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Research article

Color and Firmness Quality Changes of Java Apple During Postharvest Transportation and Storage

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Abstract

Keywords

java apple;
packaging;
quality;
vibration;
transportation

Transportation vibration adversely affects fresh produce during transportation. In addition, storage temperature affects the quality of fresh commodities. The physical changes in Java apples during transportation and storage were evaluated in this study. Java apples were transported from local farms to wholesale markets (180 km). Java apples were stored at room temperature (28°C) for six days. Physical qualities such as weight loss and firmness of the Java apple samples were evaluated. The RGB image acquisition system was used to assess changes in the color of the Java apple. The vibration showed that more than 70% of the acceleration occurred between 220-290 cm/s^2 in the vertical and horizontal directions during transportation. Analysis showed that physical qualities, such as weight loss and firmness, were strongly affected by the packaging used, vibration during transportation, and storage temperature. The weight loss and reduction in firmness was highest in Java apples transported using wholesaler packaging (packaging A). The lightness, yellowness, and hue values decreased significantly because transportation vibration was relatively high, and the Java apples were stored at room temperature. Redness, total color difference, and color index increased significantly in Java apples that were transported using package A and stored at room temperature. The results showed that the use of transportation packaging affected changes in the physical quality of Java apples. Packaging A generally increase in weight loss, hardness, and changes in fruit color than other packaging types.

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1. Introduction

Postharvest handling of fruit is very important as it has a direct impact on fruit quality, shelf life, and economic value [1]. Appearance and taste are factors that consumers value highly when assessing the quality of fresh produce [2]. For this reason, the quality attributes of fresh produce, including firmness, freshness, size, and color, must align with international standards in order to cater to the market demands [3]. Postharvest handling has a significant impact on the quality and storage of agricultural produce [4]. Improper postharvest handling can diminish the quality of fruit products and lower their selling price [5]. This includes the transportation of fresh products from farmers to markets or consumers during the postharvest period [6]. However, the majority of existing literature has primarily focused on impacts associated solely with the product [7]. Transportation [8], storage [9], and harvesting [10] play significant roles in determining fruit quality. Inadequate management of transportation leads to decreased post-harvest yields and substantial economic losses [11]. Factors such as poor road conditions, surrounding environment, poor transportation, insufficient transportation practices, packaging issues, as well as the mechanical and physiological aspects of fresh produce, contribute to postharvest losses during transportation [12, 13]. Mishandling fresh produce during transportation results in considerable potential damage and mechanical injuries, particularly on poorly maintained roads [14]. This, in turn, amplifies losses throughout the supply chain.

Lu *et al*. [15] demonstrated that considerable damage to agricultural produce such as fruits and vegetables resulted from vibrations generated by vehicles during late-stage transportation. This issue is a primary challenge frequently faced by farmers later in the supply chain [16]. Transport distance is a factor that correlates directly with vibration levels. Longer transportation distances result in higher vibration levels experienced by fresh produce [17]. The occurrence of significant damage due to elevated vibration levels during transit was observed in grapes [18] and bananas [19]. In tomatoes, rapid enzymatic and metabolic processes induced by extended transport times led to mechanical damage, consequently reducing the market value [20]. Vibration during transportation can lead to rapid degradation [18] and induce physical change in agricultural products, thereby affecting color and firmness [21]. Numerous studies have investigated variations in physical attributes that occur during the transportation process for various products including oranges [22], grapes [23], strawberries [24], and mangoes [25]. Mangoes subjected to high levels of vibration exhibited reduced firmness compared to those exposed to no vibration [26]. Xu *et al*. [27] reported color changes in vibrated samples of broccoli after two hours vibration.

The Java apple (*Syzygium aqueum*) is popular within Indonesia and beyond, owing to its comprehensive nutritional profile that includes calories, minerals, and vitamin C, which contribute to the enhancement of the body's immune system [28]. Furthermore, its aesthetically pleasing skin hue and delicious sweet and crisp flesh serve as alluring factors that entice consumers to make purchases. Characteristics including color, size, shape, firmness, and fruit weight serve as quality indicators that wield influence over marketing strategies [29], thereby exerting an impact on consumer decision-making processes [30]. The Java apple stands out as a delicate product when compared to other fruits as it is particularly susceptible to damage from factors such as temperature variations, vibrations, and impact loads during transportation. Furthermore, packaging containers contribute to the softening of the fruit's flesh and the attenuation of its savory taste [31].

The Java apple is a fruit characterized by its high water content, which influences the challenges associated with managing the fruit during storage. Limited research has been conducted on the real-time effects of transportation vibrations and the development of various packaging models for Java apples. Such work is needed to address crucial issues related to post-harvest losses and the perishable nature of these commodities. Therefore, the impact of vibrations generated during road transportation on the quality of Java apples was investigated using three different packaging models. The study encompasses assessments of firmness, color, and weight during the storage period.

2. Materials and Methods

2.1 Packaging formats

2.1.1 Format of packaging A

A total of 84 Java apples were packed using corrugated paperboard in package A (Figure 1a). Dimensions (length × width × height) of Package A were 520 x 380 x350 mm. The cargo density of Packaging A is 4253,16 fruits/cm^3, density of packaging in this study was measured using method from Iswahyudi *et al.* [28].

2.1.2 Format of packaging B, C and D

Packages B, C, and D (Figures 1b, 1c and 1d) were designed to package Java apples in this research. As shown in Figure 2, corrugated paper board was BC flute and RSC (Regular Slotted Container) type packaging, with outer dimensions: 357 × 217 × 216 mm, and internal dimensions: 345 × 205 × 204 mm). Some differences existed in the packaging treatment: packaging B lacks layered coverage, Packaging C incorporated a layer of PU foam (net foam), and Packaging D involved a layer of 32 thick paper. The packing density measures 2278.48 fruits/cm^3, allowing for an average fruit capacity of 4.5-5 kg.

2.2 Field experiment

To ascertain the impact of vibration and the duration of post-transportation storage on the quality of fresh produce, a sum of 50 cartons of RSC (Regular Slotted Container) type measuring 357 × 217 × 216 mm, were procured. These cartons contained Java apples and were sourced from a farm situated in Sampang, Indonesia. The corrugated cardboard packaging for the Java apples was subsequently transported to a wholesale market located 125 km away, utilizing an uncooled pickup truck (Model: L300, Mitsubishi, Indonesia). Subsequently, the samples underwent analysis at the Agricultural Technology Laboratory of Universitas Trunojoyo Madura. The transportation duration for each carton of Java apples was approximately 150 min, with an average vehicle speed of 100 km/h. The road conditions were favorable, and traffic congestion was minimal. The corrugated cardboard packaging for Java apples was sealed to prevent direct sunlight exposure and featured four ventilation apertures. This research was undertaken during the summer months spanning May to October.

2.3 Vibration

In this study, a vibration data logger (Model: Samsung SM-T311) with the Vibration Meter Pro Version 2.4.6 application was utilized to record vibration data acquired during transportation. The Vibration Meter featured built-in sensors on all three axes: X, Y, and Z, and provided vibration references classified based on the Mercalli intensity scale, spanning from <3.5 to >8.1 MMI (Modified Mercalli Intensity Scale). The sensor was mounted at the uppermost position within the Java apple container and oriented vertically to capture a greater magnitude of vibrations within the

Figure 1. Packaging formats to protect Java apples during road transportation: (a) Utilizing corrugated paperboard (Packaging A). (b) Employing a distinct corrugated paperboard packaging design (Packaging B). (c) Employing specialized packaging with a PU foam (net foam) enclosure (Packaging C). (d) Introducing specialized packaging featuring a cover composed of 32 gsm (grams per square meter) thick paper (Packaging D).

package. For data collection, vibration measurements were recorded at a sampling rate of 1 s during the entirety of the road journey. These vibration data were logged at various distances during transportation and expressed in Modified Mercalli Intensity (MMI) units, which were subsequently converted to units of cm/s^2. The connection between MMI and frequency, as well as amplitude, was approximated by establishing the relationship between MMI and amplitude at a constant frequency, and between MMI and frequency at a consistent amplitude. This approximation was achieved using third-order polynomial regression. The Modified Mercalli Intensity (MMI) serves as a vibration classification unit with a scale ranging from I to XII, denoting ascending levels of intensity and impact corresponding to the indicated scale. For instance, the XII scale represents the most elevated intensity and exerts the most potent impact, even leading to the destruction of objects in proximity to the vibration source. An empirical equation can be employed to delineate the connection between MMI and acceleration. Namely, $log\ a\ = 0{,}33I - 0{,}50$ where a = acceleration (cm/s^2) and I is MMI [32, 33].

2.4 Sample preparation and laboratory experiments

A total of 200 Java apple fruits, exhibiting uniform hardness, and weight (100±0.1 g), and devoid of any defects, were meticulously chosen for the research analysis. The Java apple samples were categorized into two main packaging groups: the first group utilized paper packaging, while the second group employed net foam packaging. The Java apple fruits were subsequently stored under ambient conditions of room temperature (28±1°C) and relative humidity (80±5% RH). Each storage condition comprised three distinct sub-groups. Each group consisted of three replications to facilitate multiple physical quality analyses, encompassing measurements of percentage weight loss, color variations, and firmness. These evaluations were conducted to assess postharvest alterations stemming from transportation and storage vibrations, and were carried out at intervals of every two days over a span of six days. Additionally, daily monitoring of temperature and relative humidity within the laboratory was performed using a temperature meter (Model: Thermopro TP50 Hygrometer Thermometer Indoor Humidity Monitor).

2.5 Weight loss

The weight loss (%) of Java apples, transported from a specified distance and subsequently stored at a predetermined temperature, was measured daily with an accuracy of ±0.01 g, employing an electric scale (Model: Mettler scale PM-4800). The outcomes of this study were computed as a percentage relative to the initial recorded weight of the Java apple group, dating back to the first day of the experiment.

2.6 Java apple color change

Twenty-five external color readings (for each color parameter) were collected daily from 3 Java apple samples per group using an RGB (Red, Green, Blue) image acquisition system. For this purpose, a Medium Photo Studio Box Folding Portable Photo Holder Box equipped with 20 LED Bulbs (Model: Philips Stellar Bright 20-Watt B22 LED Bulb) was utilized. This configuration was employed to encompass the entire system, thereby mitigating the impact of backscattering effects. The light source was positioned parallel to the platform containing the Java apples. Moreover, the sample images of the Java apples were captured using an RGB color camera (Model: D5100, Nikon, Thailand), which was vertically positioned at the center of the cardboard box. The camera was positioned at a distance of 0.26 m from the Java apple samples. To achieve this, the EOS Utility remote shooting software bundled with the camera was utilized to obtain images at the highest achievable resolution. The captured images were saved in JPG format. For each sample, manual placement and orientation were ensured. The Adobe® Photoshop® CS5 software was employed and expanded upon using the subsequent approach: for every image (with a resolution of 300 pixels/inch) replicated in triplicate for each fruit sample, preliminary adjustments were performed through the image menu's adjustment submenu. Specifically, the 'Level' option within the RGB channel was set to 'Auto,' and brightness was augmented by +75 units to rectify deficiencies in lighting and color rendition [34]. Subsequently, the RGB values underwent conversion to the CIEL*a*b* color space, chosen primarily for its application in food quality studies [23].

The total color difference (ΔE) signifies the extent of color alteration in the stored Java apples, as defined by equation (1). Additionally, chroma, which characterizes the intensity of the preserved color, is represented by equation (2). The hue parameter, reflecting the purity of the Java apple's color, is determined by equation (3). Furthermore, the color index (CI) (equation (4)) and the Java apple color index (COL) (equation (5)) were computed to monitor the progression of red color development in stored Java apples transported with various packaging methods. These calculations were executed according to the formula provided by Pathare *et al*. [35]:

$$\Delta E = \sqrt{\Delta a *^2 + \Delta b *^2 + \Delta L *^2} \quad (1)$$

$$Chroma = \sqrt{a *^2 + b *^2} \quad (2)$$

$$Hue = \left(\frac{b *}{a *}\right) \quad (3)$$

$$CI = \frac{a^*}{b^*} \quad (4)$$

$$C0l = \left(\frac{2000\ x\ a^*}{L^*\ x\ Chroma}\right) \quad (5)$$

2.7 Firmness

Fruit firmness was determined using a digital fruit firmness tester (Model: TA-XTplus) equipped with an Acoustic Envelope Detector (AED) device (Stable Micro Systems Ltd., Godalming, UK) [36, 37]. A suitable stainless steel cylindrical probe with a diameter of 5 mm was utilized, and penetration occurred at a constant rate of 0.01 m/s. Three samples (with 3 readings per group) of Java apples were subjected to two measurements at opposing positions on each fruit.

2.8 Statistical analysis

The data analysis was conducted utilizing analysis of variance to ascertain the impact and interaction of treatments on the physical parameters (weight loss, color, and elasticity) of Java apples. The average values were deemed significant at the 5% level of significance ($p < 0.05$). Subsequently, post hoc comparisons were performed using the Duncan's Multiple Range Test (DMRT) at a significance level of 5%, employing the Statistical Analysis Software (SAS)

3. Results and Discussion

3.1 Vibration during transportation

Vibration levels during transportation were measured in vertical and longitudinal directions. The results of acceleration values were consistent across all four packages (Figure 1). The transportation results show that the maximum acceleration (374 cm/s^2) was generated from the vertical direction, followed by the longitudinal direction (276 cm/s^2). The vertical direction gave the dominant vibration value. Figure 2 shows that more than 70% of the acceleration was recorded in the 220-290 cm/s^2. In this range, accelerated fruit transportation can have a negative effect on fruit quality and durability. Tender fruit or fruit with thinner skin is more susceptible to this damage. In general, the acceleration was observed while transportation was positively correlated with the rise in on-road miles.

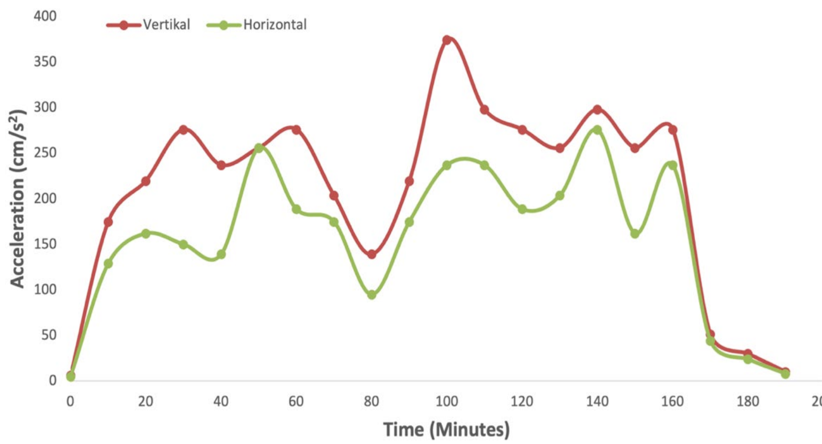

Figure 2. Acceleration interval (cm/s^2) generated during transport

The vibration response of packaged products caused by vehicles is described by vibration transmissibility [22]. Vibration transmissibility may be influenced by several causes, including elasticity and stiffness of the packing material, vehicle suspension system and vibration frequency [38]. In the context of handling fruits during transportation, high vibration transmissibility can potentially cause damage to the fruit [13, 39]. Strong and sustained vibrations can damage fruit tissues and cells, causing bruises and abrasions, thus affecting fruit weight loss, firmness, and color [40].

The force distributed to the packaged product is one of the main factors causing mechanical damage to the fruit [19, 41]. Vibration impact damage on fruit during transportation may occur due to overfilling [42]. The most common mechanical damage to fresh horticultural products is bruising [43], which reduces consumer quality and income to fruit [44].

Bruising can occur during harvest and at all stages of postharvest handling, especially during the packing, transportation, and storage process [43]. According to Iswahyudi *et al*. [28], Java apples using wholesale packaging had more than 20% of bruises compared to other packages. In line with this, Fernando *et al*. [45] stated that mechanical damage was affected by acceleration values. The occurrence of bruising may also be attributed to the static and dynamic pressures exerted on the fruit during packaging, surpassing the fruit's structural integrity [46]. The fragile skin of the Java apple makes it susceptible to impact and easily damaged, resulting in physical defects such as scratches and bruises. Zhao *et al*. [47] stated that damage to the fruit surface would accelerate fruit ripening and increase the chance of microbial spoilage.

3.2 Effect on physical quality characteristics of Java apple

3.2.1 Weight loss (%)

Weight loss, a key indicator of physiological changes, was monitored in Java apples during transportation. The weight loss percentage increased for packaging A, B, C, and D, respectively, by 40.1%, 30.3%, 24.7%, and 26.45% at 28°C (Figure 3). Over six days, all packages showed an average weight loss increase rate of 14-15%. The increase in weight loss at room temperature was not significant across all packages. Changes in weight loss during storage showed rapid physiological changes under the conditions tested. Weight loss in Java apples may affect a decrease

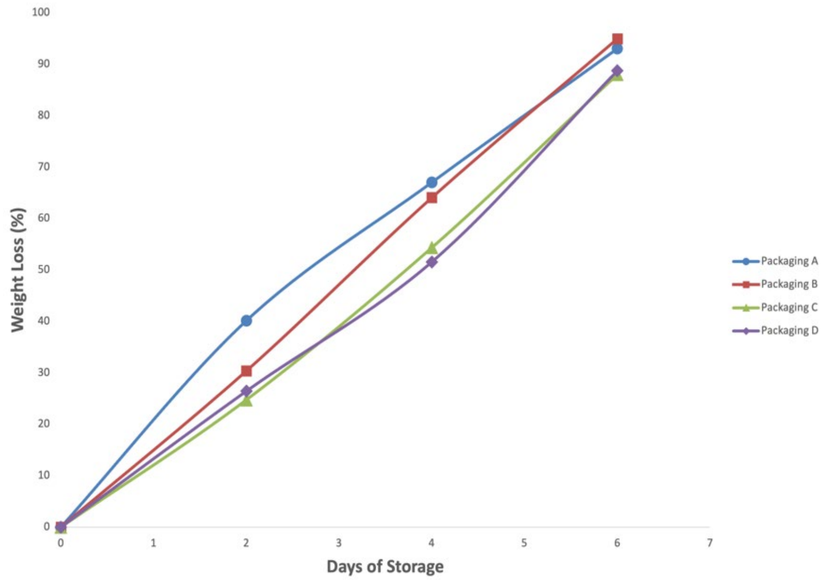

Figure 3. Weight loss of Java apple after road transportation

in overall fruit volume and size. An increase in fruit weight loss can decrease the concentration of nutrients in the fruit, including vitamins, minerals, and phytochemical compounds. This can affect the nutritional value and nutritional quality of the fruit. According to Al-Dairi *et al*. [23], storage of tomatoes at a temperature of 22°C increases weight loss during storage.

Weight loss is an important factor because it affects the price of fruit [18]. Strong vibrations can cause mechanical stress to the fruit. This stress can result in uneven pressure on the fruit cell membrane. If this mechanical stress exceeds the cell membrane's elastic limit, then membrane damage can occur. When the cell membrane is damaged, cell components such as organelles and cytoplasm can leak out of the cell or into it. This can cause disturbances in cell function and damage to the overall cell structure. Damaged cell membranes can result in increased water loss through a process called transpiration. When the cell membrane is damaged, the integrity of the structures that regulate transpiration can be disrupted, so water is more easily lost from the fruit. Increased water loss due to cell membrane damage can cause a decrease in fruit volume and weight [13]. Exposure to external vibrations results in a higher respiration rate, which causes more weight loss during storage [48]. Furthermore, Wei *et al*. [49] reported that fresh produce experienced high weight loss due to increased transport vibration, which accelerated fresh product water reduction and shrinkage due to intracellular damage. Regarding storage, Endalew *et al*. [50] stated that storage time and temperature significantly reduced Java apple weight. Storage at ambient temperature increases the weight loss of Java apples due to transpiration, respiration [51], and dehydration [52], resulting in loss of water, which causes an increase in physical barriers between fresh produce and ambient air [50].

3.2.2 Firmness

Java apple fruit firmness was significantly influenced by storage temperature and storage duration (Figure 4). Overall, the level of fruit hardness decreased drastically during the storage process. As the duration of Java apple storage increased, the level of hardness of the fruit decreased. It can be seen in Figure 1 that packaging A was a wholesale transportation package for Java apples. Packages B, C and D were new packages specifically designed for transportation; which could cause the difference in the loss of firmness of Java apples. In packaging A and packaging D, there was a decrease in firmness of 69%. Meanwhile, in packaging C and packaging B, the hardness levels decreased by 66% and 64%, respectively.

The vibrations that occur during the transportation of the fruit can potentially affect the hardness of the fruit [53]. Good fruit firmness is often associated with good fruit quality [54]. When fruit undergoes a decrease in firmness, such as becoming softer or more brittle, its appearance may also be affected [55]. Fruit that looks wilted, mushy, or visually damaged tends to have lower marketability [56]. The distribution or transportation of agricultural products can significantly impact fruit ripening and hardness [57]. Micro storage factors like ambient temperature, for example, might result in a loss of stiffness [58].

Reduced texture and firmness are linked to various factors, including turgor pressure losses, cell wall disintegration, and degradation of polysaccharides. In addition, a sharp rise in enzyme activity is due to a close relationship between the firmness condition and the fresh produce's ripening stage [48]. Adequate turgor pressure plays an important role in maintaining fruit firmness [59]. If vibration results in water loss or damage to cell membranes, turgor pressure may decrease, which in turn can reduce fruit firmness [60]. A reduction in fruit firmness indicates a decrease in fruit quality during storage [61]. Fruit packaging can protect against vibration during transportation and reduce turgor pressure on the fruit [62].

Fruit exposed to less vibration stress maintained higher firmness, according to Zhou *et al*. [63]. Pear fruit held at room temperature and subjected to long transit times softened more quickly. Moreover, Al-Dairi *et al*. [23] reported 67.80% decrease in tomato firmness during 12 days at room temperature.

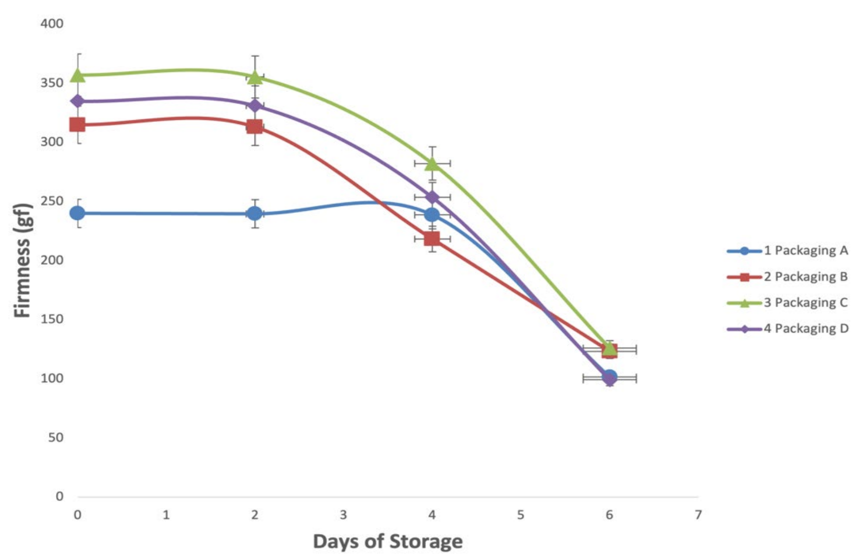

Figure 4. The firmness of Java apple

3.2.3 Color change

It can be seen in Figure 1 that packaging A is a wholesale transportation package for Java apples. Packages B, C, and D were new packages specifically designed for transportation, which can cause difference in the color change of Java apples. The Java apple's color brightness (L*) and the type of packaging (p = 0.0435), storage temperature (p = 0.0044), and storage time (p = 0.0023) all showed significant variations (Figure 5). On days 2 and 6, Java apples in package C, which was kept at a temperature of 27.5°C, displayed the most significant drop in L* value, going from 66.67 to 46.33. Java apples in package D came in second with L* values of 64.67 and 29.33 (Figure 5), respectively. Figure 5 demonstrates that storing Java apples at room temperature diminished their brilliance, which can be impacted by vibration during transportation to the point of sale. This is because of the frequent vibrations that occur when Java apples are transported over long distances, which can cause significant decreases and brightness variations according to Zhou *et al*. [63].

The decreased in lightness (L*) occurs due to high storage temperatures. High temperature can inhibit enzyme activities and quickly reduce lightness (L*) [64]. Moreover, transport vibration over a lengthy period revealed significant changes in L* when kept at room temperature, according to Zhou *et al*. [63]. The vibration events during fruit transportation may intensify the ripening process, which quickens the development of redness in the Java apple fruit [65].

The a* value was linked to the Java apple fruit's increased "redness" and decreased "greenness". The findings showed that independent variables such as storage temperature and duration impacted the red color (a*) of Java apple fruit (Figure 6). The most significant change in a* value occurred in Java apples that had been carried over a long distance and then stored at room temperature; the a* value went from -9.33 to 19.67 on the final day of storage according to La Scalia *et al*. [66]. After being transported, the Java apples packaged in package C, which had been kept at room temperature, displayed the highest level of red color development. The value went from -8 to 19.63.

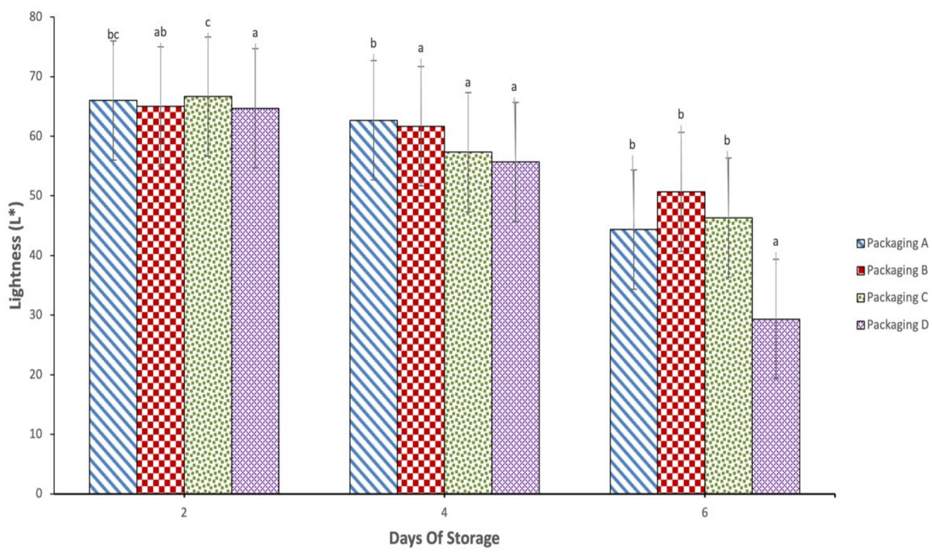

Figure 5. L* values of Java apples from four different packages stored at 28±1°C and at 80±5% RH for 6 days. Error bars represent standard error (SE) of the mean values±S.E. of 25 measurements (readings) of 3 Java apple replicates. Bars with different letters (per two days) are significantly different (p<0.05) performed by the DMRT test and numerical values of A, B, and C are p-values.

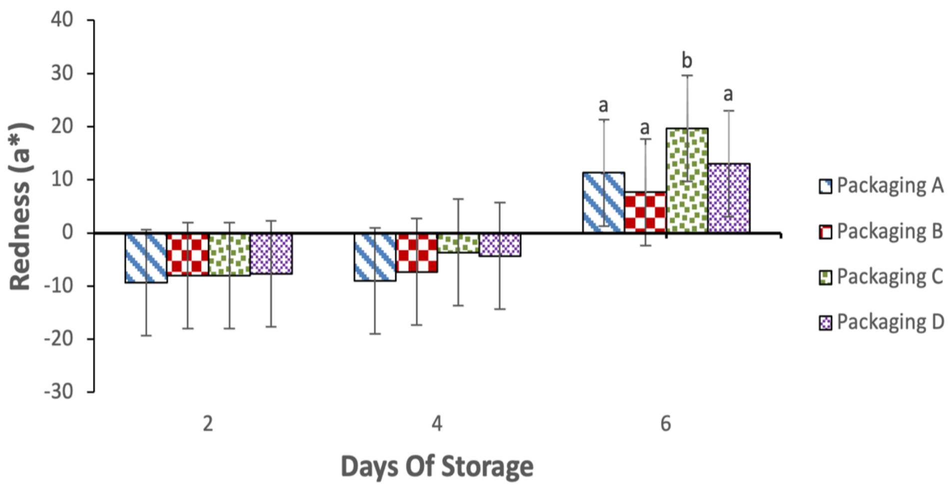

Figure 6. a* values of Java apples from four different packages stored at 28±1°C and at 80±5% RH for 6 days. Error bars represent standard error (SE) of the mean values±S.E. of 25 measurements (readings) of 3 Java apple replicates. Bars with different letters (per two days) are significantly different ($p<0.05$) performed by the DMRT test and numerical values of A, B, and C are p-values.

Fruit stored at room temperature may demonstrate increased a* values due to ethylene production and chlorophyll degradation [67]. La Scalia *et al*. [66] found that vibration length had a minor but considerable impact on the a* values of strawberries during transport. Similar findings were made by Wu and Wang [68], who discovered that tomatoes turned redder after 60 min of simulated transit when exposed to increased acceleration vibration.

Figure 7 illustrates the relationship between two variables—storage temperature and time—and four different packing types in terms of how the yellowness color of Java apple changes. The b* value of the Java apples in A, B, and D after transportation increased on day four and fell on day six. However, the treatment of package C revealed a decline in b* value throughout storage. An increase in yellowness, specifically a transition from green to a dark yellow tint [35]. The development of a red hue is mainly linked to the yellowness (b*) decrease during storage [50]. The yellowness (b*) value of fruit continuously dropped as temperature and duration rose, according to the findings of Khairi *et al*. [69].

The modification of the L*, a*, and b* values are thought to be the cause of the overall color change. The statistical analysis revealed a significant relationship between the variance in color of Java apples and the factors of transportation, packaging, and storage temperatures. (Figure 8). Due to the naturally occurring correlation between temperature and the pace of biological processes, the color of fruit held at room temperature significantly fades with time [57]. The distance traveled can influence the rise in color and high chroma after storage at room temperature [63]. The intensity (chroma) and purity (hue) of the Java apple product color is not considerably influenced by the kind of packing used; however, it is affected by the storage temperature following transportation.

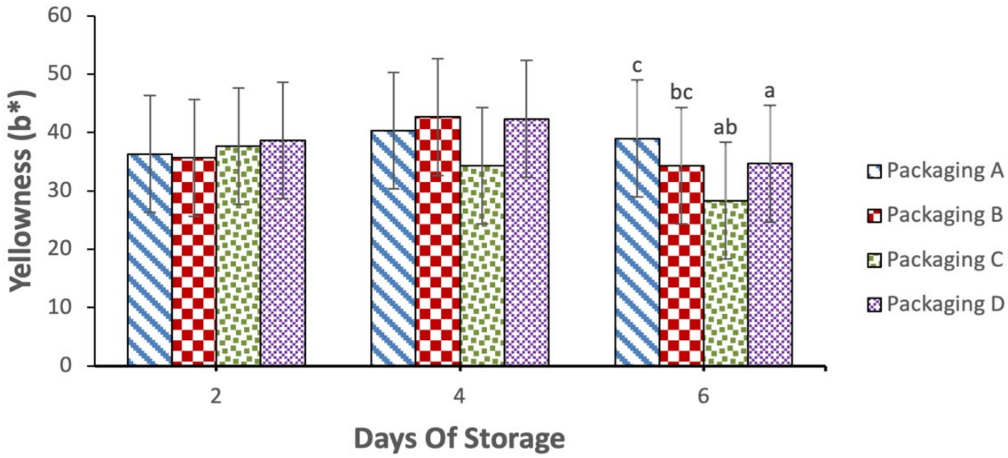

Figure 7. b* value of Java apples from four different packages stored at 28±1°C and at 80±5% RH for 6 days. Error bars represent standard error (SE) of the mean values±S.E. of 25 measurements (readings) of 3 Java apple replicates. Bars with different letters (per two days) are significantly different ($p<0.05$) performed by the DMRT test and numerical values of A, B, and C are p-values.

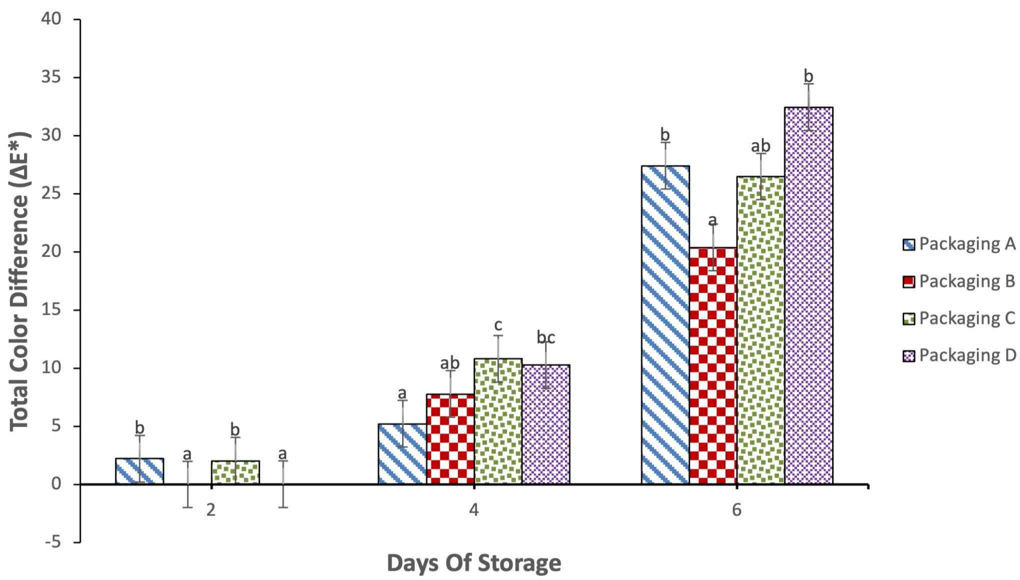

Figure 8. Total color difference (ΔE) values of Java apples from four packages stored at 28±1°C and at 80±5% RH for 6 days. Error bars represent standard error (SE) of the mean values±S.E. of 25 measurements (readings) of 3 Java apple replicates. Bars with different letters (per two days) are significantly different ($p<0.05$) performed by the DMRT test and numerical values of A, B, and C are p-values.

In line with recent studies, storage at high temperatures can impact color purity (hue) compared to low temperatures [70]. La Scalia *et al*. [66] observed that the fresh vibrated strawberry chroma values at cold storage temperature significantly decreased.

This study demonstrates a strong connection between hue values and the parameters it examined, including packing and vibration during transit (Table 1). The color value of the Java apples had a drop of 84.68% on the sixth day after its arrival, while they were stored at room temperature. The color index (CI) was statistically influenced by storage temperature and storage time. In addition, a similar scenario was observed with the Java apple color index (COL) (Table 1). A dramatic increase in CI and COL of Java apples was observed on the second day of storage at ambient temperature being transported.

Bright, fresh, and visually appealing fruit colors are generally more attractive to consumers. Fruit that has an attractive color can trigger visual interest and increase the perception of the quality of the fruit. On the other hand, unwanted discoloration, such as brown spots or discoloration, can be considered a sign of bad quality or deterioration, and can affect the marketability of the fruit. Color change in Java apples to a brownish color will reduce consumer interest.

Table 1. Chroma, hue, CI, and COL changes in Java apples stored at ambient temperature for 6 days. Error bars represent standard error (SE) of the mean values±S.E. of 25 measurements (readings) of 3 Java apple replicates. Bars with different letters (per two days) are significantly different (p<0.05) as performed by the DMRT test.

Color Quality Parameters	**Packaging**	**Days of Storage**		
		2	**4**	**6**
Chroma	Packaging A	37,51±0.23^{ab}	41,32±0.23^{b}	40,61±0.35^{b}
	Packaging B	36,55±0.28^{a}	43,29±0.22^{b}	35,17±0.56^{a}
	Packaging C	38,50±0.53^{bc}	34,52±0.57^{a}	34,48±0.30^{a}
	Packaging D	39,41±0.37^{c}	42,55±0.45^{b}	37,02±0.20^{ab}
HUE	Packaging A	-1,31±0.01^{b}	-1,35±0.03^{b}	1,28±0.05^{b}
	Packaging B	-1,35±0.01^{a}	-1,40±0.05^{ab}	1,35±0.11^{b}
	Packaging C	-1,36± 0.15^{a}	-1,46±0.04^{a}	0,96±0.40^{a}
	Packaging D	-1,37±0.14^{a}	-1,46±0.05^{a}	1,21±0.20^{ab}
CL	Packaging A	-0,25±0.07^{b}	-0,22±0.10^{a}	0,29±0.05^{b}
	Packaging B	-0,22±0.20^{ab}	-0,17±0.18^{ab}	0,22±0.01^{a}
	Packaging C	-0,21±0.01^{a}	-0,10±0.02^{b}	0,69±0.04^{d}
	Packaging D	-0,19±0.27^{a}	-0,10±0.23^{b}	0,37±0.05^{c}
COL	Packaging A	-7,53±0.17^{a}	-6,95±0.05^{a}	12,58±0.02^{b}
	Packaging B	-6,73±0.14^{b}	-5,49±0.37^{b}	8,60±0.03^{a}
	Packaging C	-6,23±0.16^{b}	-3,70±0.43^{c}	24,61±0.03^{c}
	Packaging D	-6,01±0.14 ^{b}	-3,65±0.05^{c}	23,94±0.02^{c}

4. Conclusions

The results of this study indicate that the vibrations generated from transportation significantly affected the packaging used and the physical quality parameters of Java apples. Packaging design and storage temperature were also found to significantly impact physical quality attributes such as weight loss, hardness, and color. Among all the packages studied, packaging C generally inhibited the increase in weight loss, hardness, and changes in fruit color. Packaging C was more effective than the others because of the special design of transportation packaging with a PU foam (net foam) cover. In addition, storage at ambient temperature conditions (28°C) accelerated all these quality changes during the 6-day storage period. The limitation of this research was the use of only one type of transportation and storage at room temperature. However, the use of other modes of transportation as well as storage of fruit at lower temperatures is suggested for further research. The results of this study can help the industrial sector avoid all critical problems while transporting and storing fresh produce. In this way, adequate packaging, facilities for transit and handling, and storage temperature management must be in place to reduce all expected damage from transport and storage.

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