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The Effect of Light Exposure Duration on the Oxidative Stability and Sensory Profile of Avocado (Persea americana)-Based Mayonnaise

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Abstract

Avocado-based mayonnaise presents a novel formulation aimed at reducing the saturated fat content typically associated with conventional emulsified condiments. This investigation sought to delineate the impact of light exposure duration on the oxidative integrity and sensory parameters of mayonnaise derived from Persea americana. Employing a completely randomized design (CRD) comprising a single experimental factor—duration of light exposure (0, 24, 48, and 72 hours) each treatment was replicated thrice to ensure experimental reliability and statistical robustness. Analytical endpoints included moisture content, pH, peroxide value, free fatty acid (FFA) concentration, and sensory attributes (color and aroma). Statistical analyses involved ANOVA followed by Duncan's Multiple Range Test at a 5% significance threshold. The results revealed that prolonged exposure led to a statistically significant decline in sensory acceptance (color score: 6.07 to 3.47; aroma score: 6.20 to 3.67) and elevated oxidative markers including moisture content, peroxide value, and FFA. Among the tested conditions, treatments L1 and L2 preserved compositional and sensory quality within permissible SNI standards for FFA (<3%). The study underscores the necessity of light-protective packaging in mitigating oxidative degradation in avocado-based emulsions and emphasizes the relevance of optimizing environmental exposure parameters during storage and distribution of lipid-rich food emulsions.

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1. Introduction

Mayonnaise is a widely consumed oil-in-water emulsion, generally consisting of vegetable oil, egg yolk, and acidifying agents, making it a product with a high lipid content ranging from 60% to 80% (De Leonardis et al., 2022). As nutritional awareness and consumer demand for healthier food products increase, modern mayonnaise formulations are adopting better lipid sources. Avocado flesh, rich in monounsaturated fatty acids, dietary fiber, phytosterols, and natural antioxidant compounds such as tocopherols and carotenoids, has emerged as a promising substitute for traditional oils in mayonnaise formulations.

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Although previous studies (Novitasari et al., 2022; Utami Mooduto et al., 2022) have evaluated the physicochemical and organoleptic properties of avocado-based mayonnaise, little attention has been given to its resistance to oxidation, especially due to light exposure, which is one of the most common and unavoidable environmental factors during the storage and distribution of products. In particular, in products with transparent plastic packaging, light can penetrate the surface and initiate photo-oxidative reactions that damage the lipid components in the emulsion.

The photooxidation reaction is triggered by the interaction of visible and/or ultraviolet light with light-sensitive molecules such as pigments, unsaturated lipids, and natural antioxidants. This results in the formation of reactive oxygen species (ROS), such as singlet oxygen, which accelerates the formation of lipid hydroperoxides. This process leads to nutrient degradation, color changes, the emergence of rancid odors, and a decline in sensory qualities.

Commercial mayonnaise products are generally packaged in transparent plastic containers that do not provide protection against ultraviolet light, potentially accelerating lipid oxidation through photochemical mechanisms. Such oxidative reactions can reduce the nutritional and sensory quality of food through pigment degradation, hydroperoxide formation, and further degradation into volatile compounds such as aldehydes and ketones (Fransisca et al., 2023).

The photooxidation mechanism is highly relevant in high-fat food systems, where reactive oxygen species and light synergistically trigger chain-peroxidative reactions (Rahim et al., 2023). This process not only disrupts the stability of the emulsion matrix but also reduces consumer acceptance by altering the color, aroma, and taste. Therefore, this study aims to thoroughly evaluate the effect of irradiation duration on the oxidative stability and sensory integrity of mayonnaise formulated with avocado, as well as to provide evidence-based recommendations for post-production handling and storage protocols for emulsion-based food products.

2. Material and Methods

This study used a Completely Randomized Design (CRD) approach with a single factor, namely irradiation duration, with four treatments: L1 (0 h), L2 (24 h), L3 (48 h), and L4 (72 h), each conducted in triplicate to ensure the replication and validity of the data. The irradiation duration range was selected based on scientific considerations regarding the dynamics of photo-oxidation reactions in fatty food materials. Exposure to light with an intensity of 2,000–3,000 lux for 24–72 hours has been reported to be sufficient to trigger the formation of primary and secondary oxidative compounds in vegetable oils, salad dressings, and lipid-based emulsions. Durations of 24 and 48 hours represent realistic conditions that may occur during storage and distribution of products in transparent packaging, while 72 hours of illumination is used as an extreme scenario to illustrate the potential for maximum damage due to photooxidation. The control treatment (0 hours) was included to describe the initial condition of the product before oxidative degradation.

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2.1 Tools and Materials

The equipment used included a mixer (Philips HR 1559), digital scale, automatic digital pH meter (Mediatech P-2Z), oven at 100 °C, destruction and distillation equipment (Kjeldahl flask, electric heater, condenser, Erlenmeyer flask, burette, volumetric pipette, and weighing bottle), and a wooden irradiation box measuring 80 × 50 × 60 cm lined with aluminum foil. Irradiation was performed using a Philips 10-watt neon lamp with an intensity of 2500 lux, measured using a LeyBold-Heraeus light meter.

The ingredients used include 2025 g of uniformly ripe avocado flesh (7 days after harvest), 675 ml of palm oil (Bimoli), 324g of chicken egg yolks, 1512 ml of lime juice, 2592 g of granulated sugar (Gulaku), and table salt (Cap Segitiga G). All the ingredients were commercially sourced from local suppliers in Gorontalo.

2.2 Mayonnaise Preparation Procedure

The avocado mayonnaise formulation was adapted from the method described by Utami Mooduto et al. (2022), with modifications. Egg yolk, salt, and sugar were first mixed using a mixer at 1500 rpm until they were homogeneous. Subsequently, palm oil was gradually added while continuously stirring. Once the mixture was stable, avocado pulp and lime juice were slowly added while homogenizing until a stable emulsion was formed.

2.2.1 Irradiation Treatment on Mayonnaise

The formulated mayonnaise samples were placed in an illumination box 20 cm from a 2,500 lux neon lamp. Irradiation was performed for the duration specified for each treatment (0, 24, 48, and 72 h). The box was tightly sealed and covered with aluminum foil to prevent the influence of external light (Figure 1).

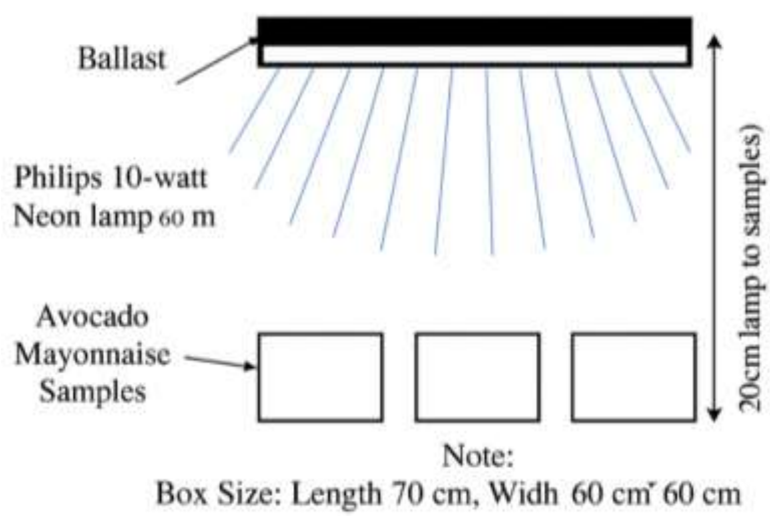

Figure 1. Illustration of the Mayones Irradiation Room.

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After the irradiation period, the samples were analyzed to measure moisture content (oven method), pH (using a digital pH meter), free fatty acids (titration with phenolphthalein indicator), peroxide value (iodometric titration, AOCS Cd 8-53 method), and organoleptic tests were conducted on color and aroma attributes by trained panelists using a hedonic scale.

2.2.2 Peroxide Number Analysis

The peroxide value was measured using the iodometric titration method (AOCS Cd 8-53). The mayonnaise sample was first reacted with a saturated potassium iodide solution, producing free iodine, which was then titrated with 0.01 N sodium thiosulfate solution using starch as an indicator until the endpoint was colorless. The peroxide value was calculated using Equation 1.

$$PV\ (meq/kg) = (V \times N \times 1000)\ /\ \text{sample weight (g)} \quad (1)$$

where V is the volume of the $Na_2S_2O_3$ solution used (ml), and N is the normality of the $Na_2S_2O_3$ solution.

2.2.3 Free Fatty Acid (FAA) Alaysis

The free fatty acids were analyzed using the alkali titration method with a phenolphthalein indicator. The mayonnaise sample was weighed and dissolved in a mixture of ethanol and ether solvents (1:1). This solution was then titrated with 0.1 N NaOH solution until a persistent pink color appeared. The FFA value was calculated using Equation 2.

$$\%FFA = (V \times N \times 25.6)\ /\ \text{sample weight (g)} \quad (2)$$

where V is the volume of the NaOH solution used (ml) and N is the normality of the NaOH solution.

All data were statistically analyzed using the latest version of the SPSS software with a one-way ANOVA test. Duncan's post hoc test was used to compare the means between treatments at a significance level of $\alpha = 0.05$.

3. Results and Discussion

3.1 Water Content

The L1 treatment showed the highest moisture content compared to the other irradiation treatments. This is related to the relatively high water content of avocados, which is approximately 84.30 g/100 g of material (Januar et al., 2024). These findings are consistent with those of Utami Mooduto et al. (2022), who reported that the greater the use of avocado, the higher the moisture content in mayonnaise. The results of the ANOVA analysis ($\alpha = 0.05$) indicate that the irradiation treatment did not have a significant effect on the moisture content, although there was a downward trend in L4 due to evaporation during irradiation. This decline is supported by Ghorbani Gorji et al. (2019), who reported that storage causes the loss of CO_2 and H_2O, thereby affecting the moisture

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content and pH. This data reinforces that although the differences between treatments are not significant, physical changes due to evaporation still occur (Figure 2).

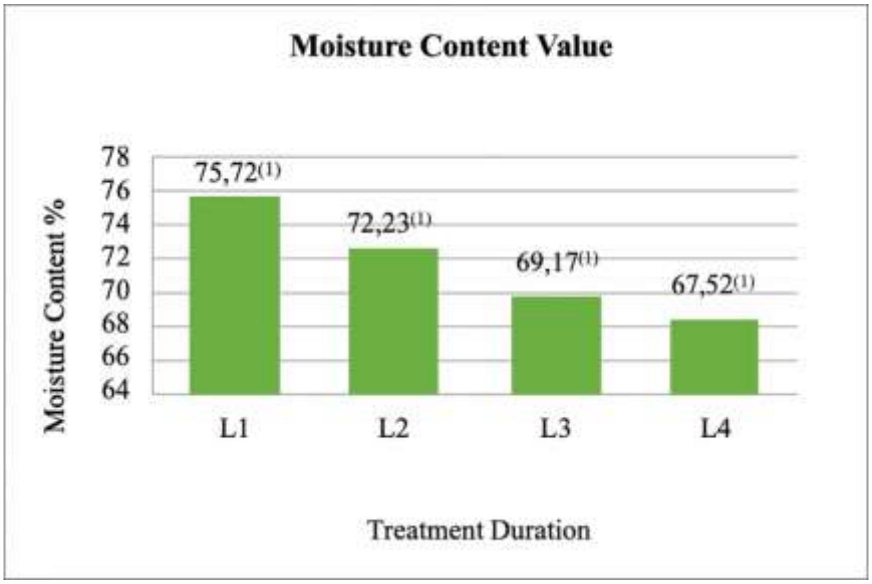

Figure 2. Moisture content values of avocado mayonnaise.

Note: L1= 0 hours, L2= 24 hours, L3= 48 hours, L4= 72 hours, (1) =notation indicates a significant difference (α=0.05)

According to SNI 01-4473-1998, the maximum moisture content of conventional mayonnaise is 30%. The moisture content values in this study (67.52%–75.72%) do indeed far exceed that limit; however, this condition does not necessarily indicate that the avocado mayonnaise product has "completely failed." The high water content mainly comes from the characteristics of the raw materials, namely avocado pulp, which naturally contains approximately 70–80% water, as well as additional water from egg yolks and lime juice. Therefore, this formulation is structurally more similar to a vegetable-based emulsion or reduced-fat mayonnaise than to high-oil mayonnaise based on Indonesian National Standard (SNI). Internationally, this product category does not use the SNI water content standard because replacing most of the oil with water-rich plant ingredients significantly increases the moisture content. Nevertheless, a high moisture content has scientific consequences, namely, a potential increase in hydrolysis reactions, decreased viscosity, and lower emulsion stability. Therefore, the moisture content values in this study reflect the natural characteristics of the avocado-based formulation rather than process inconsistencies and should be considered within the context of a product category different from conventional mayonnaise.

3.2 Degree of Acidity (pH)

The irradiation duration affected the pH, which ranged between 3.72 and 4.22. This value is within the SNI 01-4473-1998 range (pH 3–4). ANOVA showed a significant difference between the treatments (α=0.05). The Duncan test results indicate a decrease in pH as the irradiation time increases (L1: 4.22

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→ L4: 3.72). This decrease is associated with the formation of carboxyl groups as secondary products of lipid oxidation, which reduces the buffering capacity of the emulsion system (Andarwulan et al., 2016; De Leonardis et al., 2022). Mechanistically, the accumulation of free fatty acids and carbonyl compounds during irradiation enriches the acid fraction in the continuous phase, thereby lowering the pH and affecting the stability of the egg yolk emulsifier protein. The decrease in pH can also be explained by the formation of carboxyl groups, which increase with oxidation.

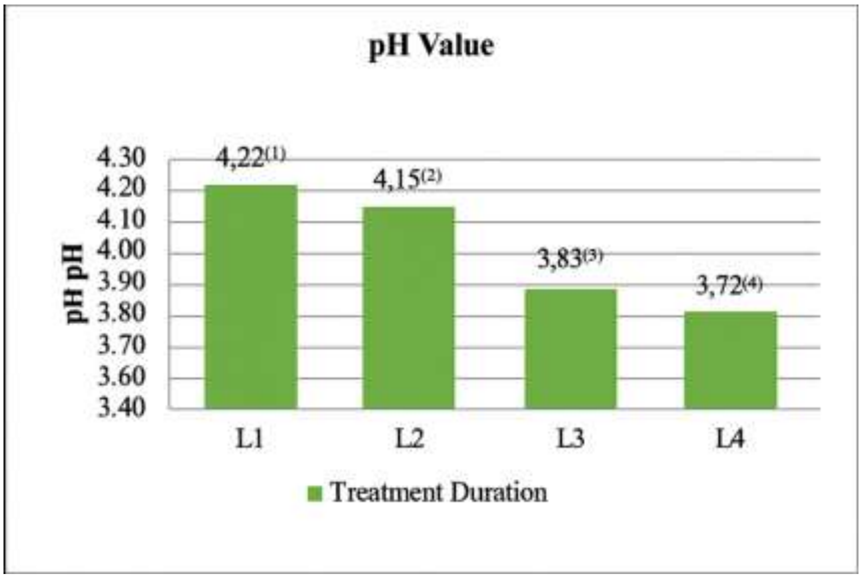

Figure 3. pH of avocado mayonnaise.

Note: L1= 0 hours, L2= 24 hours, L3= 48 hours, L4= 72 hours, (1) =notation indicates a significant difference (α=0.05)

The carboxyl group is a functional group in carboxylic acid molecules (Rumiarsa et al., 2018; Wehantouw & Roreng, 2021) that can be formed through hydrolysis or oxidation. This accumulation of carboxylates alters the chemical quality of avocado mayonnaise during exposure to light, primarily by lowering the pH and affecting the stability of the emulsion system. The pattern of pH decrease is consistent with the results obtained for irradiated modified starchy materials (Rizkyyani et al., 2020). This finding reinforces the interpretation that irradiation duration is a key variable triggering pH decline in lipid-rich emulsions (Figure 3).

3.3 Peroxide Value

Avocado mayonnaise exposed to different irradiation durations showed an increase in peroxide value during L4 irradiation. The resulting peroxide values ranged from 1.9–5.2 meq/kg, with the avocado mayonnaise sample without irradiation showing the lowest peroxide value (1.9 meq/kg). The irradiation treatments L2 and L3 showed an increase in peroxide values (2.9 and 4.2 meq/kg, respectively), while treatment L4 had the highest peroxide value (5.2 meq/kg). The results of this study still meet the SNI 3741:2013 standard, which is a maximum of 10 meq/kg of Na +.

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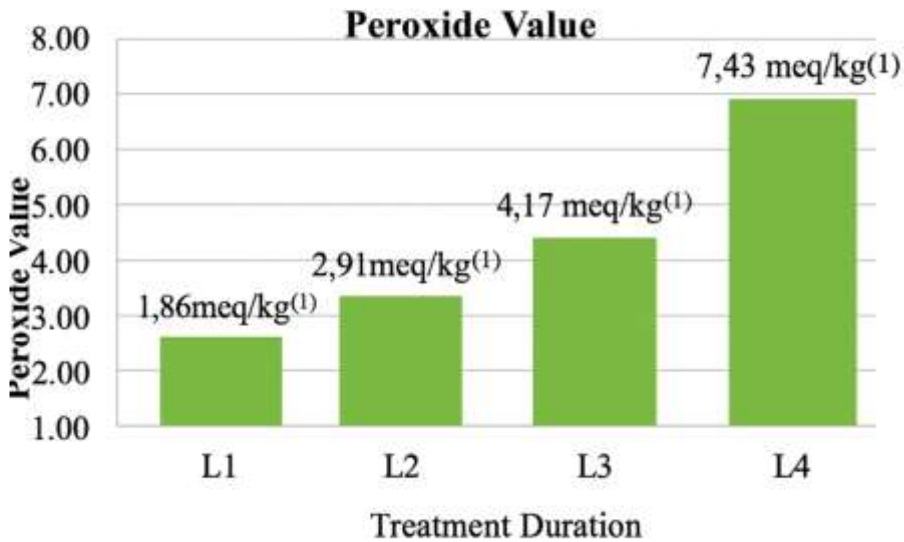

Figure 4. Peroxide value of avocado mayonnaise.

Note: L1= 0 hours, L2= 24 hours, L3= 48 hours, L4= 72 hours, (1) = notation indicates a significant difference (α=0.05)

Statistically, ANOVA showed no significant difference (α>0.05), which is likely due to the fact that a light intensity of 2500 lux and a distance of 20 cm are not sufficient to drastically accelerate hydroperoxide formation during the testing period. Nevertheless, the increasing PV trend indicates continuous primary oxidation during irradiation. Chemically, light-induced singlet oxygen reacts with the double bonds of unsaturated fatty acids to form hydroperoxides, which can then dissociate into aldehydes/ketones that affect aroma (Tirtayasa, 2020). The qualitative correlation between increasing PV and decreasing aroma scores (Figure 7) strengthens the relationship between primary oxidation and organoleptic degradation. Thus, PV serves as an early indicator of oxidative damage in this system (Figure 4).

3.4 Free Fatty Acids (FFA)

The duration of irradiation treatment on avocado mayonnaise products affected the resulting free fatty acid values. The free fatty acid values obtained ranged from 0.89–6.80%. The avocado mayonnaise sample without irradiation produced the lowest free fatty acid content at 0.89%, which then increased in the L2 and L3 irradiation treatments with values ranging from 1.76–3.71%, while the L4 irradiation treatment resulted in the highest free fatty acid value compared to the other treatments, at 6.80%. According to the Indonesian National Standard (SNI), the maximum ALB value is 3% (Remit Winardi & Healty Aldrianty Prasetyo, 2022). Therefore, the ALB values for L1 and L2 still met the requirements.

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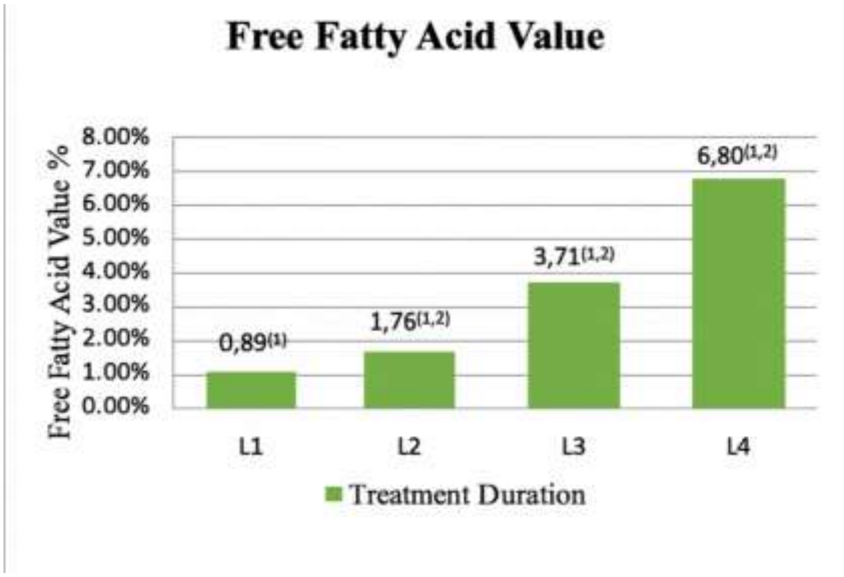

Figure 5. Free fatty acid values of avocado mayonnaise.

Note: L1= 0 hours, L2= 24 hours, L3= 48 hours, L4= 72 hours, (1) =notation indicates a significant difference (α=0.05)

FFA levels increased from 0.89% (L1) to 6.80% (L4) The values in L1 and L2 still met the Indonesian National Standard (SNI) (max. 3%), while L3 and L4 exceeded the limit. An increase in FFA is generally associated with the hydrolysis of triglycerides into free fatty acids and glycerol (Sarungallo et al., 2021). However, the data in this study show a contradiction: the water content in the L4 treatment was relatively lower than that in the other treatments, but the FFA value was higher. This condition can be explained by the fact that, although the total water content decreases due to evaporation, the availability of water in the bound form remains sufficient to trigger hydrolysis reactions. In addition, prolonged exposure to light accelerates the formation of free radicals and oxidative processes, resulting in the formation of peroxides and compounds such as aldehydes and ketones. These compounds can catalyze the further release of free fatty acids, even as the water content decreases (De Leonardis et al., 2022; Norouzzadeh et al., 2024).

The decrease in pH (Figure 3) also enriches the acidic environment, facilitating lipid hydrolysis. Thus, the spike in FFA at L4 is more accurately attributed to a combination of photo-oxidative conditions, decreased pH, and the availability of bound water rather than solely to the total water content. These results indicate that prolonged exposure (L4) carries a high risk of accelerating both hydrolytic and oxidative rancidity; therefore, it is not recommended for maintaining the chemical and sensory quality of the product (Figure 5).

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3.5 Sensory Test

3.5.1 Color

The color values obtained ranged from 3.47–6.07, with treatment L1 having the highest value at 6.07 (like), followed by treatment L2 at 4.93 (somewhat like), treatment L3 at 4.0 (neutral), and treatment L4 at 3.47 (somewhat dislike).

Based on the results of the ANOVA statistical test at a significant level (α=0.05), different irradiation treatments on avocado mayonnaise had a significant effect on the resulting colors. Because of the significant effect of the different irradiation treatments on avocado mayonnaise, a further Duncan test was conducted. The Duncan test results showed that the treatments L1, L2, L3, and L4 were significantly different.

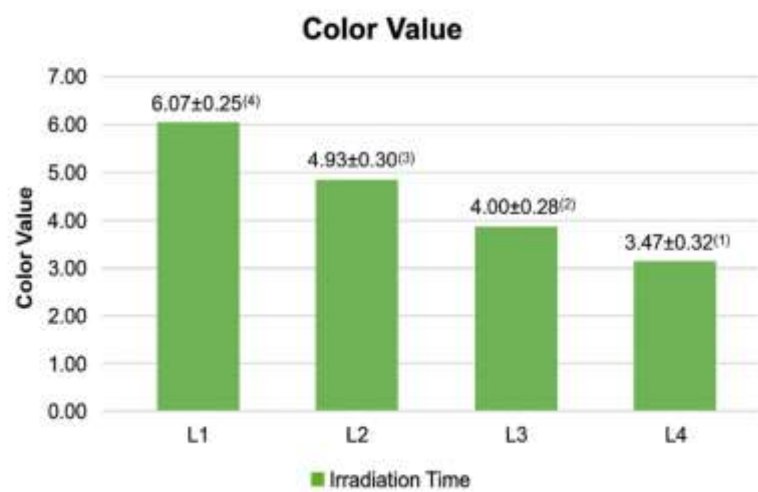

Figure 6. Color attribute values in the sensory test of avocado mayonnaise Note: L1 = 0 h, L2 = 24 h, L3 = 48 h, L4 = 72 h, (1) = notation indicates a significant difference (α=0.05).

The L1 treatment had a relatively high color value compared to the other treatments, which was influenced by the raw material used, namely, avocado fruit. The use of avocado in mayonnaise not only serves as a good source of fat but also provides a natural color to the mayonnaise. The green color differs from that of regular mayonnaise. Similarly, research has shown that consumers are more attracted to mayonnaise with a high color intensity than to that with a low intensity.

The decrease in the panelists' preference scores for the color of avocado mayonnaise in each irradiation treatment indicates that the different irradiation effects had a significant impact on the color value of the avocado mayonnaise. This indicates that light is one of the factors that can trigger oxidation reactions, thereby affecting the color differences in the mayonnaise product.

This study used avocados as one of the main ingredients in the production of mayonnaise. Avocados are highly susceptible to oxidation; the oxidation process in avocados occurs because

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oxygen reacts with polyphenol compounds, assisted by the enzyme polyphenol oxidase. This reaction gradually damages the avocado, causing it to turn brown.

The brown color that appears on avocados is produced by melanin, a dark pigment formed as a result of the oxidation of polyphenols. This browning process is influenced by environmental conditions, such as temperature, oxygen availability, and acidity. If the room temperature increases, oxidation occurs more rapidly. Likewise, exposure to oxygen accelerates melanin formation, causing the color to become brown. If the flesh of the avocado is left at room temperature for several days, the oxidation process becomes more intense, and the fruit tissue may rot. In addition to enzymatic browning, non-enzymatic browning reactions, such as the Maillard reaction, may also occur. This reaction occurs between the carbonyl group of the reducing sugar and the amino group of the protein/peptide in the mayonnaise matrix, triggered by light exposure and storage conditions. Both of these browning pathways (enzymatic and non-enzymatic) can contribute to the observed color changes. The consistency between the decrease in color score and the increase in oxidative parameters further supports the hypothesis that irradiation is the main trigger of the decline in visual appearance.

3.5.2 Aroma

Based on the research, it can be seen that the different durations of irradiation treatment on avocado mayonnaise products resulted in varying panelist scores, ranging from 3.67 to 6.20. The L1 treatment, or no irradiation, received the highest score of 6.20 (liked), whereas the L2 and L3 irradiation treatments received panelist scores of 5.60 (liked) and 4.80 (somewhat liked), respectively. Meanwhile, the L4 irradiation treatment received the lowest score of 3.67 (neutral).

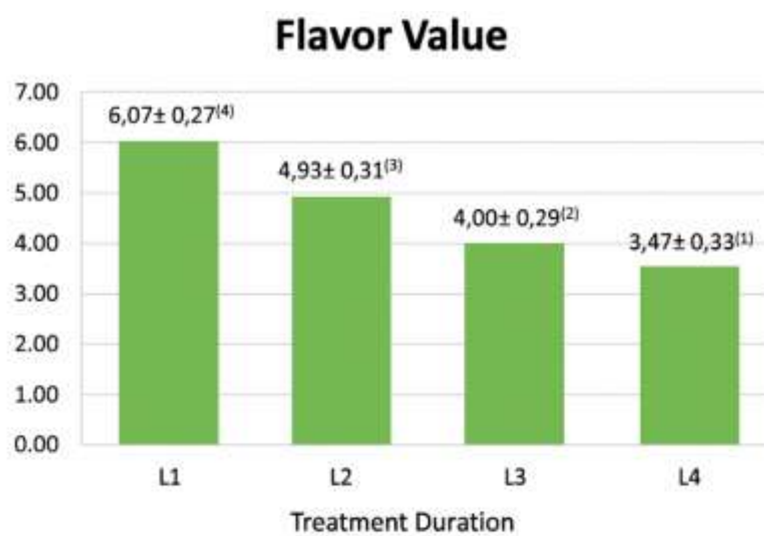

Figure 7. Aroma attribute scores in the sensory test of avocado mayonnaise

Note: L1= 0 h, L2= 24 h, L3= 48 h, L4= 72 h, (1) =notation indicates a significant difference (α=0.05).

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The results of the ANOVA statistical test at a significance level (α=0.05) indicated that irradiation of avocado mayonnaise products had a significant effect on the resulting aroma values. Because of the significant effect of the different irradiation treatments on avocado mayonnaise, a follow-up Duncan's test was conducted. The Duncan follow-up test results showed that the different irradiation treatments (L1, L2, L3, and L4) on avocado mayonnaise had a significant effect.

Prolonged irradiation also caused the mayonnaise to have a pungent odor, especially at L4, which is a strong indication of further oxidation. This process produces peroxides or hydroperoxides, which are then degraded into other chemical groups, such as aldehydes, ketones, and alcohols, owing to exposure to high-energy light (Fransisca et al., 2023). Thus, the dynamics of PV–FFA–pH–aroma are interconnected and demonstrate a consistent trajectory of oxidative deterioration during irradiation. The relationship between these parameters reinforces the explanation that the decline in aroma does not occur in isolation but is a direct consequence of increased PV, a surge in FFA, and a decrease in pH, all of which create ideal conditions for the emergence of rancid odors (Figure 7).

This study conducted tests on free fatty acids and peroxide values, the results of which showed an increase. Exposure to light can trigger reactions that produce free radicals, which may contribute to the development of rancid odors (Włodarczyk et al., 2022). Free radicals can damage food materials, resulting in nutrient loss and changes in key parameters of food, such as aroma, taste, texture, consistency, and appearance. Free radicals are reactive, and if not deactivated, they can damage the macromolecules that make up cells, namely proteins, carbohydrates, fats, and nucleic acids, potentially leading to degenerative diseases.

4. Conclusion

Different irradiation durations significantly affected the oxidative stability and sensory quality of avocado mayonnaise. Increases in the peroxide value and free fatty acid content indicate the susceptibility of the product to oxidative deterioration. Significant sensory changes also occurred, as evidenced by a drop in the color score from 6.07 (liked) to 3.47 (disliked) and an aroma score from 6.20 (liked) to 3.67 (neutral). The results of this study confirm that sensory and oxidative parameters are closely linked through photooxidation. Based on these findings, it is recommended that the production and storage of avocado-based mayonnaise be conducted with minimal light exposure and not exceed 24 h (L2), as at this duration the FFA value still meets the Indonesian National Standard (SNI) and the sensory quality remains acceptable. However, the moisture content exceeding the SNI standard suggests that this product naturally possesses characteristics that differ from those of conventional mayonnaise. Therefore, formulation adjustments, such as reducing the proportion of avocado, increasing the oil content, or using stabilizing agents, should be considered if compliance with mayonnaise standards is necessary. In addition, the use of light-impermeable packaging or packaging with UV protection is important for maintaining oxidative stability and sensory quality

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during distribution and storage. By implementing these strategies, the nutritional quality, emulsion stability, and consumer acceptance of avocado mayonnaise can be optimally maintained in the future.

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