Master Thesis

The effect of temperature and packaging on the quality of fresh cucumbers during storage

MSc Thesis report

Student name: Yuexin YANG (1186469)

Chair group: Food Quality Development

Course code: FQD80436

Date: 23/02/2024

Supervisor(s): Annelies Blok

Abstract

This study investigated the influence of temperature (4°C and 35% humidity, 20°C and 55% humidity) and plastic film packaging conditions (with or without) on cucumber quality changes during a 17-day storage period. Physicochemical experiments, including weight loss, color changes, firmness, pH values, and total soluble solids content, were conducted at various time points. Sensory evaluation with 20 participants were performed after physicochemical experiments. 1 fresh control cucumber and 12 cucumbers under different conditions at three time points (day7, 14, 17) were used as test samples. Participants rated the color, roughness, firmness, and overall quality of the samples, and answered questions about the habits of preserving cucumbers.

Cucumbers stored at low temperatures, with or without packaging, exhibited lower weight loss rates than room temperature cucumbers after 17 days. Low-temperature cucumbers showed increasing pH over time, while room temperature cucumbers exhibited a continuous decrease, with no significant difference between packaged and unpackaged cucumbers. Firmness decreased over time in all groups. However, the total soluble solids content fluctuated and there was no significant effect over time. Lab color analysis only revealed significant effects on the b* value of middle and tail-end sections of cucumbers. Low-temperature cucumbers maintained a consistent grey-green hue, while room temperature cucumbers exhibited noticeable color changes. Unpackaged room temperature cucumbers showed a yellowish tint on day 14, and packaged cucumbers displayed a distinct yellow hue by day 17. Consumer sensory evaluation aligned with physicochemical experiments, highlighting higher ratings for low-temperature packaged cucumbers and the lowest scores for room temperature unpackaged cucumbers on color, roughness, and firmness.

Both temperature and packaging conditions impact cucumber shelf life, with temperature exerting a more substantial influence than packaging.

Key words: Cucumber, Temperature, Plastic packaging, Shelf-life, Quality changed, Sensory evaluation.

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1. Introduction

Cucumbers (*Cucumis sativus*) are globally recognized by consumers for their unique flavor and prominent health benefits (Uthpala et al., 2020). However, due to their susceptibility to spoilage and deterioration, even under low-temperature conditions, long-term storage of cucumbers remains challenging (Labuza & Breene, 1989). The general shelf life of cucumbers is about 14 days in refrigerator, while some of them start to lose the qualities after only a few days of storage at room temperature(Li et al., 2018). Understanding the proper cucumber storage methods becomes crucial to maximizing quality preservation within the 2-week period. This study aims to investigate the quality changes of cucumbers under various temperature and packaging conditions over a 17-day period and combined with the results of consumers' sensory evaluation.

There are two common retail scenarios for cucumbers' sale mode, including with plastic film packaging and those without it. Consumers often retain the original packaging or adopt additional preservation methods based on personal habits and preferences. Research and consumer surveys suggest that plastic wrap aids in extending cucumber shelf life by maintaining moisture and preserving aroma (Mangaraj et al., 2009). Additionally, plastic packaging significantly reduces food waste associated with cucumbers (Shrivastava et al., 2022). Data indicate that cucumbers with plastic packaging result in 4.6% food waste, while those without packaging lead to 9.4% food waste in supply chain and transportation from farms to supermarkets. Storage temperatures are also a critical factor determining cucumbers' shelf life and quality changes. Studies propose an optimal temperature of 12°C for cucumbers storage (Nasef, 2018). However, it is challenging for consumers to consistently maintain cucumbers at the ideal temperature. Therefore, for consumers, cucumbers are often stored in household refrigerators or just at room temperature (Nunes et al., 2009).

Existing research has primarily focused on temperature or packaging condition as single variable. This study assesses the combined impact of both plastic packaging and temperature on cucumber quality changes, aiming to understand the physicochemical quality variations under different conditions during the shelf life. Cucumbers quality can be measured through various features or attributes such as physical, chemical, and sensory characteristics. The main deterioration changes during cucumber storage include weight loss (i.e., water loss), color change, texture changes, and internal chemical property variations due to the biochemical respiration (Dhall et al., 2012). Therefore, weight loss rate, firmness, color analysis, pH values and total soluble solids content are essential quality characteristics of cucumbers under different storage conditions over time in these physicochemical experiments of the study.

For consumers, assessing cucumbers quality at the time of purchase only relies on external physical properties, such as color, firmness, and roughness of the skin. Hence, after the conclusion of physicochemical experiments, sensory evaluations were conducted, inviting consumers to evaluate the color, roughness and firmness of cucumbers stored under different external conditions at various time points in an objective manner. The results were then compared and discussed in conjunction with the experimental data.

In summary, the study aims to comprehensively discuss the influence of temperature and packaging conditions on cucumber physicochemical and sensory properties by observing and analysing quality indicators, coupled with the judgement by consumers.

Therefore, the following research questions were defined:

1. What is the effect of temperature on the quality properties of cucumbers during storage?
2. What is the effect of packaging conditions on the quality of properties of cucumbers during storage?

2. Materials and methods

2.1 Materials

Fresh cucumbers (*Cucumis sativus*) were purchased from the local market Jumbo of Wageningen, Netherlands. All the cucumbers were selected by the same time and same shelf to decrease the original individual biological differences. All the cucumbers were wrapped by the plastics packaging from the supermarket, half of the packaging was removed in the experiments.

Cucumbers were divided into 4 groups by temperature and packaging. Every three cucumbers were treated as a group to perform the triplicate experiments.

Group A: samples were stored at 4°C with the original plastic packaging film.
Group B: samples were stored at 4°C without the original plastic packaging film.
Group C: samples were stored at 20°C with the original plastic packaging film.
Group D: samples were stored at 20°C without the original plastic packaging film.

Group A and Group B were stored for 17 days at cold storages (4°C and 35% humidity), while Group C and Group D were stored at room temperature (20°C and 55% humidity). These two environments simulated the conditions under which consumers often store purchased cucumbers, which were cold storage in the refrigerator and storage at room temperature. There were both physicochemical properties experiments and sensory evaluation in the study. The sample preparations were shown especially.

Physicochemical properties

There were 72 cucumbers in total bought at same time for the physicochemical properties' experiment. Three cucumbers were taken randomly from each group at an interval of 0, 3, 7, 10, 14, and 17 days. All the samples were for measuring the physical and chemical attributes, such as appearance for color analysis (*L*a*b*), weight loss, firmness (F), pH, and total soluble solids content (TSS).

Sensory evaluation

According to the physicochemical properties experiments' result, day 7, 14 and 17 were chosen as the specific time points for the sensory evaluation. Then, the

cucumbers were purchased separately at three time points to meet the conditions for storage on the evaluation day. One fresh cucumber which was bought one day before the evaluation was as the control sample. In total 13 cucumbers were used for the sensory evaluation

2.2 Weight loss

All the cucumbers were weighted using a precise balance at the beginning of experiments (W_i) and the test day (W_f). The PLW of the cucumbers was calculated as cumulative per cent loss in weight based on the initial weight and final weight.

$$\%PLW = \frac{w_i - w_f}{w_i} \times 100\%$$

where w_i is the weight on the first day and w_f is the weight on the test day.

2.3 Appearance photography (color change in L*a*b)

The *Iris V400* was used to measure the surface color of the cucumbers in terms of color values *L*, a*, b**. '*L**' indicated the lightness or darkness, '*a**' indicated the redness or greenness, and '*b**' indicated the yellowness or blueness of the samples, respectively. Each cucumber was divided into 3 segments as the part near the stem (*Head*), the middle part of the cucumber (*Middle*), and the part away from the stem (*Bottom*). The color analysis was measured for each segment. The 16mm lens and both top and bottom light were used to take the photos. The L*, a* and b* values of the main color components were recorded as the results.

2.4 Firmness (F)

The firmness of the cucumbers was measured by a texture analyzer (TA.XT2). The samples were compressed at strain for 20% with a 50kg load cell, at speed of 5 mm/s using a compression plate (50 mm diameter) and expressed in kg force. Measurements were made at each cucumber's middle part (3 cm thickness) with peel and in triplicate.

2.5 Total soluble solids (TSS)

100g of the cucumber including peel was homogenized using a domestic juice extractor. The mixture of juice and other components was filtered with a cotton muslin cloth, until the volume of pure juice was graduated to 50ml.

Soluble solid content (°Brix) of homogenized cucumber juice was determined using a hand refractometer, previously calibrated with distilled water to a value of zero. 0.5ml of filtered juice was used for testing the TSS content. Distilled water was used to clean the platform surface of the refractometer between each sample.

2.6 pH

To determine the pH in the cucumber, the extracted juice was used. Subsequently, 5ml aliquot was taken from the sample in a 10ml centrifuge tube, where a reference electrode of the potentiometer, previously calibrated with buffer solutions with pH values of 4, 7 and 10, was introduced.

2.7 Sensory evaluation

After the physicochemical experiments, the sensory evaluation was carried out. The results of the physicochemical experiments were compared with the results of the objective evaluation of cucumbers by consumers in the sensory evaluation.

Cucumbers were prepared of time points at day 7, 14 and 17 of storage, one fresh cucumber was as the control one. Liking of cucumbers appearance and overall cucumber quality were recorded for each of the temperatures, packaging conditions and time points by an untrained, 20-member panel. Participants were only asked to observe and touch the cucumbers for relevant quality issues, and they were not to smell or taste the samples. After completing all cucumbers samples, participants were also required to answer a few questions about cucumber preservation based on their habits, such as temperature and packaging. The panellists were university students and employees who signed up voluntarily. Snacks were provided for the participants after finishing the evaluation.

A group of participants, consisting of no more than 3 individuals, were seated at different locations facing a white wall in the testing room. The evaluation duration was approximately 15-20 minutes, during which communication among participants was not allowed. Participants used their own smart phone to scan the QR code and did the evaluation in Qualtrics. They would rate only one cucumber at a time. After the evaluation, the participants would get the second cucumber and continue to evaluate, and so on until the 13 cucumbers have been evaluated. Every participant was assigned test samples in a different order, and the order is randomized to reduce judgement errors caused by order the preconceptions.

A 100-point scale was used to rate the color (from yellow to green), roughness (from smooth to rough) and firmness (from soft to hard). Participants cannot see the specific values in the scale but only adjust the position. The final scores would be in the specific values and do the statistical analysis. A nine-point hedonic scale was used to rate the overall quality. The scale was labelled from 1 to 9 where "1" represents dislike extremely and "9" represents like extremely. The questionnaire used for this sensory evaluation is included in the **Appendix**.

2.8 Data analysis

Means and standard deviations were calculated using Excel (Microsoft 365). To determine if there were significant differences between samples, three-way Analysis of variance (three-way ANOVA) and Tukey post hoc tests at a pre-set significance level of 0.05 were performed using IBM SPSS 29 for Windows.

3. Results and discussion

3.1 Weight loss

Changes in the weight loss of cucumbers with or without plastic packaging during cold storage (4°C, 35% RH) and room temperature storage (20°C, 55% RH) conditions are shown in Figure 1.a and Figure 1.b, respectively.

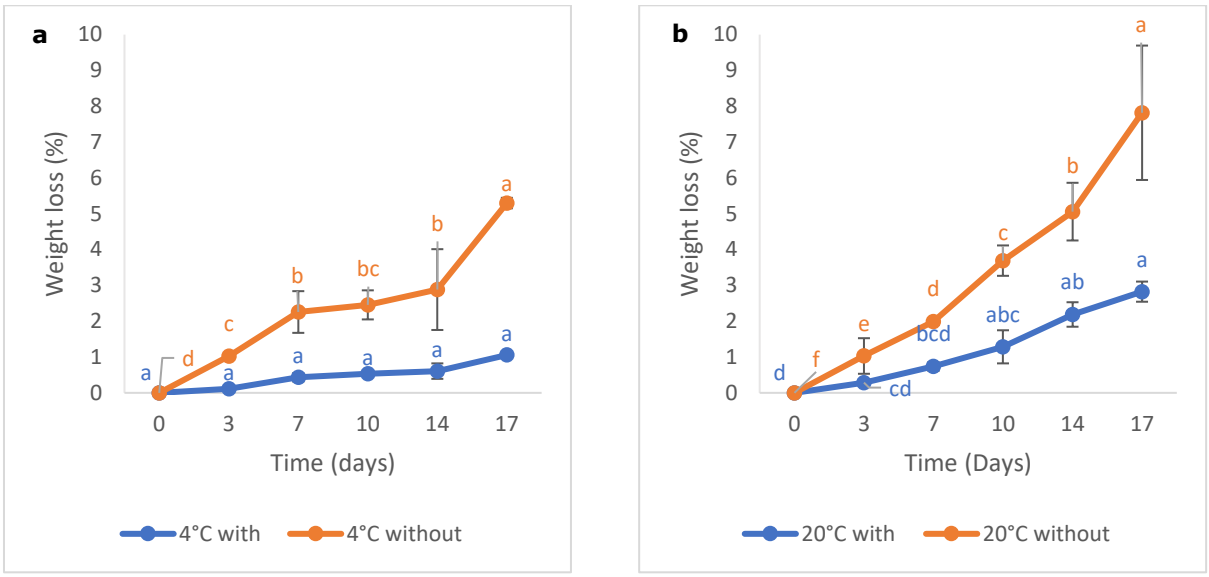

Figure 1*: Changes in physiological loss in weight (%) of with packaging vs. without packaging cucumbers (n=3) over time.* ***a****: cold storage (4°C, 35% RH);* ***b****: room temperature conditions (20°C, 55% RH)*

Data points with the same alphabet in the same color of each condition are not significantly different (p<0.05).

There was a significant effect of temperature (*F=29.693, p<0.001*), packaging condition (*F=159.630, p<0.001*) and storage duration (*F=48.975, p<0.001*) on cucumber weight loss. The weight loss was significantly less in cucumbers with packaging compared to cucumbers without packaging during both storage conditions. The weight loss value in unpackaged cucumbers was consistently shown higher, with a faster increase rate at room temperature. For the cold conditions, the weight loss of cucumbers with packaging was stable and low at the end of the experiment (1.1%±0.1), while the weight loss of cucumbers without packaging increased gradually, reaching 5.3%±0.1 by day 17. At room temperature, weight loss in both groups increased faster and reached 2.8%±0.3 and 7.8%±1.9 for cucumbers with packaging and cucumbers without packaging, respectively. Loss of weight in fresh fruits and vegetables is mainly due to the loss of water caused by transpiration and respiration processes (Zhu et al., 2008). Respiration rates were reduced under low temperature and plastic packaging minimized environmental contact, notably isolating oxygen and reducing moisture loss from microbial decay (Exama et al., 1993.). Temperature and relative humidity also are the important factors on water loss. Higher temperature and lower humidity levels can accelerate water loss through enhanced evaporation (Linke et al., 2021). For evaporation, plastics packaging could help to keep the water content and decrease the weight loss of the cucumbers.

3.2 pH

Changes in pH of cucumbers which wrapped plastics packaging film or not during cold storage (4°C, 35% RH) and room temperature storage (20°C, 55% RH) conditions are shown in Figure 2.a and 2.b, respectively.

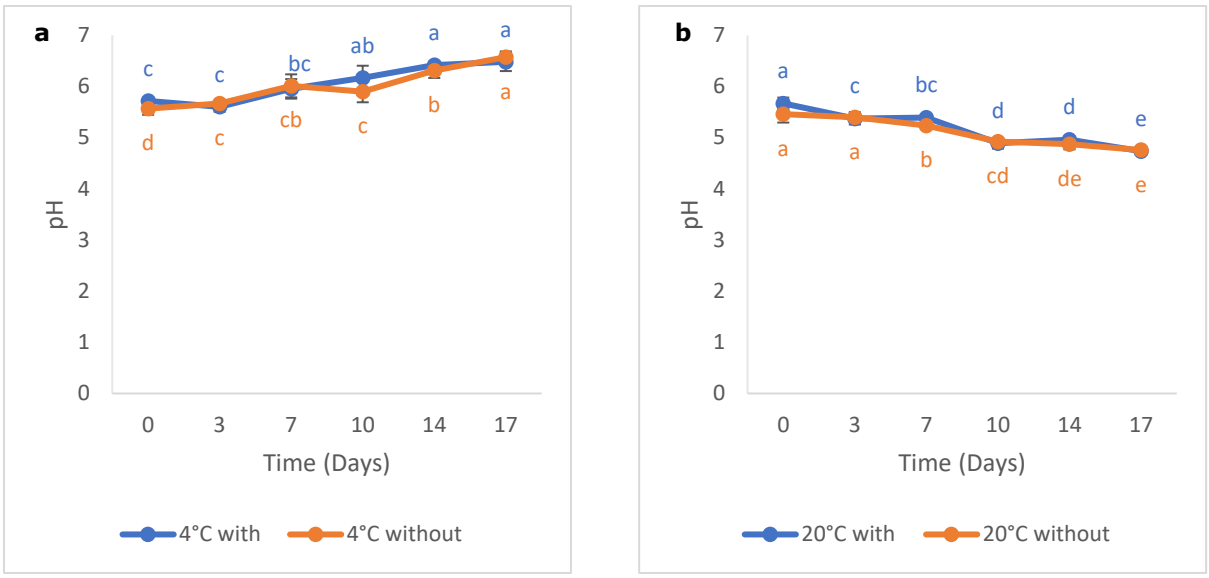

Figure 2*: Changes in pH of with packaging vs. without packaging cucumbers (n=3) over time.* ***a****: cold storage (4°C, 35% RH);* ***b****: room temperature conditions (20°C, 55% RH)*

Data points with the same alphabet in the same color of each condition are not significantly different (p<0.05).

The pH variations in cucumbers during storage exhibited distinct trends influenced by different storage temperatures (*p<0.05*) and time (*F=33.409, p<0.001*), while there was no significant impact of packaging conditions on pH changes (*F=0.326, p=0.326*). Under low temperature condition, pH of cucumbers gradually increased over time, rising from 5.7 and 5.4 to 6.5 and 6.6 (with and without packaging), respectively. The increase in pH is attributed to various biochemical and enzymatic processes. The primary factor is the conversion of organic acids, such as citric acid, into corresponding alkaline salts during respiration (Olawuyi & Lee, 2019; Rodriguez Borbon et al., 2023). The acidity content in cucumbers was reduced by the transformation, leading to an increase in pH values. However, an unexpected decrease in pH from 5.7 and 5.5 to 4.7 and 4.8 (with and without packaging) was shown in cucumbers stored at room temperature. The deviation from the anticipated experimental outcome may be attributed to several factors. One of the possible reasons is the fermentation process of the cucumbers due to the higher temperature, resulting in the production of acidic byproducts like lactic acid and acetic acid, leading to a decrease in pH (Rodriguez Borbon et al., 2023). Additionally, some acidic compounds in cucumber tissues may be broken down due to the increased enzyme activity, particularly those involved in organic acid decomposition, leading further decrease of pH (Ghafoor et al., 2022).

3.3 Total soluble solids (TSS) content

Changes in total soluble solids content of cucumbers which wrapped plastics packaging film or not during cold storage (4°C, 35% RH) and room temperature storage (20°C, 55% RH) conditions are shown in Figure 3.a and 3.b, respectively.

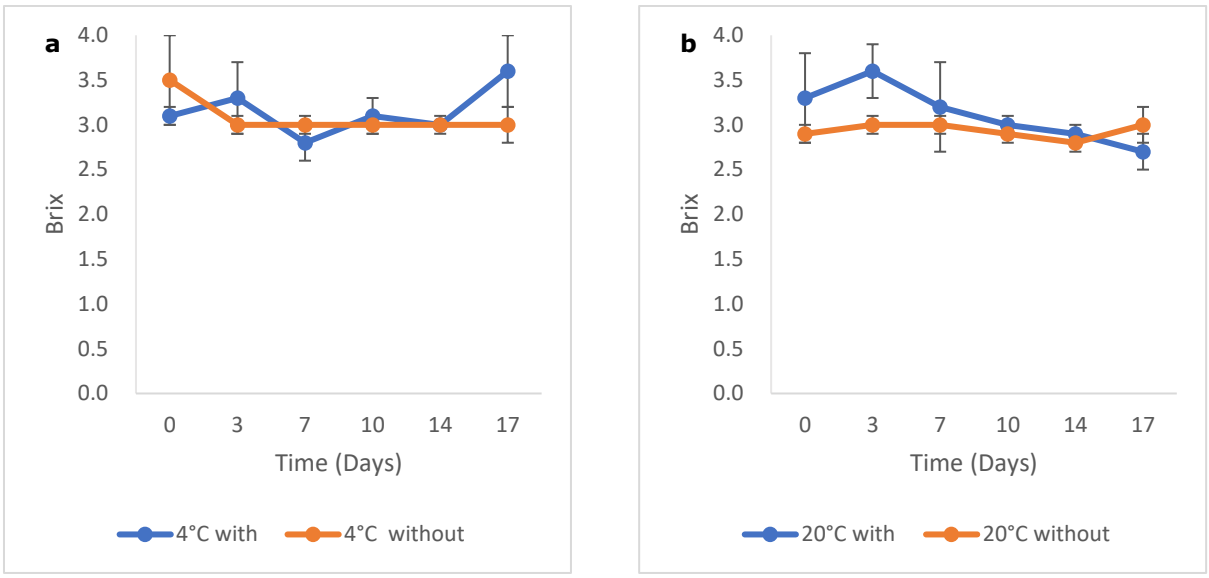

***Figure 3**: Changes in total soluble solids content of with packaging vs. without packaging cucumbers (n=3) over time. **a**: cold storage (4°C, 35% RH); **b**: room temperature conditions (20°C, 55% RH)*

According to the statistical analysis of the results, there were not a significant impact of time, temperature, and packaging conditions on the TSS content of cucumbers during storage ($p>0.05$). The TSS content of all 4 groups of cucumbers fluctuated between 2.8 and 3.8 without displaying a clear upward or downward trend. The observed results were different from what was expected/hypothesized of an initial increase followed by a decrease (Olufunmilayo & Uzoma, 2016). The results may be attributed to several factors. The most plausible reason is the initial TSS content of each cucumber. The cucumbers at each time point were undergone structural disruption due to the physicochemical experiments and could not be retained for subsequent experiments. The cucumber at each time point was independent, leading considerable biological individuality. The initial TSS content of cucumbers is relatively low, ranging only between 2.2% and 5.4% (Bumgarner & Kleinhenz, 2012). Hence, the observed variations in the experiment exhibit noticeable disparities and lack regularity. Another contributing factor is the interplay of respiration and fermentation. Like the disparities observed in pH results, different levels of respiration and fermentation of cucumbers were undergone under varying temperature conditions. This influences the transformation and decomposition metabolism of polysaccharides and monosaccharides within cucumbers, subsequently affecting the final sugar content (Valverde-Miranda et al., 2021).

Improvements in measuring TSS content as a parameter will be addressed in future experimental designs to enhance the more accurate results.

3.4 Firmness (F)

Changes in firmness of cucumbers which wrapped plastics packaging film or not during cold storage (4°C, 35% RH) and room temperature storage (20°C, 55% RH) conditions are shown in Figure 4.a and 4.b, respectively.

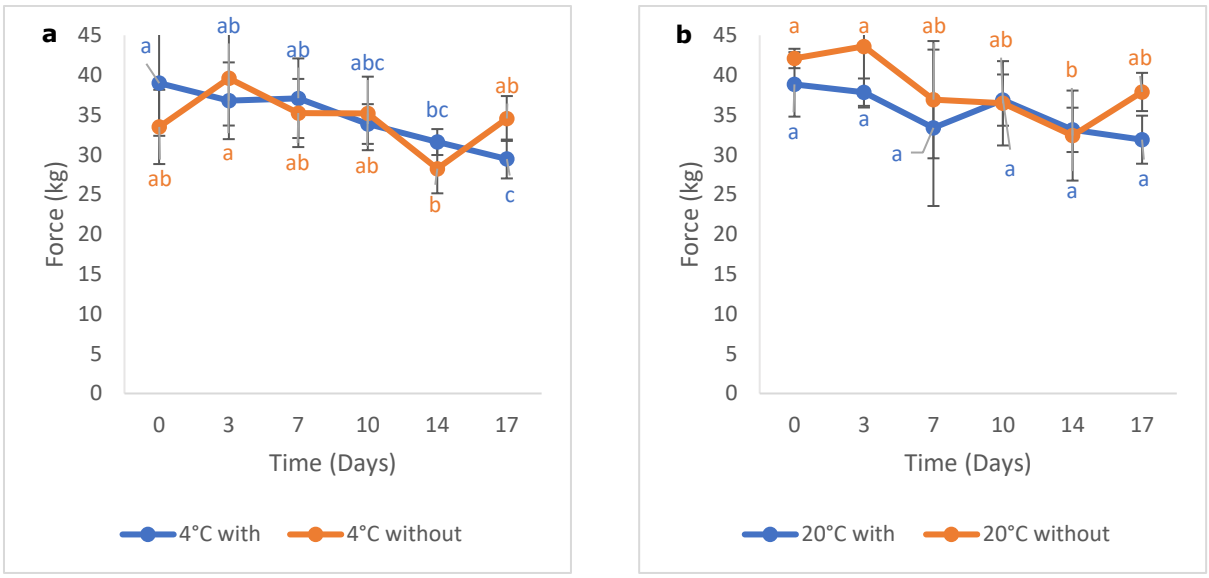

Figure 4*: Changes in firmness of with packaging vs. without packaging cucumbers (n=3) over time.* ***a****: cold storage (4°C, 35% RH);* ***b****: room temperature conditions (20°C, 55% RH)*

Data points with the same alphabet in the same color of each condition are not significantly different (p<0.05).

There were significant effects of time *(F=3.038, p=0.029)* and temperature *(p<0.05)* on the firmness of cucumbers during storage according to the statistical analysis, while the packaging conditions do not show a significant impact *(F=0.029, p=0.867)*. Like the TSS content, the results were significantly affected by the individual biological variation inherent in each cucumber. Therefore, specific cases at certain time points were excluded in the analysis to observe the overall trends. For cucumbers stored at low temperature, excluding the unpackaged cucumbers on day 0 and day 17, an overall trend of decreasing firmness with time was shown. Similarly, for the cucumbers stored under room temperature, excluding the unpackaged cucumbers on day 17, there was also a decreasing tendency during the storage. The results were like the previous study on firmness of cucumbers (Thommohaway et al., 2007.). While the firmness is influenced by the temperature due to the acceleration of metabolic processes (Ghafoor et al., 2022; Olawuyi & Lee, 2019), the results were not exceptionally pronounced in the experiments, with an overall range from 45 kg force to 25 kg force during the storage.

The primary cause of cucumber firmness reduction is the degradation of cell walls. During storage, the enzymatic activity of relevant biological enzymes in cucumbers increases, such as pectinase and cellulase. These enzymes catalyze reactions leading to the decomposition of cell wall structural components, resulting in a softening of texture (Brummell et al., 2004). Another possible contribution is the decrease in firmness due to dehydration. Combining previous results of weight loss, the reduction

in water content during cucumber storage leads to surface wrinkling, and cells in cucumber lost turgor pressure by dehydration, contributing to decreased firmness (Amer & Azam, 2019). Respiration was also a factor in softening the texture. Carbohydrates stored in cucumbers were consumed during respiration, leading to the change of structural components, and reducing firmness (Ghafoor et al., 2022; Olawuyi & Lee, 2019).

However, not only the individual biological variation is a factor which leads to the inaccurate results, the way how to prepare the test samples also is the factor. It is important to note that manual cutting during the experiment may lead to non-parallel surfaces, potentially influencing the texture analyzer's measurement of firmness. In future improvements, the preparation of experimental materials should be improved to minimize possible errors in results.

3.5 Appearance photography (color change in L*a*b)

The color changes of different parts (Head, Middle and Bottom) in cucumber peel as influenced by storage time and different temperature and packaging conditions are shown in Table 5.1, and the detailed values of L*, a* and b* of the color are shown in Table 5.2 to 5.4.

Table 5.1 Color chart of packaged and unpackaged cucumbers (n=3) stored at different room temperature and cold temperature conditions.

Sample		Day 0	Day 3	Day 7	Day 10	Day 14	Day 17
Group A (4°C with packaging)	Head						
	Middle						
	Bottom						
Group B (4°C without packaging)	Head						
	Middle						
	Bottom						
Group C (20°C with packaging)	Head						
	Middle						
	Bottom						
Group D (20°C without packaging)	Head						
	Middle						
	Bottom						

The color chart clearly illustrates the changes in cucumbers' peel color. For cucumbers stored at low temperature, the changes were not prominent, while those cucumbers stored at room temperature exhibited noticeable changes from day 14 onwards. At room temperature, unpackaged cucumbers firstly showed a yellow hue, and by day 17, packaged cucumbers also displayed a yellow hue. According to the experimental data and statistical results, there was no significant impact of time, temperature, and packaging conditions on the color change in the Head section (the nearest one-third to the stem) of cucumbers ($p>0.05$). For the Middle and Bottom sections, longer storage duration and higher temperature led to significantly higher b*values ($p<0.05$)

in the L*a*b color system. A higher b* value indicated a higher yellow component in the color, aligning with both numerical values and the observed color changes, consistent with the expected color transformation during cucumber storage, as the cucumbers would be yellower during maturity (Hurr et al., 2009).

Although there was no significant effect of time on the colour of the Head section, according to the observation during the storage period, the Head section tended to undergo the fastest color change, followed by the Bottom section, while the Middle section showed the least noticeable color change. This may be attributed to ethylene production, catalysing cucumber ripening. The stem is a crucial source of ethylene production, and the sections closer to the stem were exposed to higher concentrations of ethylene, leading to faster color changes (Xin et al., 2019). The Head and Bottom sections are the primary nutrient and water transport areas, accumulating and obtaining more moisture during the ripening process, resulting in more active metabolism and color changes in these sections (Wdowikowska et al., 2023). Additionally, during transportation, the Head and Bottom sections were easier to be affected by the external stimuli, such as environmental conditions and the influence of other fruits and vegetables, potentially accelerating color changes. As cucumber maturation processes, chlorophyll decreased, metabolizing into yellow components. Prolonged storage may erode chlorophyll in most green vegetables, shortening their shelf life and hastening color changes (Jahan et al., 2020).

Table 5.2 Color values of **Head part** in packaged and unpackaged cucumbers stored at room temperature and cold temperature conditions over time. Values represent means of triplicate (n=3) and standard deviation separated using *Iris V400*.

Storage (days)	0	3	7	10	14	17
L* (lightness to darkness)						
4°C with packaging	39.146±3.65	37.041±0	42.440±0.79	40.793±3.32	41.175±3.58	39.146±3.65
4°C without packaging	41.250±3.65	41.250±3.65	38.126±3.44	38.609±2.72	38.514±2.80	38.688±2.85
20°C with packaging	37.041±0	39.146±3.65	46.494±8.73	42.897±0.79	52.640±7.72	65.939±7.59
20°C without packaging	43.355±0	40.793±3.32	42.401±5.58	40.793±3.32	57.441±12.54	55.441±13.38
a* (redness to greenness)						
4°C with packaging	-2.939±1.08	-2.317±0	-8.763±3.97	-5.851±4.60	-4.064±1.69	-2.939±1.08
4°C without packaging	-3.560±1.08	-3.560±1.08	-8.225±5.12	-5.810±6.05	-6.431±5.59	-5.229±5.04
20°C with packaging	-2.317±0	-2.939±1.08	-9.634±6.37	-6.472±3.97	-11.203±2.46	-6.576±3.09
20°C without packaging	-4.182±0	-5.851±4.60	-8.665±5.55	-5.851±4.60	-7.346±2.80	-7.189±3.83
b* (blueness to yellowness)						
4°C with packaging	12.257±5.06	9.334±0	16.697±1.22	14.477±4.58	18.109±8.78	12.257±5.06
4°C without packaging	15.179±5.06	15.179±5.06	13.932±3.99	14.499±8.95	17.588±7.80	11.554±3.85
20°C with packaging	9.334±0	12.256±5.06	21.911±1.57	17.399±.22	29.998±9.88	44.262±4.95
20°C without packaging	18.102±0	14.477±4.58	16.540±7.49	14.477±4.58	35.949±15.84	35.695±20.55

Values with the same alphabet along the same row are not significantly different for time ($p<0.05$). Values without any alphabet along the same row are not significantly different ($p>0.05$).

Table 5.3 Color values of **Middle part** in packaged and unpackaged cucumbers stored at room temperature and cold temperature conditions. Values represent means of triplicate (n=3) and standard deviation separated using *Iris V400*.

Storage (days)	0	3	7	10	14	17
L*						
(lightness to darkness)						
4°C with packaging	39.146±3.65	39.146±3.65	42.401±5.58	40.793±3.32	42.322±5.59	42.897±0.79
4°C without packaging	39.146±3.65	43.355±0	38.593±2.94	40.797±3.32	44.343±4.50	42.897±0.79
20°C with packaging	40.793±3.32	37.041±0	42.440±0.79	38.688±2.85	42.440±0.79	51.484±9.26
20°C without packaging	40.793±3.32	39.146±3.65	40.335±2.85	40.793±3.32	48.930±6.10	45.250±7.11
a*						
(redness to greenness)						
4°C with packaging	-2.939±1.08	-2.939±1.08	-8.665±5.55	-5.851±4.60	-9.246±6.00	-6.472±3.97
4°C without packaging	-2.939±1.08	-4.182±0	-5.850±4.60	-5.851±4.60	-10.449±4.07	-6.472±3.97
20°C with packaging	-5.851±4.60	-2.317±0	-8.763±3.97	-5.229±5.04	-8.763±3.97	-6.099±2.11
20°C without packaging	-5.851±4.60	-2.939±1.08	-8.141±5.04	-5.851±4.60	-8.804±4.96	-5.443±2.71
b*						
(blueness to yellowness)						
4°C with packaging	12.257±5.06^{a}	12.257±5.06^{a}	16.540±7.49^{a}	14.477±4.58^{a}	19.486±8.80^{a}	17.399±1.22^{a}
4°C without packaging	12.257±5.06^{b}	18.102±0^{ab}	14.643±4.78^{b}	14.477±4.58^{b}	25.333±0.87^{a}	17.399±1.22^{ab}
20°C with packaging	14.477±4.58^{b}	9.334±0^{b}	16.697±1.22^{a}	11.554±3.85^{b}	16.697±1.22^{ab}	28.616±11.82^{a}
20°C without packaging	14.477±4.58^{bc}	12.257±5.06^{c}	13.774±3.85^{c}	14.477±4.58^{bc}	30.842±11.95^{a}	26.179±14.59^{ab}

Values with the same alphabet along the same row are not significantly different for time ($p<0.05$). Values without any alphabet along the same row are not significantly different.

Table 5.4 Color values of **Bottom part** in packaged and unpackaged cucumbers stored at room temperature and cold temperature conditions. Values represent means of triplicate (n=3) and standard deviation separated using *Iris V400*.

Storage (days)	0	3	7	10	14	17
L*						
(lightness to darkness)						
4°C with packaging	41.250±3.65	42.897±0.79	42.859±5.59	41.250±3.65	42.322±5.59	44.964±2.79
4°C without packaging	39.146±3.65	43.355±0	42.440±0.79	42.897±0.79	46.424±4.13	44.964±2.79
20°C with packaging	40.793±3.32	40.793±3.32	42.440±0.79	41.982±0	42.440±0.79	53.058±9.16
20°C without packaging	41.250±3.65	39.146±3.65	40.335±2.85	42.897±0.79	53.093±7.36	51.064±7.87
a*						
(redness to greenness)						
4°C with packaging	-3.560±1.08	-6.472±3.97	-6.374±5.49	-3.560±1.08	-9.246±6.00	-6.996±4.87
4°C without packaging	-2.939±1.08	-4.182±0	-8.763±3.97	-6.472±3.97	-10.866±4.47	-6.996±4.87
20°C with packaging	-5.851±4.60	-5.851±4.60	-8.763±3.97	-11.053±0	-8.763±3.97	-8.835±4.91
20°C without packaging	-3.560±1.08	-2.939±1.08	-8.141±5.04	-6.472±3.97	-8.913±3.47	-8.436±2.27
b*						
(blueness to yellowness)						
4°C with packaging	15.179±5.06^{a}	17.399±1.22^{a}	17.243±7.52^{a}	15.179±5.06^{a}	19.486±8.80^{a}	20.166±3.57^{a}
4°C without packaging	12.257±5.06^{c}	18.102±0^{bc}	16.697±1.22^{bc}	17.399±1.22^{bc}	27.927±4.13^{a}	20.166±3.57^{ab}

20°C with packaging	14.477±4.58^{b}	14.477±4.58^{b}	16.697±1.22^{b}	15.994±0^{b}	16.697±1.22^{b}	30.538±11.73^{a}
20°C without packaging	15.179±5.06^{b}	12.257±5.06^{b}	13.774±3.85^{b}	17.399±1.22^{b}	30.680±9.35^{a}	28.059±10.45^{a}

Values with the same alphabet along the same row are not significantly different for time ($p<0.05$). Values without any alphabet along the same row are not significantly different.

3.6 Sensory evaluation

Sensory evaluation of cucumbers was performed by an untrained panel consisting of 20 adult participants of both sexes (7 males and 13 females) aged between 20 to 34. The results of sensory evaluation scores (color, roughness, firmness, and final overall quality assessment) of cucumbers under different conditions are presented in Figure 6.a to Figure 6.d.

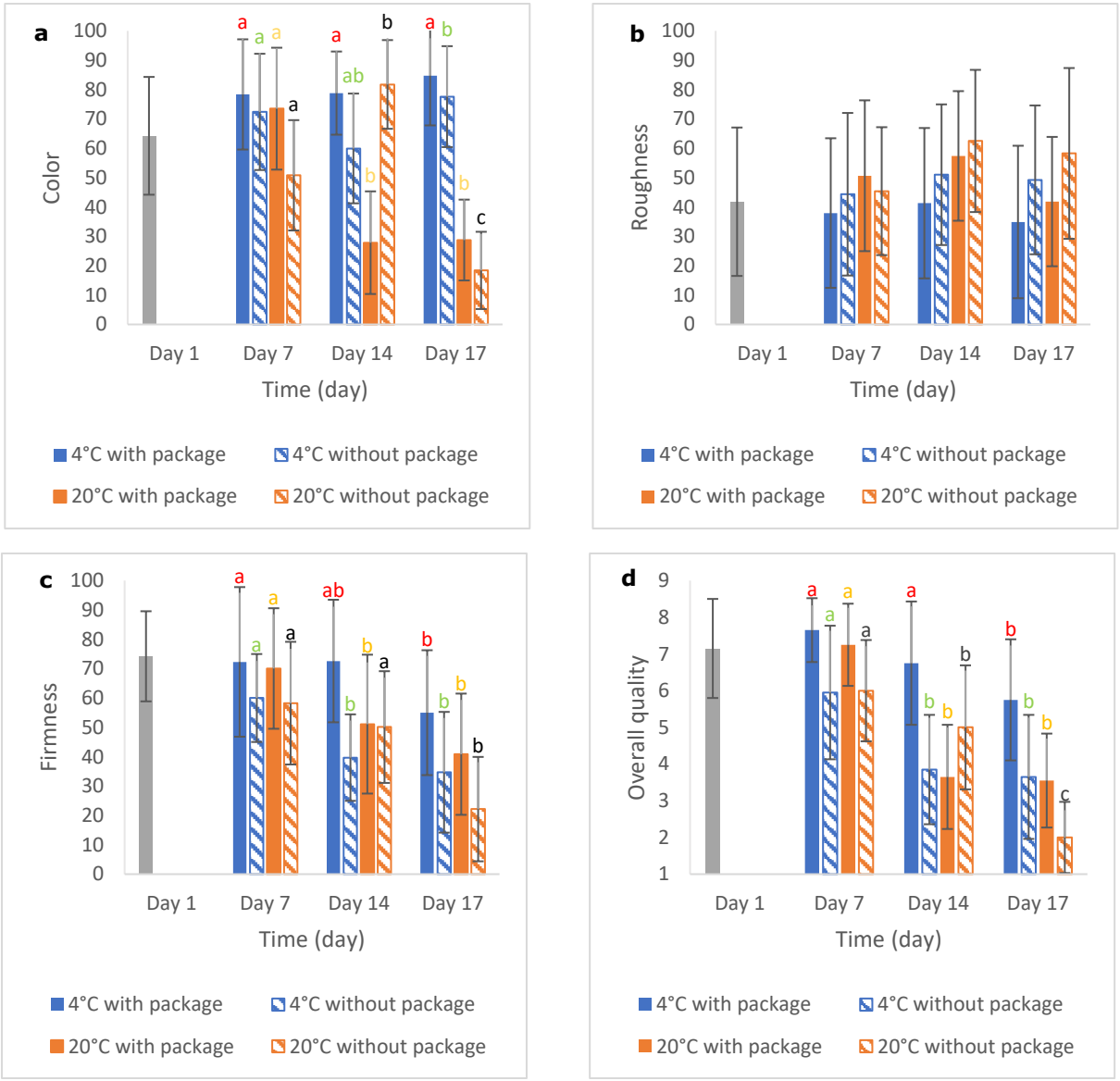

Figure 3.6.1: Sensory evaluation of scores evaluated by 20 participants on the different conditions of the cucumbers. ***a****: Color;* ***b****: Roughness;* ***c****: Firmness;* ***d****: Overall quality*

Data points with the same alphabet in the same color of each condition are not significantly different ($p<0.05$). The alphabets in same color were for the cucumbers in same condition and different time points.

Color: Higher scores indicated that participants perceive cucumbers as greener, while lower scores suggest that the cucumbers as a yellower condition. There were significant effects of time *($F=18.319$, $p<0.001$)* and temperature *($F=163.956$, $p<0.001$)* on the color change of cucumbers during storage according to the statistical analysis, while the packaging conditions did not show a significant impact *($F=0.692$, $p=0.406$)*.

Under low temperature conditions, participants consistently assigned relatively high scores across three time points. For the control group, despite the cucumber with the shortest storage time, the highest green color values were not exhibited. This might be attributed to the influence of individual variations in cucumbers and the subjective judgments of the participants. This aligns with the similar results regarding to the anticipated color changes in cucumbers and corresponds with the finding in Section 3.5. For cucumbers stored at room temperature conditions, only the unpackaged cucumber on day 14 displayed an unexpected score, even reaching the greenest (81.75) within the same time point. This unexpected score is most likely attributed to individual biological factors inherent in that cucumber. Excluding this outlier, the cucumbers exhibited a trend in color evaluation. As time progressed, cucumbers were perceived to become increasingly yellow. Notably, unpackaged cucumbers tended to be perceived as more yellow compared to the packaged ones, which is also consistent with the discussion results in Section 3.5.

Roughness: Higher scores indicated that participants perceive cucumbers as rougher, while lower scores suggest that the cucumbers as a smoother condition. There were no statistically significant effect of time, temperature, and packaging conditions on the roughness of cucumbers during storage by the consumer aspect ($p>0.05$).

Therefore, the impact of individual biological differences on the results is significant, with the inherent roughness of cucumbers determining consumers' final judgement. For the results on day 14 and day 17, participants consistently perceived unpackaged cucumbers as rougher than their packaged ones under the same temperature conditions. The possible reason is the water loss, as increased dehydration leads to more pronounced surface wrinkling, resulting in a coarser texture (Amer & Azam, 2019). This observation aligns with the experimental results discussed in Section 3.1 regarding cucumbers' weight loss.

Firmness: Higher scores indicated that participants perceive cucumbers as harder, while lower scores suggest that the cucumbers as a softer condition. There were significant effects of time *($F=35.657$, $p<0.001$),* packaging *($F=38.217$, $p<0.001$)* and temperature *($F=7.097$, $p=0.008$)* on the firmness change of cucumbers during storage according to the statistical analysis.

Participants perceived a gradual reduction in cucumbers firmness over time under the same conditions, while unpackaged cucumbers were softer than the packaged ones at the same temperature. The control cucumber was firmest among all the samples. This conclusion aligns with the findings discussed in Section 3.4 regarding cucumbers'

firmness. To compare unpackaged cucumbers under low temperature conditions with packaged cucumbers at room temperature, the former exhibited a softer texture. This could be attributed to a higher proportion of water loss in the unpackaged cucumbers, leading to structural changes in the cucumbers and resulting in a softer texture, consistent with the results in Section 3.1. It is noticeable that the sensory evaluation started at 10:30 AM and continued until 4:00 PM, with each group duration lasting half an hour. During this period, cucumbers taken out of the cold storage condition gradually soften as they returned to room temperature. This softening may be attributed to the enhance transpiration due to the rise in temperature, accelerating cucumber respiration and evaporation (Linke et al., 2021). Water loss led to a loss of turgor pressure, further softening the cucumber (Amer & Azam, 2019). Additionally, the increase in temperature enhanced that enzyme activity and related reactions, causing the breakdown of cell wall components and contributing to the observed softening texture (Brummell et al., 2004). These factors may introduce a certain level of influence on the sensory evaluation results. Therefore, the future improvements should be focused on minimizing errors arising from the duration of the evaluation.

Overall quality assessment: Higher scores indicated that participants perceive cucumbers as higher qualities and like more, while lower scores suggest that the cucumbers as lower qualities and like less. There were significant effects of time *(F=29.859, p<0.001),* packaging *(F=52.437, p<0.001)* and temperature *(F=85.994, p<0.001)* on the overall quality of cucumbers during storage according to the statistical analysis.

The results provided by participants aligned with the anticipated outcomes of the experiments, indicating a gradual decrease in consumer preference for cucumbers over time. The control cucumber showed higher quality than most of the samples, however, it was like the cucumbers with packaging in day 7. Regarding day 14, unpackaged cucumber at room temperature, previous discussions acknowledged the exclusion of data from this sample due to the influence of individual biological variations. Under the same packaging conditions, cucumbers stored at low temperature tend to preserve better quality; while under the same temperature, packaged cucumbers can keep better quality. Unpackaged cucumbers at low temperature and packaged cucumbers at room temperature often got the similar scores by participants, suggesting that consumers perceived the quality of cucumbers stored in these two ways as comparable, with external factors from sensory evaluation not significantly revealing differences. Many participants mentioned that they judged the color of the cucumbers more than the roughness and firmness, and even the cucumbers did not change the texture hardness and the roughness, they would choose to throw them away rather than to eat them once the color started to turn yellow.

Among the 20 participants, 17 of them choose to store cucumbers in the refrigerator, while 3 choose to store cucumbers at room temperature. Additionally, 17 participants choose to retain the plastic packaging film, while 3 participate prefer to remove the packaging. Personal habits can influence the results of sensory evaluations (Ismael & Ploeger, 2020). Two participants mentioned," I believe store-bought cucumbers are

not yet at their optimal ripeness, then I prefer to let them store for a few more days until they reach the level I like before consuming." Due to the scoring method in the evaluation, where participants cannot see specific numerical values for the first three indicators (color, roughness, and firmness) and can only express results by sliding the scale to a certain position, six participants expressed concerns such as, "Not seeing the final scores makes me feel troubled. Sometimes, I think the second cucumber is greener than the first one, but I don't know if the position I slid to indicates a higher score." The order of participation may also influence certain results, as mentioned in the firmness section regarding the accelerated softening after cucumber recovery temperature. Three participants raised questions like, "If the participant before me applied a strong force when judging firmness, will it affect the judgement of later participants?" These issues will be noted and minimized as much as possible in the future improvement.

4. Conclusion

Temperature demonstrated a notable impact on cucumbers' weight loss, pH values, firmness, and color changes, while packaging conditions had a significant effect only on the weight loss rate ($p<0.05$). Neither temperature nor packaging conditions had a significant impact on the total soluble solids content. The individual biological variation between each cucumber should be considered in this case study.

Among the cucumbers stored under four different conditions, those with plastic film packaging in a low-temperature environment exhibited the best overall quality, as evident in both physicochemical properties and sensory evaluation results. Cucumbers without packaging in a low-temperature environment and those with packaging at room temperature showed similar results in aspects other than color changes, receiving comparable scores in sensory evaluation. Additional experimental parameters are required to make a more accurate comparison between these two groups. Cucumbers without packaging at room temperature demonstrated the poorest quality results and were the first to exhibit signs of deterioration.

In conclusion, both temperature and packaging conditions significantly influenced the quality of cucumbers during the shelf life, with temperatures exerting a more pronounced effect compared to packaging conditions. Lower temperatures and the retention of plastic packaging can be more effective in preserving cucumbers and extending the shelf life, thereby potentially reducing food waste.

5. Recommendations

Based on the Results and Discussion section, improvements for future study can be made by introducing additional variable groups. This may involve expanding the range of temperature variations and introducing different packaging methods, such as vacuum sealing or household cling film wrapping. The existing experiments in the study only considered two temperature conditions, however, in real scenarios, there are various changes. Additionally, in this study, humidity was not controlled, which

may have some impact on certain physicochemical properties, such as weight loss. Controlling humidity should be considered in future experimental improvements.

In the physicochemical experiment component, introduction of measurement for chlorophyll content can provide additional experimental data on the relationship between cucumber maturity and color changes during the shelf life. For sensory evaluations, to reduce the number of experimental groups while to increase the number of participants within each group should be taken into consideration. This adjustment aims to streamline the overall experimental duration, minimizing the potential quality changes resulting from prolonged experimental procedures.

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Appendix

Questionnaire for the sensory evaluation

Q2 Welcome to the sensory test on cucumber quality!

In this study, you will get 13 cucumbers one by one. For each cucumber, please give the scores on three separate parameters (peel colour, peel appearance and firmness) and the final score from the overall aspect.

When you finish evaluating your sample, please raise your hand. And you will get a new sample. If you have any questions during the study, please raise your hand.

Your participation is voluntary and anonymous; all data will only be used for this experiment and not for other purposes.

The Q3 to Q7 repeated for 13 times.

Q3 Please enter the 3-digit code on the label of the cucumber:

_____

Q4 What do you think of the colour of the cucumber peel?

	Yellow	**Green**
	0	100
Colour ()		

Q5 What do you think of the roughness (e.g. shrivelling, wrinkles) of the cucumber peel?

	Not rough at all	**Extremely rough**
	0	100

Roughness ()	

Q6 What do you think of the firmness of the cucumber?

	Not firm at all	**Extremely firm**
	0	100
Firmness ()		

Q7 What do you think of the overall quality of the cucumber?

- ○ Dislike extremely
- ○ Dislike very much
- ○ Dislike moderately
- ○ Dislike slightly
- ○ Neither like nor dislike
- ○ Like slightly
- ○ Like moderately
- ○ Like very much
- ○ Like extremely

Q69 When you buy cucumbers with plastic packaging from a supermarket, how will you store the cucumbers?

Q70 Where will you put a cucumber?

- ○ In the fridge
- ○ At room temperature
- ○ other: (3) _____

Q71 When you want to store a cucumber, how will you treat the plastic film wrapped around the cucumber?

- ○ Keep it (1)
- ○ Remove it (2)
- ○ Other: (3) _____

Q72 Thank you very much for your participation! Please make sure you submit the evaluation. Please take the snacks when you leave the room.