. The spoilage of produce is caused by the presence of bacteria such as Pseudomonas and Enterobacter, which can reproduce rapidly on fresh-cut cabbage, resulting in slime formation, off-odors, and reduced consumer acceptability of the produce. Microbial community composition and sensory evaluation are important aspects of evaluating maturity-related losses in produce.

Temperature is the most important environmental factor affecting the respiration rate, enzymatic activities, and microbial growth of produce. Cold storage of produce reduces metabolic activity, thereby increasing its shelf life. In particular, the storage of cabbage at low temperatures reduces moisture loss. According to research, temperatures below 5 °C result in significantly lower respiration rates, color loss, and vitamin C loss compared with storage at 10 °C or 20 °C. The relationship between quality changes in fresh commodities and quality, as well as physiological predictors, is an evolving area of research.

The objectives of the present study were to identify the quality changes in fresh-cut cabbage during cold storage by establishing the relationship between quality and physiological factors at various storage temperatures. The results of this study are expected to provide scientific data for the establishment of models for evaluating the quality of fresh commodities.

2. Material and Methods

2.1 Sample Preparation

Fresh cabbage (Brassica oleracea var. capitata L. capitata) was collected from a local farm. The cabbage was sliced into 2 mm-wide strips using a food processor (CL 50 Ultra, Robot Coupe, France). The cabbage was then packaged in a polypropylene film and stored at 5 °C, 10 °C, or 20 °C. Cabbage samples were collected daily in groups of five from different cabbages for five days.

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2.2 Respiration Measurement

The respiration of the cabbage was measured using a 4.8 L acrylic chamber (a transparent plastic container) equipped with inlet and outlet tubes (for controlling air movement) to measure gas flow. Approximately 300 g of cabbage sample was introduced into the chamber. Fresh air was pumped into the chamber using an air compressor (a device that moves air into the chamber) and a mass flow controller (a device that maintains a constant airflow; SEF-E40, Horiba, Japan) at a flow rate of 100 mL min^{-1}. The gases released from the chamber were analyzed to determine CO_2 production, that is, the respiration rate of the cabbage.

2.3 Determination of Ascorbic Acid

Ascorbic acid content in the cabbage sample was determined using a modified version of the method described by Mazurek and Pankiewicz (2012). Two grams of the cabbage sample was extracted with 8 mL of 5% metaphosphoric acid. The mixture was vortexed for 1 min and centrifuged for 15 min at 4°C. Subsequently, the supernatant was filtered, and 500 μL of the filtrate was mixed with 50 μL of 100 mM Tris(2-carboxyethyl) phosphine hydrochloride (TCEP). The mixture was then agitated at 2500 rpm for 25 min at 25°C in the dark to prevent oxidation. Finally, the total ascorbic acid (T-AsA) content in the cabbage sample was determined using a reversed-phase HPLC system equipped with a Hydrosphere-C18 column (50 × 4.6 mm i.d., 5 μm; YMC, Japan) and detected at 245 nm.

2.4 Colour Measurement

The color of the fresh-cut cabbage was determined using a chromameter (CR-20, Minolta Corp., Japan), and the CIE L *, a *, and b * color system was employed for color evaluation. The hue angle (h°) was calculated using the following formula: $h° = \tan^{-1}(b/a)$. Three random readings were taken for each sample, and the average value was recorded.

2.5 Microbial Population Analysis

The microbial quality of fresh-cut cabbage was assessed using the total plate count method (a technique used to estimate the total number of viable bacteria). Ten grams of a fresh-cut cabbage sample was transferred to a stomacher bag (a sterile plastic bag used to homogenize food samples for microbial testing) containing 90 mL of sterile distilled water, and the mixture was homogenized for 1 min. Dilutions were prepared, and 1 mL of the sample homogenate was plated onto Plate Count Agar (PCA), a nutrient-rich medium used to grow bacteria from samples. The cultures were incubated at 35°C for 48 h and expressed as log CFU/g fresh weight (colony-forming units per gram of cabbage, logarithmically transformed).

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2.6 Sensory Evaluation

A panel of 10 members assessed the overall visual quality of the fresh-cut cabbage using a 5-point scale:

5 = Very Fresh (no wilting, dryness, browning, black spots)

4 = Fresh

3 = Relatively fresh

2 = Edible, no significant defects

1= Not edible

The panel members rated the appearance of fresh-cut cabbage over five days, and scores of three or higher were considered acceptable for marketability.

2.7 Statistical Analysis

All experiments were performed in triplicate for reliability and statistical validity. Significant differences were found using one-way ANOVA, and Duncan's Multiple Range Test was applied at a $p < 0.05$ level of significance. All statistical analyses were performed using R Studio version 4.5.2.

3. Results and Discussion

3.1 The Alteration of Respiration as an Indicator of Physioligocal Stress

Fresh-cut cabbage showed a respiration rate pattern that was dependent on the storage temperature (Figure 1 and Table 1). A significant increase in the production of CO2 was observed in the damaged cut cabbage. The highest respiration rate was recorded at 20 °C, whereas the respiration rate was moderate at 10 °C, with the lowest respiration rate recorded at 5 °C. This is consistent with the value of Q_{10} for living tissues, which shows that the respiration rate doubles with every 10 °C increase in storage temperature.

Table 1. Total accumulated production of cut cabbage during storage.

Storage Days	Total Accumulated Production of CO_2 (mL CO_2 kg^{-1})		
	20 °C	10 °C	5 °C
1	146.39	63.05	33.5
2	212.56	127.35	63.12
3	264.75	182.78	93.94
4	317.14	223.7	124.34
5	358.28	256.29	152.47

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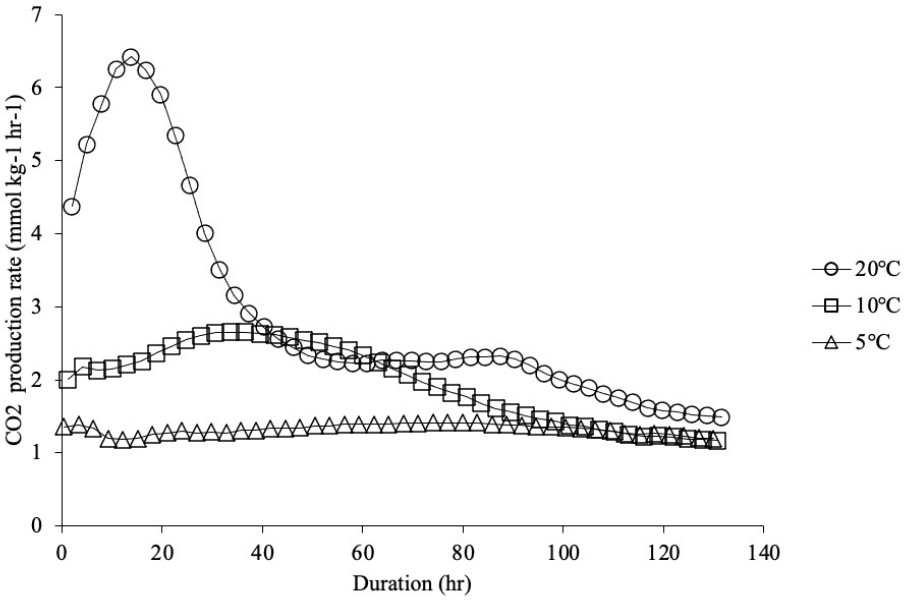

Figure 1. Changes in the CO_2 production rate of stored cut cabbage under various temperature conditions.

The cumulative amount of CO_2 generated increased with storage time at all temperatures studied (Table 1). The generation of CO_2 was significantly higher at higher temperatures, with the highest levels recorded in cabbage samples stored at 20 °C, followed by those stored at 10 °C and 5 °C. On day 5, the cumulative amount of CO_2 increased to 358.28 mL CO_2 kg^{-1} in cabbage samples stored at 20 °C, 256.29 mL CO_2 kg^{-1} at 10 °C, and 152.47 mL CO_2 kg^{-1} at 5 °C.

High temperatures during storage increase the rates of glycolysis and the TCA cycle, thus increasing the production of CO2, which in turn reduces the available respiratory substrates (Kays & Paull, 2004). At 20 °C, increased respiration causes rapid consumption of carbohydrates, leading to depletion of energy reserves, premature senescence, and membrane disorganization. In contrast, the low storage temperature of 5 °C slows down metabolism, thus maintaining the homeostasis of the cells (Kays & Paull, 2004). This is evidenced by the increased amount of CO2 produced at 5 °C (Figure 1), as the metabolism was slowed down by approximately 40-50% compared to the cabbage stored at 20 °C. This study supports the findings of Xie et al. (2020) that the cold storage of cut cabbage delays the onset of senescence, as the enzymatic reactions are slowed down in the vegetables. Therefore, the respiration rate of cabbage can be used as an indicator of the deterioration of the freshness of cut cabbage after minimal processing.

3.2 Degradation of Ascorbic Acid (AsA)

The AsA content in fresh-cut cabbage exhibited a non-linear trend during the storage period. Initially, it decreased until day 1, followed by a gradual increase until day 4, after which a further

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decrease was observed on day 5 (Figure 2). Thus, AsA loss due to oxidative degradation does not follow a linear trend but changes dynamically with storage duration. The lack of correlation between storage time and AsA level is evident from the low R^2 values for each temperature, which range from 0.0857 at 5 °C to 0.2457 at 10 °C and 0.1538 at 20 °C.

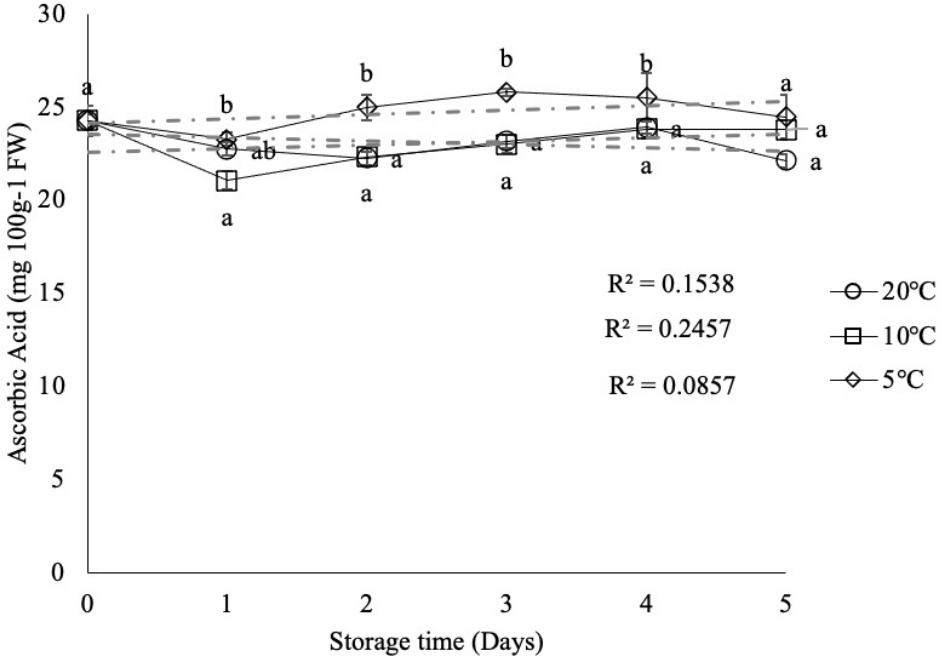

Figure 2. Alteration of ascorbic acid in stored fresh-cut cabbage under various temperature conditions.

According to Duncan's multiple range test, the AsA level was significantly influenced by storage temperature at various time points ($p < 0.05$). For instance, from day 1 to day 4, fresh-cut cabbage preserved at 5 °C (group b) exhibited significant differences when compared to the sample at 10 °C (group a), while the sample at 20 °C (group ab) showed no differences from groups a and b. In other words, lower temperatures contributed to better preservation of AsA content during this period. However, on day 5, no significant differences were observed between the samples at different temperatures.

Fluctuations in AsA levels were a result of the interaction between oxidative degradation and metabolic processes stimulated by the cutting stress. The immediate reduction in AsA level was possibly due to cutting stimulating oxidation reactions owing to increased oxygen intake and enhanced activities of ascorbate oxidase and peroxidase (Yahia et al., 2001). Moreover, mechanical injury triggers the ascorbate–glutathione cycle due to compartmentalization impairment, which leads to increased oxidation reactions and reduced levels of antioxidants, such as AsA (Yahia et al., 2001).

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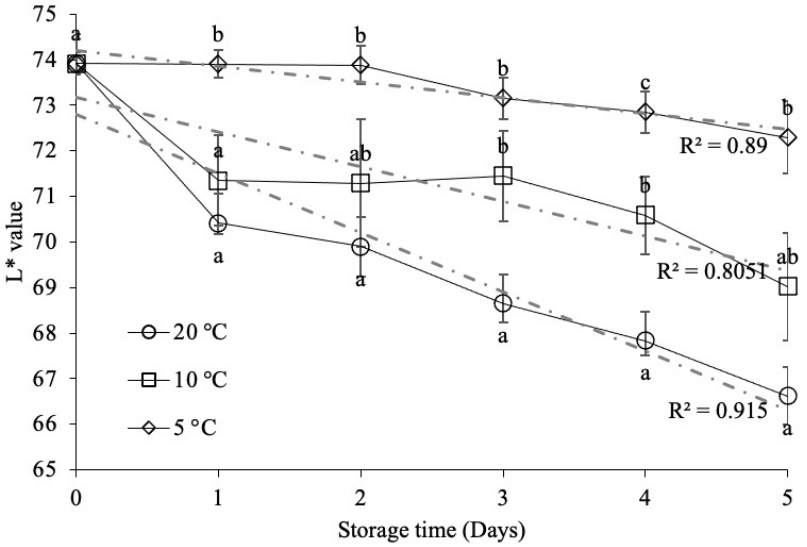
The increase in AsA levels occurred as a result of the activation of antioxidant mechanisms during the middle stage of storage; however, this process was apparently not very effective, as the AsA content further declined during the final stages of storage. Previous studies have found that high storage temperatures enhance biochemical reaction rates, causing faster depletion of AsA in fresh-cut vegetables (Lee & Kader, 2000). Therefore, as expected, lower temperatures (5 °C) were associated with higher AsA levels in the present study.

3.3 Color Degradation

The results of the color analysis showed a decrease in both the L* value and the hue angle (h°) during storage, which indicated a gradual decrease in the visual quality of fresh-cut cabbage (Figsures 3a-b). This indicates that the hue angle decreases as the bright green color becomes yellower. However, at higher storage temperatures, particularly at 20 °C, a more significant reduction was observed. Highly significant linear relationships were observed between storage time and color degradation, with coefficients of determination (R^2 = 0.8051–0.915 for L* and R^2 = 0.9311–0.9561 for hue angle), indicating that storage time was the primary cause of visual quality deterioration.

Duncan's multiple range test proved the impact of storage temperature on the measured color parameters ($p < 0.05$). In general, throughout all storage periods, the samples stored at 5 °C showed significant differences in L* compared to samples stored at higher storage temperatures, whereas significant differences were observed in hue angles throughout storage, except for the first three days, where no difference was found. This suggests that lower storage temperatures prevent a decrease in color characteristics, although the difference varied.



(a)

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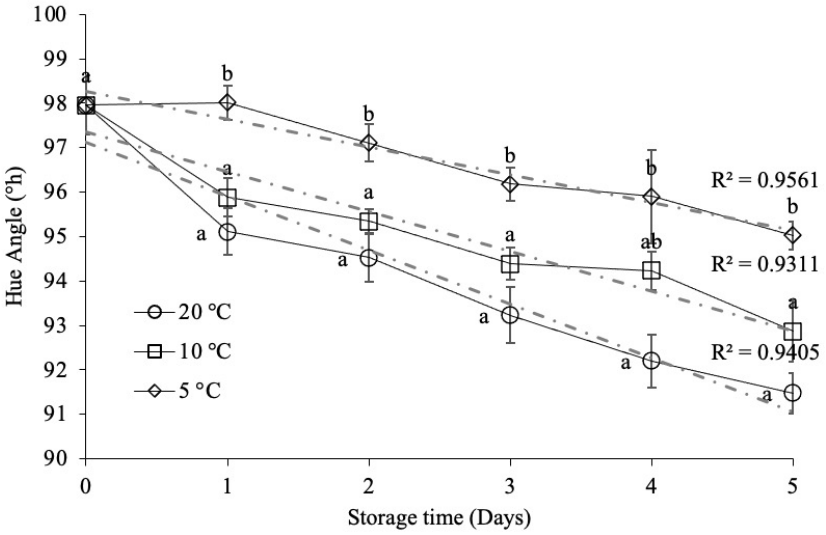

(b)

Figure 3. Consumer perception of the freshness of cut cabbage during storage at various temperatures.

The reduction in color characteristics can be attributed to chlorophyll degradation and an increased amount of carotenoids due to the action of heat-sensitive enzymes (Hörtensteiner, 2013). Chlorophyll is degraded by chlorophyllase and Mg-dechelatase, which affect the pigment-protein complexes in thylakoid membranes. Oxidation of chlorophyll a also leads to conversion into pheophytin, resulting in dull green or yellow colors during senescence (Hodges et al., 2004; Hu et al., 2021; Zhang et al., 2025).

Visual assessment is important because color is one of the primary qualities affecting consumer perception of product freshness. It can be assumed that the reduction in hue angle can be considered an indicator of reduced visual quality. The decrease in hue angle correlated well with the decline in the sensory score (Figure 3b).

3.4 Microbial Dynamics

The microbial load showed a gradual increase with storage time, regardless of the temperature treatment (Figure 4), suggesting continued microbial proliferation in fresh-cut cabbage. In this respect, microbial growth was especially prominent at higher storage temperatures, being the most prominent at 20 °C, followed by 10 °C and 5 °C. The relatively high coefficients of determination (R^2 = 0.72–0.81) suggest a high correlation between the storage period and microbial growth. Notably, the total plate count at 20 °C reached or surpassed 7 log CFU g^{-1} by day 3, reflecting an increased risk of food spoilage at warmer temperatures.

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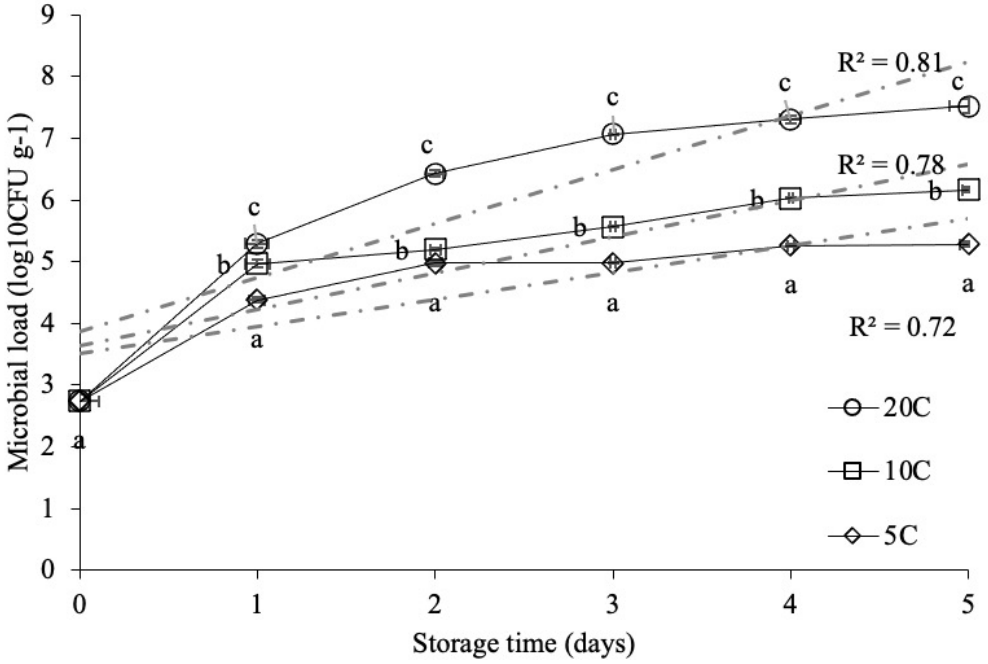

Figure 4. Multiplication of microbes in stored cut cabbage.

As confirmed by statistical analysis based on Duncan's multiple range test, significant and constant differences were observed among the temperature treatments ($p < 0.05$). Regardless of the storage period (1–5 days), samples preserved at 5 °C belonged to group (a), those at 10 °C to group (b), and samples kept at 20 °C belonged to group (c), indicating considerable differences in microbial load at each sampling stage. Therefore, microbial growth decreased at lower temperatures.

Several factors account for the increase in microbial load. Mechanical damage caused by cutting compromises cell integrity and thus leads to nutrient leaching, providing favorable conditions for microbial proliferation. Increased temperatures enhance microbial metabolism and growth rates (Nguyen-the & Carlin, 2009; Francis et al., 2012). Common microorganisms involved in the spoilage of fresh-cut products include psychrotrophic bacteria and enterobacteria. Such groups of bacteria usually cause tissue breakdown through enzymatic activity, although precise microbial identification was beyond the scope of this study.

At 5 °C, microbial proliferation slowed considerably owing to inhibited bacterial growth, thus maintaining the high quality of fresh-cut products. These findings corroborate those of Koseki and Itoh (2001), who noted that low-temperature storage extended the shelf life of fresh-cut products by reducing microbial proliferation.

In addition to influencing physicochemical changes, microbial proliferation may have affected the quality of the samples. As stated previously, microbial respiration and metabolic activity can change the surrounding conditions and, hence, accelerate tissue decomposition. Overall, the interaction

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between microbial proliferation and physiological changes contributed to the deterioration of the properties of the whole sample. Therefore, controlling microbial growth at appropriate storage temperatures is necessary to preserve the freshness and safety of fresh-cut products.

3.5 Sensory Evaluation and Freshness Perception

The sensory attributes exhibited a decreasing trend at all storage temperatures (Figure 5). Sensory scores decreased at a higher rate in samples stored at higher storage temperatures, with samples stored at 20 °C having the highest deterioration rate until the acceptability limit (score of 3) was reached on day one. Although they remained acceptable at this point, samples stored at 20 °C exhibited a steep decrease and became unacceptable in subsequent days. In contrast, samples stored at 10 °C remained acceptable until day 4, whereas samples stored at 5 °C had acceptable sensory attributes throughout the entire storage period.

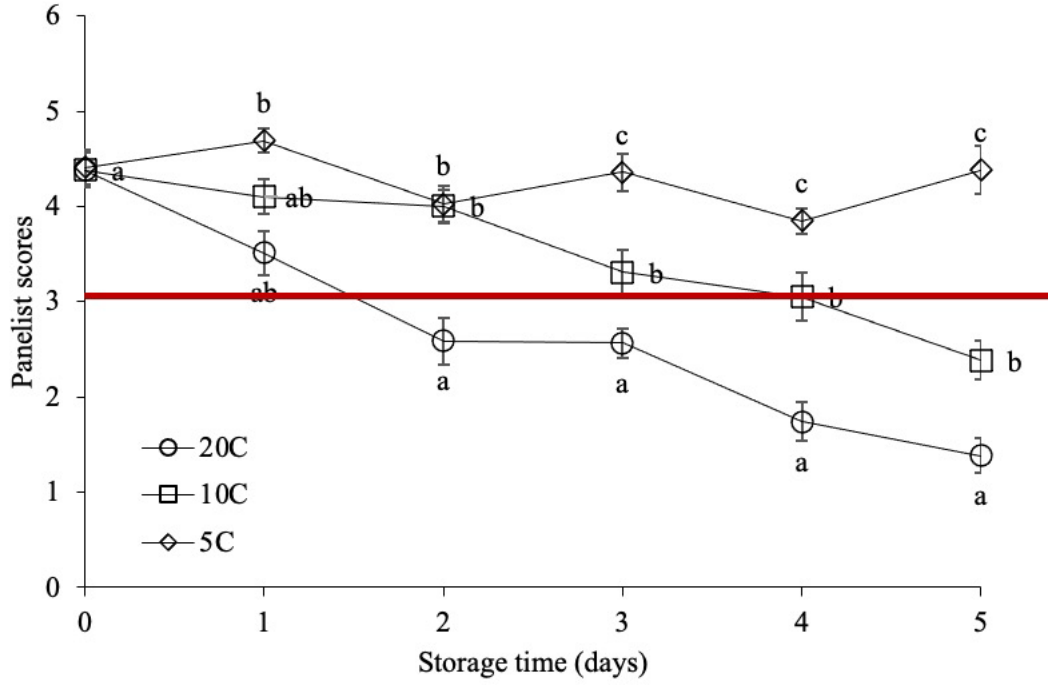

Figure 5. Scores for sensory evaluation-panelists at various storage temperatures of fresh-cut cabbage. Letters (a, b, c) in the graph indicate significant difference in storage temperatures of the same storage period ($p < 0.05$). Means with the same letter (ab) have no significant difference in terms of storage temperature.

The multiple range test by Duncan indicated highly significant differences ($p < 0.05$) among the storage temperatures. For each storage period, samples stored at 5 °C were classified as group (a), those stored at 10 °C as group (b), and those stored at 20 °C as group (c), indicating significant differences among the sensory attributes of all treatments.

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From the panelist ratings, it can be deduced that there is a strong relationship between physicochemical characteristics and the perceived freshness. This can be seen from the maintenance of very high scores (> 4) by samples stored at 5 °C compared to a quick drop to non-marketable scores (< 2) by samples stored at 20 °C. A possible reason for the decrease in sensory scores could be linked to the change in color attributes (hue angle and L*), AsA content, and microbial load, as established in this experiment.

Deterioration in sensory qualities could be due to changes in appearance, nutrient status, and microflora. The decline in the hue angle and L* values indicates a loss of green coloration in the samples. A high microbial load in samples might also lead to off-odor and texture alteration. The integration of these changes is thought to lead to low panelists' acceptance levels.

The current findings lend credence to the theory that the perception of freshness is based on the integration of multiple sensory perceptions (Saba et al., 2018; Tran et al., 2024). Overall, sensory evaluation serves as an integrated parameter for assessing quality.

4. Conclusion

This study revealed that storage temperature plays an important role in the physiological, biochemical, microbiological, and sensory characteristics of fresh-cut cabbages. Increasing the storage temperature to 20 °C accelerated the respiration rate, degradation of chlorophyll, and growth of microorganisms, resulting in the deterioration and loss of freshness in three days. However, storage of cabbage at 5 °C slows down the respiration rate, maintains the ascorbic acid content, and controls the growth of microorganisms, thereby increasing shelf life and freshness.

The findings indicate that the loss of freshness is due to a single, integrated process. The connection between physical, chemical, and taste properties makes the use of overall freshness measures valid for assessing quality. Further studies using metabolomics, scent compounds, and digital imaging could assist in the development of simple methods for measuring the freshness of cabbage.

5. AI Writing Statement

The author used the Generative AI tool ChatGPT solely for language editing in the Introduction section. All analyses, data interpretations, and conclusions are the result of the author's own thinking.

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