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Investigation of the Improvement of Physical and Chemical Changes in Banana Fruits under Different Lighting and Packaging Conditions

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ABSTRACT

Given the importance of storing and handling bananas to preserve their quality, flavor, and nutritional value, this study used various light treatments and packaging methods to maintain the quality of bananas. The bananas were first prepared, and any damaged bananas were removed. After standardizing the size, they were washed in a sterile environment. The bananas were then stored in polyethylene films, PVC, plastic, and without packaging, under LED light (blue, red, green), and without light for 7 days. Properties such as firmness, pH, weight change percentage, and soluble solids content were measured afterward. According to the research results, using blue light treatments increased the firmness of the bananas by approximately 40% compared to the conditions without light. Polyethylene film packaging helped retain about 35% more firmness compared to no packaging. These findings suggest that using specific combinations of blue light treatments and PVC packaging can significantly improve bananas' quality and shelf life, potentially reducing wastage and financial losses in the food industry. The potential financial benefits of these findings should motivate further research and implementation in the food industry.

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INTRODUCTION

Fruits are an essential component of a nutritious diet and act as a supplementary food source. Among thme, bananas are particularly valuable for their nutritional and medicinal properties (Ranjha et al., 2022). The scientific name of the banana is *Musa sapientum*, and its English name is Banana, belonging to the *Musaceae* family. Bananas are the most well-known tropical fruit, typically harvested unripe and ripened during transport to their destination (Liew & Lau, 2012). Due to the presence of vitamins A and B6, bananas help prevent cancer and heart diseases. The high potassium content in bananas helps reduce cardiovascular diseases, thus controlling blood pressure (Siriwardana et al., 2017). Bananas are delicate and perishable fruits, so exposure to oxygen and moisture over time leads to fruit degradation and reduced shelf life. Additionally, improper handling, transportation, and storage can lead to wastage and financial losses in the food industry. Storing bananas under optimal conditions, such as appropriate temperature, can extend their shelf life. Lowering the temperature and oxygen levels delays respiration activity, increasing banana longevity (Othman et al., 2021). The appearance of fruits greatly influences their market value; therefore, it is crucial to properly handle them after harvesting to prevent any physical damage, maintain the visual quality of the fruit, and boost exports. Bananas exhibit different characteristics during ripening under various storage conditions, such as firmness, color, texture, and sensory attributes (Facundo et al., 2015). Fruits are graded based on physical properties such as shape and size. Knowing the dimensions of fruits is essential for packaging and uniform placement in standard boxes. In agricultural packaging, if the size and dimensions of the products are unknown, selecting the packaging with maximum capacity becomes difficult. This can lead to issues like empty spaces between fruits, causing movement and potential damage, ultimately resulting in financial losses (Aviara et al., 2015). Fruits are seasonal and perishable products, making their processing, storage, and packaging a necessary and obvious task. It is worth noting that safety and hygiene issues have gained significant attention in recent decades. Additionally, the quality of fruits or fruit products must be preserved during various processing and packaging stages (Kalia & Parshad, 2015). Different materials, such as plastic, cardboard, and metal, produce packaging containers. The choice of material depends on the nature of the food product, as the packaged materials have a wide range of functional characteristics that significantly impact the product's shelf life (Azadbakht et al., 2020). Using plastic as a packaging type offers unique marketing advantages. Unlike aluminum and metal packaging, transparent plastic films have become famous for better product visibility, allowing consumers to assess the product visually. However, one drawback of plastic films is their permeability to gases and vapors (Manetto et al., 2017). Various types of plastic films include high-density polyethylene (HDPE), polypropylene (PP), polyethylene (PE), low-density polyethylene (LDPE), and multi-layered aluminum foil (LAF). In this regard, several researchers have conducted studies:

Hailu et al. experimented with the impact of packaging materials on different banana varieties' shelf life and quality. The results indicated that bananas packaged in polyethylene film remained marketable for up to 36 days, while unpackaged bananas lasted only 15 days. Packaging helped preserve the quality of the bananas, with spoilage rates of 16% for unpackaged bananas and 41.2% and 43% for packaged ones (Hailu et al., 2014). Zerga and Tsegaye also studied the effects of various packaging materials on banana quality and shelf life, revealing that the highest weight loss, 21.74%, occurred in unpackaged bananas, while the lowest, 6.56%, and was found in bananas packed with polyethylene film. Packaged bananas displayed a more vibrant color compared to unpackaged ones, suggesting that packaging contributes to extending the fruit's shelf life (Tsegaye, 2020).

Dladla and workneh conducted a study to evaluate the effects of different packaging materials on the quality characteristics of tomatoes. The results showed that packaging and storage conditions have a significant effect on the quality of tomatoes, and tomatoes that were in cold conditions and PVC packaging had the best quality compared to other packaging (Dladla & Workneh, 2023).

Ochigobo and Harris conducted a study on the effects of plastic film covering on the growth and yield of tomato bushes grown in beds, and the results were as follows; using perforated plastic film to cover the plants for three weeks after they were placed in the ground increased the growth of shoot dry weight and growth in leaf area (Ochigbo & Harris, 1989).

Light is one of the most critical environmental factors affecting the pigments in fruits and vegetables. Light can alter the formation of fruit colors, creating a deeper hue (Huang et al., 2018). Vegetables and fruits in controlled environments, such as growth rooms and greenhouses, are increasingly exposed to artificial light sources like light-emitting diodes (LEDs) due to several benefits, including low mass and volume, relatively cool temperatures, long lifespan, and high energy conversion efficiency (Nassarawa et al., 2021).

Light, including its intensity, quality, and photoperiod, plays a crucial role in the growth and development of plants. LEDs offer various advantages, such as high energy conversion efficiency, long life, and adjustable emission spectra while reducing energy consumption (Liu et al., 2016). A common feature of LEDs is their ability to enhance the quality of agricultural products. Blue and red LEDs have improved color and secondary metabolites in vegetables and fruits (Pola et al., 2019). Several researchers have conducted studies on this topic:

Stutte et al. investigated regulating bio-protective content in red leaf lettuce using LED lighting. They found that red light increased leaf length and chlorophyll absorption by 95% to 100%, while the dry weight of lettuce under red light was 20% lower than under blue and infrared light. Thus, blue and red light improved the characteristics of lettuce (Stutte et al., 2009). Similarly, Huang et al. studied the effect of LED radiation on the ripening and nutritional quality of post-harvest bananas. Their findings showed that blue LED light accelerated ripening and improved the nutritional quality of bananas, followed by red and green LED lights. Consequently, blue LED light, in particular, accelerated the skin color change and enhanced the chemical and physical properties of bananas (Huang et al., 2018).The use of packaging and lighting is crucial for fruit preservation. These measures reduce waste, increase shelf life, and maintain fruit quality. They also reduce the oxidation and physical degradation of fruits. Appropriate lighting and packaging are essential to maintaining fruit quality and preserving nutritional value. This study aims to evaluate the effect of packaging and lighting on the physical changes in bananas during storage. It assesses each parameter's positive and negative impacts to propose the best-LED treatment and packaging film for post-harvest banana storage.

MATERIALS AND METHODS

Preparation and Equipment

In this study, bananas were procured from local markets in Gorgan, Golestan Province, Iran. Initially, bananas with visible defects were separated and excluded from the experiment. After sorting, the defect-free bananas were cleaned with a damp cloth. All bananas were categorized by size to ensure uniformity in dimensions and weight, reducing experimental error. Very large or tiny bananas were excluded from the experiment. After sorting, the bananas were packaged using polyethylene, PVC, and plastic films and left unpackaged. The packaged bananas were subjected to three lighting conditions (blue, red, and green LED light) and one condition without light, with 16 hours of light exposure and 8 hours of darkness per day for seven days. This experiment took place in the mechanical engineering laboratory of Gorgan University of Agricultural Sciences and Natural Resources, and the bananas were stored at room temperature. Daily measurements of the bananas' color and physical properties (weight, dimensions, and size) were taken, while chemical properties were measured on the final day. The moisture content of the bananas was determined based on standard procedures. Three 9-W LED lamps were used for each lighting. Red LEDs have a wavelength of 600 to 650 nanometers, blue LEDs have a wavelength of 450 to 500 nanometers, and green LEDs have a wavelength of around 520 to 570 nanometers.

Figure 1. 5 main stages of conducting research laboratory tests in the Biosystems Laboratory of Gorgan University of Agricultural Sciences and Natural Resources

Changing in Fruit Weight

A digital scale model DJ 2000 A with a precision of 0.01 was used to measure changes in banana weight during storage. After seven days of storage, the percentage change in the fruit's weight compared to its initial weight was calculated.

Firmness Measurement

A penetrometer (model EFFEGI, made in Italy) was used to measure the firmness or strength of the fruit flesh. During this test, care was taken to ensure that the skin of the samples remained intact while applying quasi-static pressure. According to the instructions, the penetrometer probe was placed on the desired part of the banana, allowing the probe to penetrate the fruit flesh after applying the necessary pressure. The value displayed on the penetrometer's screen indicated the firmness of the fruit (Azadbakht et al., 2019).

Measurement of Soluble Solids

Fruit extracts were obtained in the laboratory, and a few drops of the extract were placed on a refractometer to calculate the amount of soluble solids. The digital refractometer model (MT - 032ATC) was made in Taiwan.

PH Measurement

The samples' pH values were determined by titrating the banana fruit with 0.1 normal sodium hydroxide based on malic acid at pH=8.1. This was done using a pH meter (model AD100 made in Hungary with a precision of ±0.01) equipped with a glass electrode and a suitable reference electrode. Each sample's pH measurement followed standard 3195 from the National Committee for Biology and Microbiology Standards.Calibration was performed using buffer solutions. First, the pH meter electrode was washed with distilled water, then the electrode was placed in the first buffer solution with a neutral pH of 7 and the calibration was performed. Then, the same step was repeated for the second buffer solution with a pH of 4 and the calibration was performed.

Statistical Analysis

This study examined the effects of the independent factors of light exposure and packaging on the dependent factors of percentage weight change, soluble solids, pH, and firmness at the end of the storage period. All experiments were conducted in three replications, and the results were analyzed using factorial tests and a completely randomized design with the statistical software SAS 9.2.

Results and Discussion

The results of the variance analysis of the characteristics of bananas during storage under different light conditions and packaging methods are shown in Table 1. According to the results, the light exposure factor significantly affected the firmness, percentage change in total weight, and soluble solids, except for the pH content, which did not show statistical significance. The significance of the remaining factors was found at the 1% statistical level. The independent packaging factor also showed significance at the 1% statistical level for firmness, soluble solids, and percentage change in total weight, while pH exhibited significance at the 5% statistical level. In experimental design, the significance level specifies the likelihood of error in rejecting the null hypothesis (the hypothesis of no effect). The 1% significance level indicates that the probability of the results being random is very low (less than 1%), providing greater confidence in the effect of the factor under investigation. This level is generally used for results requiring stronger evidence. In this study, the effects of lighting and packaging on firmness and soluble solids were reported to be significant at this level. The 5% significance level represents an error probability of less than 5% and is suitable for results that require moderate evidence. In this study, the effects of packaging on reducing pH and moisture were reported to be significant at this level.Considering the significance of mean comparisons, an investigation was conducted into the interaction effects of the dependent factors. Based on the table, significance in interaction effects was observed for soluble solids and pH. In contrast, firmness, the percentage change in total weight, and their interaction effects were not statistically significant. These results indicate that light has a much greater effect on banana firmness compared to PVC packaging, as its F-value is significantly higher. Light preserves the fruit's cellular structure, preventing softening, while packaging is also effective but less impactful.

When comparing the percentage of total weight loss and fruit moisture, both light and packaging effectively prevent water evaporation and weight reduction, although the effect of light is slightly stronger. Packaging has a greater impact on reducing soluble solids, likely due to restricted gas exchange and reduced metabolic activity within the packaging. In contrast, light may increase soluble solids, potentially accelerating the ripening process. Packaging significantly reduces pH, which could help maintain fruit quality and limit microbial growth. The effect of light on pH was not significant, indicating that this factor primarily influences physical attributes.

Table 1. Analysis of Variance for the Characteristics of Bananas during Storage under Different Light Conditions and Packaging Methods

Percentage reduction in moisture content		Firmness		
F value	**Mean Squares**	**F value**	**Mean Squares**	**Variables**
7.05*	0.019	31.06**	217.95	Light
3.22*	0.009	8.22**	57.67	Packaging
1.54ns	0.004	1.75ns	12.27	Light * Packaging
Soluble Solids		**Percentage Change in Weight**		
23.09**	11.24	9.55**	285.32	Light
29.96**	14.58	8.07**	189.39	Packaging
2.83*	1.37	1.97ns	15.48	Light * Packaging
		PH		
		0.197ns	0.099	Light
		3.122*	0.22	Packaging
		5.53*	0.3329	Light * Packaging

Firmness

Figures 2(a) and 2(b) present the results comparing the mean firmness of the fruit in various packaging and lighting conditions. According to Figure 2(a), the best firmness value for the samples was obtained under blue light, showing a significant difference compared to the other conditions. Moreover, no significant difference was observed between the no-light condition and the green light; however, the firmness of the fruit under the green light was more significant than in the no-light condition. The obtained values indicate that the use of lighting resulted in approximately a 40% increase in the firmness of the fruit compared to the no-light condition. Additionally, there was no significant difference in packaging between polyethylene and PVC films, as these two types of packaging were in the same statistical group. Conversely, the packaging with plastic film and the no-packaging condition were classified into two different statistical groups. Furthermore, PVC film maintained about 35% more firmness for different packaging conditions compared to the no-packaging condition.

Firmness relates to the maturity of many agricultural products and serves as one of the quality indicators for fruits and vegetables. Generally, the firmness of fruits decreases as they mature, with the rate of decrease accelerating as they ripen. Overripe or damaged fruit tends to be soft, while healthy fruit exhibits firm tissue (Jarimopas & Kitthawee, 2007). Huang et al. stated in their research on the effects of LED radiation on the ripening and nutritional quality of bananas that blue LED light was the most effective option for accelerating ripening compared to green and red lights. Under LED light exposure, the color of the fruit changed rapidly from green to yellow, reducing fruit firmness during storage (Huang et al., 2018). Kokalj et al. reported that the effect of light-emitting diodes on various fruits after seven days showed a significant increase in ascorbic acid content, total phenols, flavonoids, and antioxidants in apples. Additionally, apples exposed to LED light were significantly firmer (Kokalj et al., 2016).

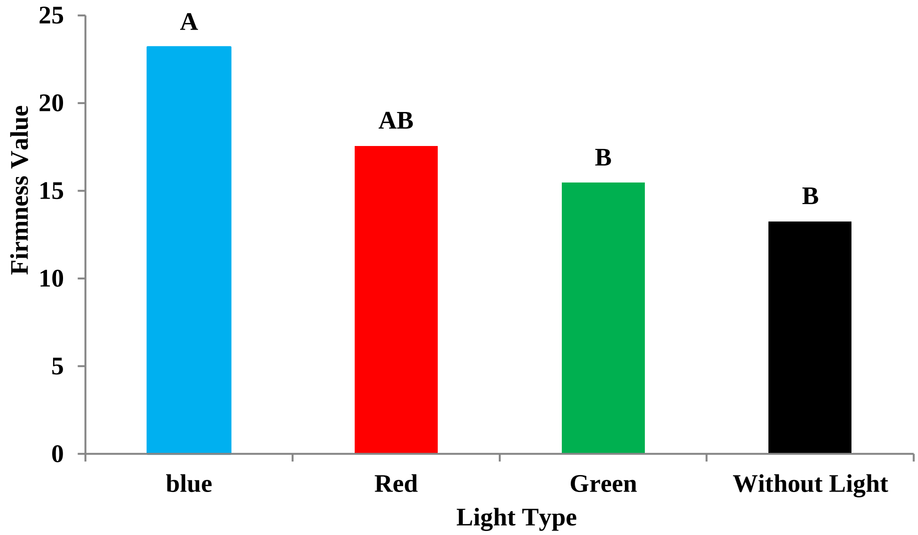


Figure 2. (a): Interaction Effect of Firmness under Different Lighting Conditions
Lowercase letters indicate significant comparisons within a fixed lighting condition.

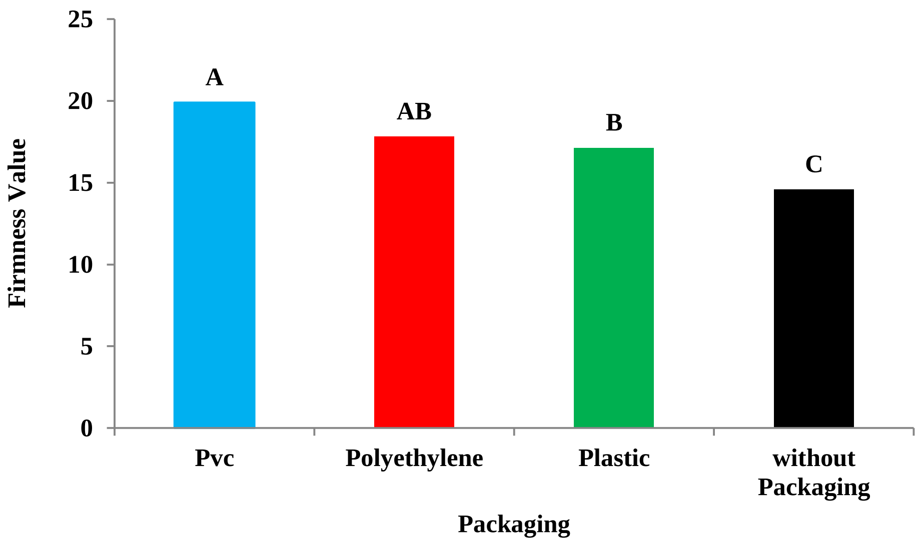


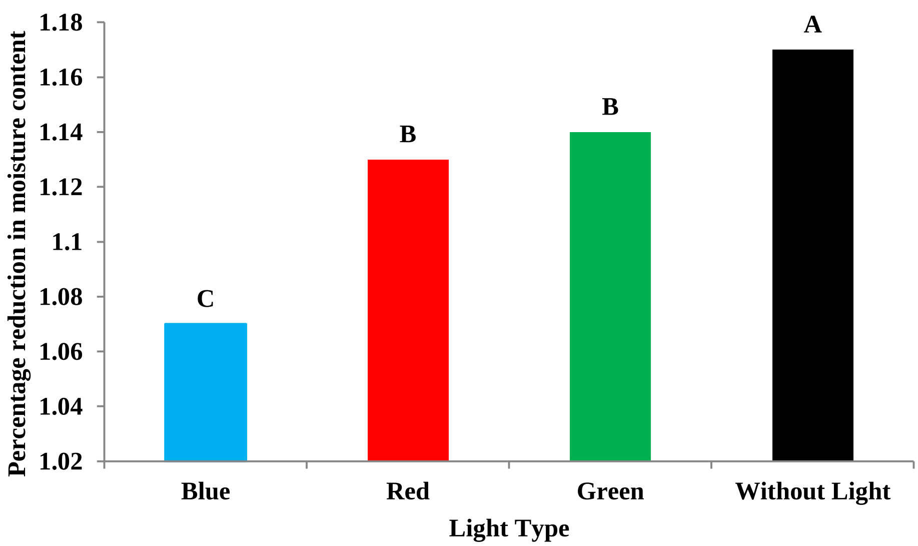
Figure 2. (b): Interaction Effect of Firmness under Different Packaging Conditions
Capital letters indicate significant comparisons within a fixed packaging condition.

Percentage Reduction in Moisture Content

Regarding the percentage reduction in moisture content in the samples, as shown in Figures 3(a) and 3(b), it can be stated that the percentage reduction in moisture content in the samples without light and packaging was more significant than in the illuminated samples and those with packaging films. No significant difference was observed between green and red light for the lighting condition, and for the packaging condition, no significant difference was found between polyethylene and plastic films; all were grouped in the same statistical category.

However, these conditions differed significantly from the blue light and PVC film. Significant differences among various lighting and packaging conditions were confirmed based on statistical values from analysis of variance. For example, blue light had a highly significant effect on banana firmness ($F=31.06$, $p<0.01$), and PVC packaging also demonstrated a significant impact on preserving firmness ($F=8.22$, $p<0.01$). The interactive effect of lighting and packaging on soluble solids was also significant ($F=2.83$, $p<0.05$). These findings highlight the importance of these factors in maintaining banana quality. Overall, the use of films and lighting resulted in a significant difference compared to the absence of these factors concerning the percentage reduction in moisture content. Environmental conditions, particularly temperature and humidity, significantly impact the quality of fresh fruits and vegetables. Numerous studies have shown that humidity notably affects the quality of fresh products. Ambient humidity is one of the most challenging environmental conditions to control, and most studies have utilized protective packaging to maintain sufficient moisture around the product, helping preserve quality and extend shelf life. While ambient humidity may not raise concerns during product packaging, low humidity levels can lead to significant quality loss. The longer the storage duration, the more moisture content is lost, resulting in diminished flavor and texture softening of the products. Bekele concluded in their research on the moisture loss of fresh fruits under various pre-harvest and post-harvest factors that significant environmental factors, such as storage temperature and relative humidity, play a crucial role and have a substantial impact on water loss and overall quality of fresh products. Furthermore, post-harvest, fruits with thick and hard skins are more susceptible to moisture and juice loss than those with thin skins (Bekele, 2018).

Roshita and Goh conducted a study on the effect of exposure to different colors of LED diodes on the performance and physical properties of gray and white oyster mushrooms. The results showed that gray oyster mushrooms had tighter stacks than the white mushroom species under blue LED light, and blue light provided better moisture retention (Roshita & Goh, 2018).



Figure(3) (a): Comparison of Mean Percentage Reduction in Moisture Content under Different Lighting Conditions

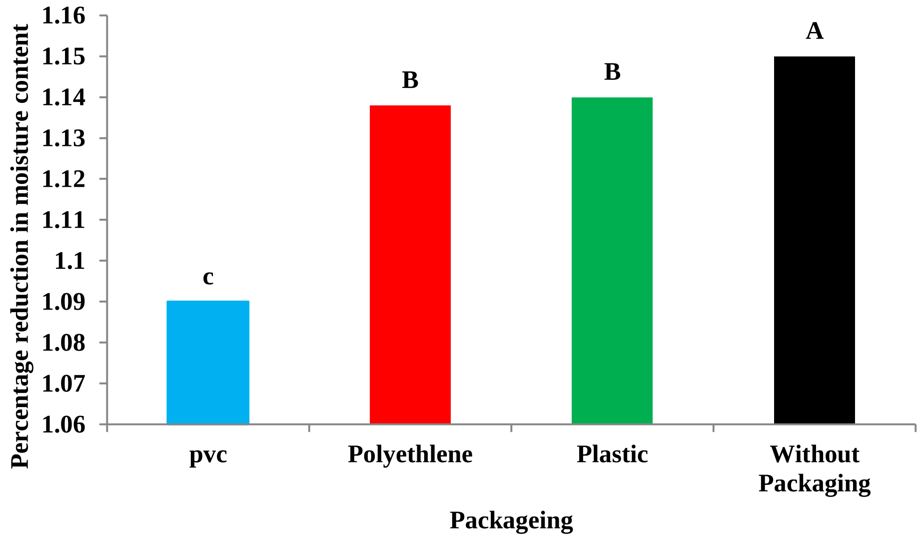


Figure 3. (b): Comparison of Mean Moisture Content under Different Packaging Conditions

PH Value

The results of the interaction effects for pH content are shown in Figure4. According to the figure, the lowest pH value was obtained for samples with blue light and PVC packaging, while the highest was for the unwrapped and unlit condition. In examining blue light under different packaging conditions, it can also be observed that there was no significant difference between polyethylene and plastic films, but a significant difference was obtained compared to the unlit condition and PVC film. Blue light and PVC packaging have played a significant role in reducing pH levels. Blue light decreases pH by stimulating the production of organic acids and enhancing the fruit's metabolic activity. PVC packaging, by restricting gas exchange and creating a closed environment, prevents the reduction of internal acidity. The combination of these two factors resulted in the lowest pH values observed in this study, which can contribute to maintaining quality and extending the shelf life of bananas. No significant difference was observed between the unwrapped condition and plastic and polyethylene films; all were grouped statistically in red and green light conditions. Moreover, all three cases with PVC film showed significant statistical differences in both light conditions. Compared to the unlit condition, a significant difference was found between the unwrapped condition and plastic film, while PVC and polyethylene films were grouped statistically, showing no significant difference. pH is an essential part of the analysis; if the pH value is below 4.4, it prevents issues with microorganisms. If the pH value is high, the time for sample analysis increases, and the difficulty in obtaining high-quality products also rises (PAULSON and STEVENS, 1974). pH primarily depends on internal metabolic processes, such as the production of organic acids, while traits like firmness and soluble solids are more influenced by evaporation, water transfer, and physical changes. Packaging has a more direct impact on these physical processes. Firmness and soluble solids are directly affected by the packaging environment. For instance, PVC packaging can limit water loss and structural changes, which have a greater impact on these traits. However, pH changes are linked to metabolic adjustments, where packaging has only an indirect effect. Kheng et al. reported that the pH of the 'Rastali' banana fruit significantly changed during the storage period from zero to five days. On the first day after ripening, the treatment reached the highest pH (6), and then, on the fifth day, the pH significantly decreased. The fruit experienced a sharp increase in respiration and ethylene production during ripening, leading to color changes and softening of banana tissue, resulting in a more acidic and sweeter fruit (Kheng et al., 2012). Khan et al. reported on the physical and chemical properties of sweet orange fruit, stating that during ripening, the color of the fruits changed, and moisture, pH, and sugar content increased, while acidity decreased during the ripening and softening of the fruit tissue (Khan et al., 2021).

Gabarakur et al. conducted a study on the effect of natural and artificial ripening factors on the pH value of selected fruits. The results indicated that the pH value increases during artificial and natural ripening, and it is recommended to consume fruits when ripe and avoid consuming organic acids related to unripe fruits (Gbarakoro et al., 2021).

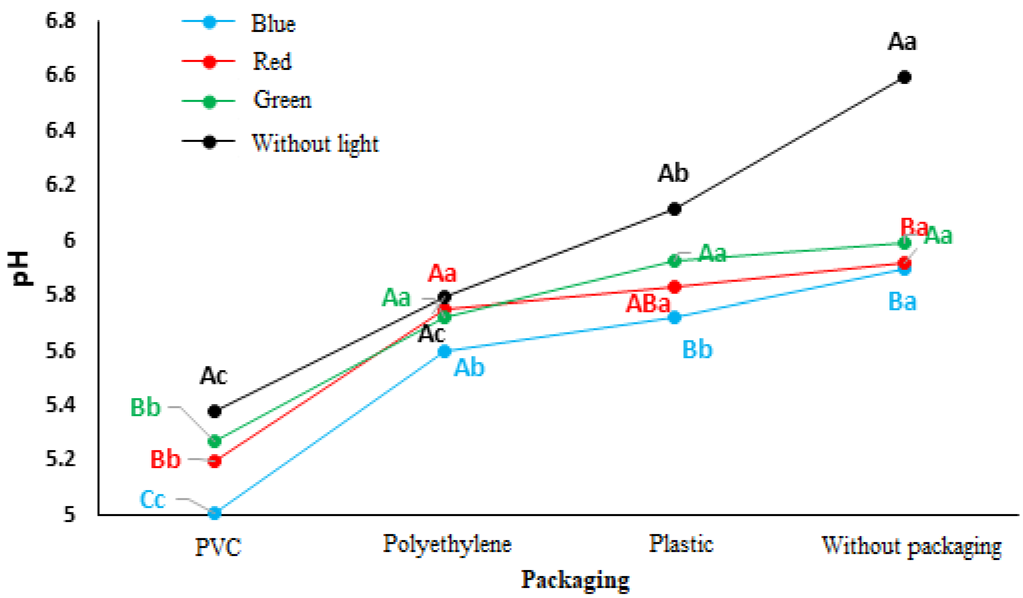


Figure 4. Interaction Effect of pH Content under Different Lighting and Packaging Conditions
Lowercase letters indicate significant comparisons under constant lighting, and uppercase letters indicate significant comparisons under constant packaging.

Percentage Change in Total Weight

According to Figure 5 (a), packaging has resulted in a lower percentage change in total weight, while the samples that were not packaged exhibited the highest percentage change in weight. Packaging plays a significant role in reducing water loss in post-harvest bananas. Packaging materials like polyethylene and PVC films act as barriers against moisture and gas exchange. These materials reduce transpiration and evaporation, maintaining relative humidity around the fruit and preventing internal moisture loss. Additionally, packaging limits excessive airflow around the fruit and provides a more stable temperature and humidity environment, which contributes to minimizing water loss and enhancing the fruit's shelf life. One reason that can be provided for this result is that packaging film has reduced transpiration, thereby preserving more moisture in the fruit and retaining a more significant amount of weight. Additionally, in Figure 5 (b), regarding the illumination level, the highest percentage change in total weight occurred when no illumination was applied. The illumination has improved the preservation of the percentage change in total weight in the fruit, leading to significantly lower percentage change values. Packaging reduces evaporation and preserves moisture by acting as a physical barrier against gas and water vapor exchange. Materials like polyethylene and PVC films, due to their specific properties, have low permeability to water vapor, which decreases transpiration and retains more moisture within the fruit. Additionally, packaging can create a microclimate with high relative humidity around the fruit, further limiting evaporation and extending its shelf life. "The mechanism behind reduced evaporation through packaging is related to the permeability properties of the packaging materials. Polyethylene and PVC films, with low water vapor permeability, minimize excessive transpiration and can create a microclimate with high relative humidity around the fruit. These factors contribute to reduced evaporation and improved fruit quality and shelf life.

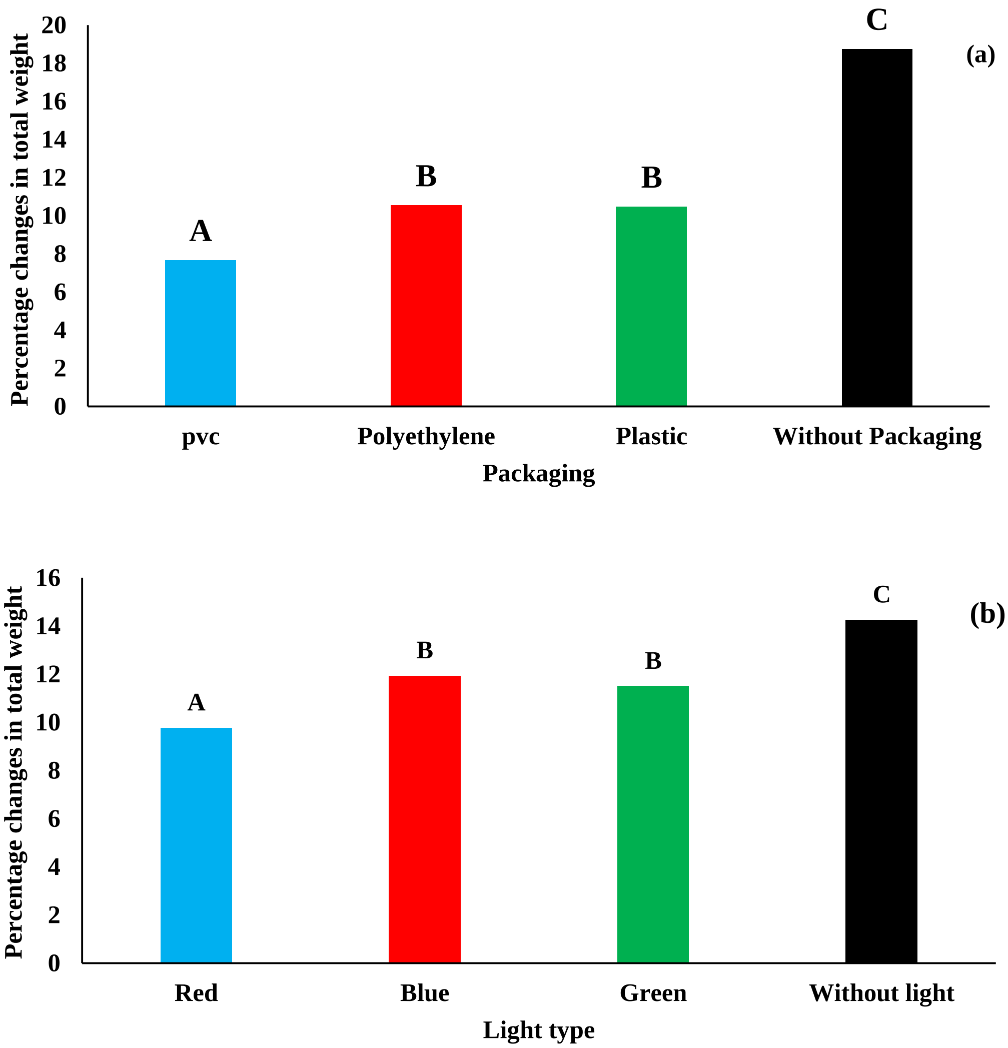


Figure 5. (a):Comparison of Mean Percentage Change in Total Weight for Different Packaging (b): Comparison of Mean Percentage Change in Total Weight under Different Illumination Conditions

Soluble Solids

The results of the interaction effects of illumination and packaging on soluble solids are shown in Figure 6. According to the figure, the highest amount of soluble solids was found in samples kept in the dark and not packaged. When comparing the different types of illumination, it can be stated that for blue light, no significant difference was observed between the unwrapped state and the plastic film, and the PVC and polyethylene films also showed no significant differences. However, the use of PVC film resulted in lower soluble solids. In Figure 6, lowercase and uppercase letters are used to indicate statistically significant differences in the groupings. Lowercase letters represent statistical differences among various illumination conditions within a specific type of packaging, while uppercase letters indicate statistical differences among different packaging types under a fixed illumination condition. This approach facilitates multiple comparisons and highlights which groups exhibit statistically significant differences.

For illumination with red LED lights, no significant differences were found between the three types of packaging films; however, the use of packaging film compared to the unwrapped state resulted in lower amounts of soluble solids, with the use of PVC film also yielding less soluble solids in this illumination. The reduction in soluble solids in packaged fruits can be attributed to decreased respiration and metabolism due to restricted gas exchange. Furthermore, blue light reduces the activity of the amylase enzyme, limiting the conversion of starch into sugars, thereby contributing to lower concentrations of soluble solids. Similar results were obtained for green light illumination, mirroring the findings from red illumination. According to the figure, the packaging had a more significant effect in the unilluminated state, and the use of PVC film yielded the lowest amounts of soluble solids. Differences among the three types of packaging films compared to each other and the unwrapped state were observed. When comparing illumination in polyethylene packaging, a significant difference was noted between the unilluminated state and illumination with LED lights. However, no significant difference was observed between red and green lights. The green illumination grouped significantly between the unilluminated state and illumination with red LED lights, while blue illumination belonged to a different statistical group regarding these factors. The same results were obtained for PVC packaging. In the unwrapped state, the difference between blue illumination and the other used LED lights was more significant, and just like with PVC packaging, green LED illumination grouped statistically between red and unilluminated conditions. The sugars and their impact on the taste and flavor of fruits are measured in various ways. These include total soluble solids (TSS), the ratio of TSS to titratable acidity, and the total sugar index (TSI), which are three standard methods. TSS is a refractometric index indicating the percentage of soluble solids in a solution. TSS reflects the dry matter content and is inversely related to fruit size (Beckles, 2012). The total solids content in fruits determines their maturity index. An increase in total soluble solids (TSS) in fruits indicates an acceleration in the ripening process. A decrease in TSS content suggests a slowdown in ripening and an increase in shelf life (Nassarawa et al., 2021). In this research, Tovar et al. stated that blue, green, and red LEDs in blueberries prevented the maximum increase of soluble solids during post-harvest storage (Taulavuori et al., 2017). Odetayo et al. conducted a study on the effect of nanoparticle-enriched coatings on the shelf life of Cavendish bananas. The results were that banana fruit with a combination of edible coating and chitosan nanoparticles had a lower respiration rate, and this combined treatment also maintained the most important fruit quality parameters, including soluble solids, skin color, and fruit firmness, with the highest quality (Odetayo et al., 2022).

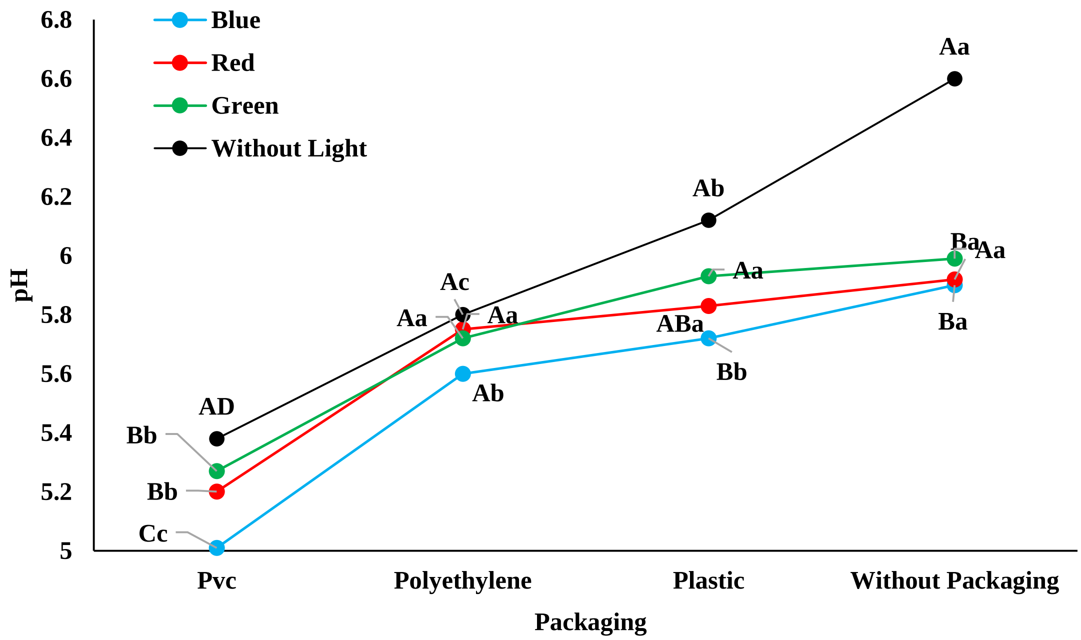


Figure 6. Interaction Effect of Total Soluble Solids under Different Illumination and Packaging
Lowercase letters indicate significant differences in constant illumination, while uppercase letters indicate significant differences in constant packaging.

CONCLUSIONS

In general, illumination and packaging serve as two critical factors in protecting fruits and enhancing the shelf life of their quality attributes. These two factors can significantly influence the physical and chemical characteristics of fruits. In the case of bananas, blue light illumination, as a lighting method, reduces the content of total soluble solids. Illumination can influence the percentage change in weight by affecting the fruit's physiological processes, including evaporation and moisture retention. Blue light, with its effects on reducing respiration and transpiration, may lower water loss and thus prevent weight reduction in fruits. This effect could be linked to regulating stomatal activity and minimizing water loss. Additionally, blue light, by delaying ripening and reducing the rate of metabolic reactions, can enhance the fruit's shelf life and help maintain more weight.Regarding the physical attributes of bananas, the percentage of weight changes and firmness are also affected by illumination and packaging. For example, blue illumination, combined with PVC film packaging, can help maintain the firmness of the fruit and prevent excessive changes. Overall, using appropriate illumination and packaging methods can significantly improve bananas' quality attributes and shelf life.

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