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Proceeding Paper

The Contribution of Impact Damage to the Quality Changes of Stored Banana Fruit †

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Abstract: Loss in fresh fruit mainly occurs due to their susceptibility to mechanical damage during the postharvest supply chain. Mechanical damage can reduce the quality of fresh produce during handling, especially if not consumed directly, which is a critical food safety challenge and economic issue. Therefore, food security and agricultural efficiency requires vital action to minimize such losses. Possible mitigation includes reducing the occurrence of damage by investigating the effects of the application of external forces during the handling of fresh fruit. Hence, this study aims to evaluate the local banana quality changes affected by impact energy and forces resulting from simulated handling practices during storage at three different temperature conditions for 12 days. By using the pendulum technique, local banana fruit were damaged by low (0.074 ± 0.003 J), medium (0.160 ± 0.008 J), and high (0.27 ± 0.016 J) impact forces. Fruit from each impact energy level were divided into groups and stored at 5 °C, 13 °C, and 22 °C. The changes in weight loss, firmness, and color (lightness (L^*) and redness (a^*)) were evaluated. The rate of transpiration was also determined. The study results showed a gradual reduction in weight loss percent in high, medium, and low impact bruised bananas under all storage conditions. The highest recorded weight loss percent was found in high impact (0.27 ± 0.016 J) injured banana fruit (19.55%) stored at 22 °C after 12 days of storage. Storage at 22 °C and damage from the highest impact energy accelerated the increment of the transpiration rate (2.031 mg kg^{-1} s^{-1}) of banana fruit on day 12 of storage. Furthermore, high impact bruising and storage at ambient temperature condition resulted in 76.69% firmness reduction in banana fruit after 12 days of storage. Storage at 13 °C showed the fewest changes in visual properties, such as color, of impacted bananas. The color parameters (lightness and redness) were statistically influenced ($p < 0.05$) by impact level, storage temperatures, and storage duration. Chilling injuries were highly observed after day 4 of storage in banana fruit stored at 5 °C in all damaged fruit. Two of the most critical factors that reduced the incidence of severe damage due to mechanical damage were: (1) storage management, and (2) increasing people's awareness about the main mechanism of this problem and how to reduce it.

Keywords: mechanical damage; impact energy; quality; storage; transpiration rate

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1. Introduction

Banana is one of the most highly produced and consumed fruit globally. It contains various types of nutrients, unique flavors, and is rich in beneficial ingredients, with several health functions such as constipation prevention, oxidation resistance, depression resistance, etc. [1]. Banana is a climacteric perishable fruit, making it highly prone to postharvest losses such as handling and transportation during the postharvest supply chain [2]. Mechanical damage is the main cause of postharvest losses in bananas [3]. During postharvest operations, fruit may be damaged through several physical effects such as dropping, packing pressure, squeezing, etc. Bruising that primarily occurs during handling and other postharvest processes is the most prevalent type of mechanical damage for most fresh produce [4]. Mechanical injury resulting from impact damage to fruit is more severe than compression and vibration. Impact damage can occur when fruit falls with a particular and sufficient force against another fruit or surface [5].

Mechanical damage has the potential to reduce fresh produce quality, which leads to a decrease in market value. This makes mechanical damage a significant issue in the fresh produce industry [6]. Mechanical damage can influence the physical structure and chemical properties of fresh produce [7]. In bananas, mechanical damage can reduce the shelf-life and visual appearance of the fruit. Banana fruit subjected to bruising/mechanical damage show different physical and physiological alterations, including an increased ripening rate, which is attributed to respiration rate, ethylene production rate, mass loss, and enzymatic activity increment [3]. Bruising increases firmness loss and total color change, and in pears, reduces the fruit's lightness [8]. Bruising increases the weight loss and red color development of tomatoes [9]. In addition, mechanical damage has been shown to increase the respiration rate, sugar, and acidity of pomegranate fruit [10]. In recent years, many studies have been conducted to identify the relationship and enormous negative contribution between impact force and resulting damage of fresh produce/commodities. Drop and or pendulum tests are typically designed and applied methods used to investigate the influence of mechanical damage on injured fresh produce [11]. Therefore, this study applied the pendulum test by dropping a weight of a given mass and shape from three different heights (angles) onto fixed banana fruit, and determined the contribution of the impact to quality changes of bananas stored under three different storage conditions for 12 days.

2. Methods

2.1. Plant Sample and Impact/Storage Treatments

Banana fruit (cv. Malindi) were obtained from a local market and transported to Postharvest Technology Laboratory at Sultan Qaboos University, Oman. Mature, well-colored, similar weight (85.75 ± 3.91 g) bananas, free from any damage, were selected for the study. In this research, a pendulum impactor [12] with a 68 cm arm length was used to study the effect of impact damage on bananas. To create different levels of energies, fruit (cheek side) was hit by a known weight (97.3 g) connected to the pendulum arm from three different angles, 30°, 45°, and 60°, representing low (0.074 ± 0.003 J), medium (0.160 ± 0.008 J), and high (0.27 ± 0.016 J) impact energies (levels), respectively. The test was carried out on a total number of 162 banana fruit, thus, 54 bananas were utilized for each impact level. After each impact, the damaged area was marked by a marker. Later, impacted banana fruit from each impact level were equally divided into further groups and stored at 5 °C, 13 °C, and 22 °C for 12 days, to study the effect of impact bruising, storage temperatures, and storage duration on the weight loss, transpiration rate, firmness, and color, at two day intervals. Three fruit were analyzed before impact and storage for day 0 analysis.

2.2. Quality Analysis

2.2.1. *Weight Loss* % and *Transpiration Rate* (TR_m)

A batch of three bananas from each treatment was weighed on the first day of analysis. The *weight loss* % was determined on days 2, 4, 6, 8, 10, and 12, relative to the first day. An electronic weight balance (Model: GX-4000, A & D Company, Tokyo, Japan) was used to conduct the measurement of weight loss %. The *transpiration rate* was calculated per unit of initial banana fruit mass in mg kg^{-1} s^{-1} by Equation (1) [13].

$$TR_m = \frac{(m_i - m_t)}{t \times m_i} \times 10^6 \quad (1)$$

where m_i (kg) is the initial banana fruit mass, and m_t is the mass of banana fruit at time t (s).

2.2.2. *Firmness*

A digital fruit firmness tester (Model: FHP-803, L.L.C., Franklin, ME, USA) was applied at two-day intervals to determine the force required to puncture two sides of a banana.

2.2.3. Peel Color

A total of 15 external readings were taken from three (n = 3) bananas per treatment (group) per day, using the image acquisition system described by Al-Dairi et al. [14]. The captured image was processed using ImageJ software (v. 1.53, National Institute of Health, Bethesda, MD, USA), and the obtained RGB color values were converted to CIE$L^*a^*b^*$ color coordinates. This study evaluated the L^* value that denotes for lightness and darkness, and a* value for redness and greenness.

2.3. *Statistical Analysis*

The resulting data were analyzed by analysis of variance (ANOVA) at 5% significance level using SPSS 20.0 (International Business Machine Crop., New York, NY, USA). The values were expressed in mean ± SD.

3. Results and Discussion

3.1. *Weight Loss % and Transpiration Rate*

The weight loss % was significantly affected by all studied factors such as impact level (p = 0.00042), storage temperature (p = 0.00052), and duration (p < 0.00001) (Table 1). High (19.55%) and medium (19.35%) impact levels increased the % of banana fruit weight loss after 12 days of storage at 22 °C (Figure 1A). Storage at 5 °C reduced the weight of low, medium, and high impact level bruised bananas by 8.64%, 10.40%, and 10.61%, respectively, after 12 days of storage, while it decreased by 10.90%, 12.03%, and 12.26% on bananas bruised by low, medium, and high impact levels at 13 °C, respectively. This was mainly attributed to alterations in the permeability of the cell wall and tissue damage in the banana fruit, resulting in higher moisture content reduction through the fruit's cell wall. In addition, mechanical injuries that cause bruising can cause severe dehydration, thus, reducing the weight of bruised/damaged bananas [3].

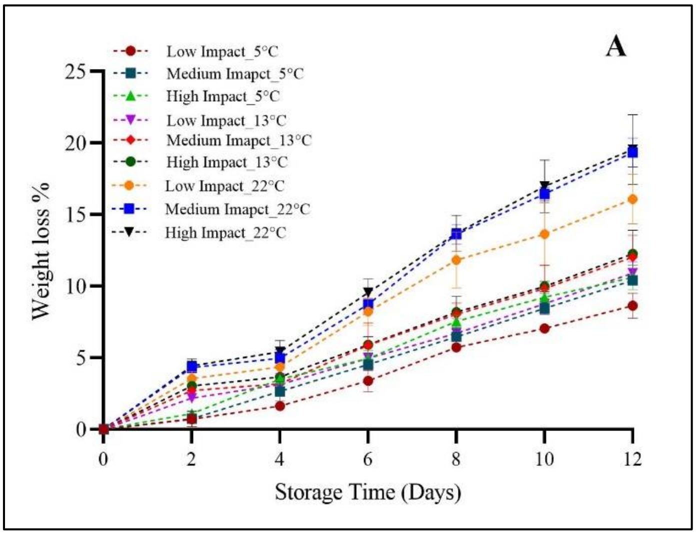

Figure 1. *Cont.*

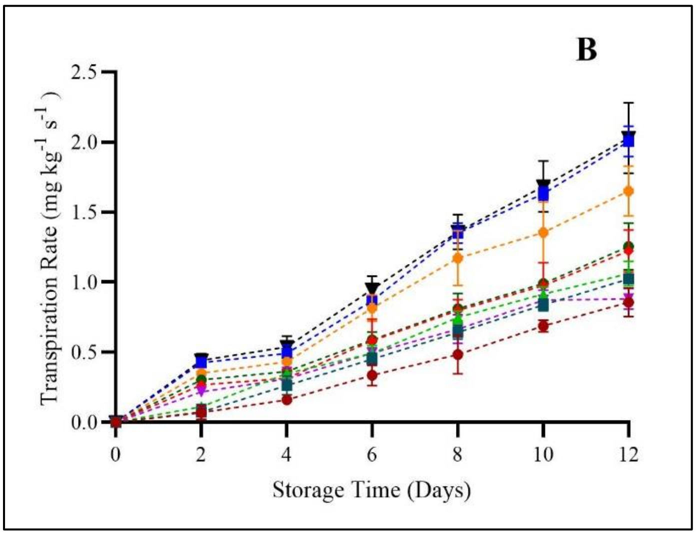

Figure 1. *Weight loss* % (**A**), and *transpiration rate* (mg kg^{-1} s^{-1}) (**B**), of banana fruit bruised at low, medium, and high impact energy levels and stored 5 °C, 13 °C and 22 °C storage conditions for 12 days. Error bars represent standard deviation (SD) of the mean values ± S.D. of 3 replicates.

Table 1. The statistical analysis of *weight loss %*, *transpiration rate* (mg kg^{-1} s^{-1}), *firmness* (*N*), lightness/darkness (*L**), and redness/greenness (*a**) of banana fruit during 12 days at three different temperatures (5, 13, and 22 °C) and bruised from three impact levels. Data were subjected to analysis of variance (ANOVA) (factor A; impact level, factor B; storage temperature, and factor C; storage duration).

Parameters	Statistical Analysis	Impact Level (A)	Storage Temp. (B)	Storage Duration (C)	A × B	A × C	B × C	A × B × C
Weight Loss %	*p*-value	=0.00042	=0.00052	<0.00001	=0.04429	=0.00106	<0.00001	=0.94626
	f-value	15.88104	15.14881	24.36446	2.87999	4.35527	56.72961	0.56676
	df	2	2	6	4	12	12	24
Transpiration rate	*p*-value	=0.00123	=0.00074	<0.00001	=0.30892	<0.00001	<0.00001	=0.96873
	f-value	12.31047	13.94133	20.52526	1.27074	7.63538	66.79782	0.51673
	df	2	2	6	4	12	12	24
Firmness	*p*-value	=0.00009	=0.00001	=0.00142	=0.03383	=0.07959	=0.00000	=0.30915
	f-value	21.90207	30.72126	7.52460	3.11297	1.94735	48.07265	1.14224
	df	2	2	6	4	12	12	24
*L**	*p*-value	=0.01822	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	=0.00001
	f-value	5.69608	112.57035	42.52026	16.24696	10.50726	36.28896	3.236100
	df	2	2	6	4	12	12	24
*a**	*p*-value	=0.00056	=0.001158	=0.00000	=0.06344	=0.49881	=0.00000	=0.07916
	f-value	17.30803	14.32833	69.93772	2.65090	0.96786	34.62060	1.492324
	df	2	2	6	4	12	12	24

Similarly, the analysis of variance showed that the storage conditions of temperature, impact bruising, and storage time significantly affected the transpiration rate (TR_m) of banana fruit ($p < 0.05$) (Table 1). The transpiration rate per unit mass (TR_m) was in the range of 0.073 to 2.031 mg kg^{-1} s^{-1} for all bruised banana fruit (Figure 1B). The highest value observed was on day 12 for high-impact bruised bananas stored at 22 °C, which resulted in increased weight loss %. The rapid ripening due to temperature and impact was critical for all bruised bananas, mainly those stored at 22 °C. The results confirmed what was previously discussed by [15], where banana fruit are highly prone to water loss because of transpiration from the fruit's peel under stored conditions. Higher transpiration rates lead to wilting and increased bruising.

3.2. Firmness

Impact bruising, storage temperature, and storage duration statistically ($p < 0.05$) influenced the firmness of bruised banana fruit (Table 1). With storage time, the largest decrease in *firmness* of bruised banana fruit, under all storage conditions, was observed for fruit stored at 22 °C damaged at a high impact level (Figure 2). For instance, as the impact level increased, the firmness tended to reduce for low (66.06%), medium (76.40%), and high (76.69%) impact level bruised banana fruit stored at 22 °C, compared to those stored at 13 and 5 °C, respectively. *Firmness* reduction could be attributed to changes in the content of structural starch, polysaccharides, and pectin substances associated with banana fruit, which increase significantly as storage temperature and bruising impact increase [16]. Li et al. [17] found that bruising is a vital parameter leading to the decrease in the firm state of pear due to polysaccharides activity increment. In addition, Pathare et al. [18] revealed that bruised pears from a higher drop height caused higher *firmness* reduction in pear fruit, particularly at ambient (22 °C) storage condition. Opara et al. [19] stated that *firmness* alterations toward softness during the ripening processes were expedited due to high storage temperature conditions.

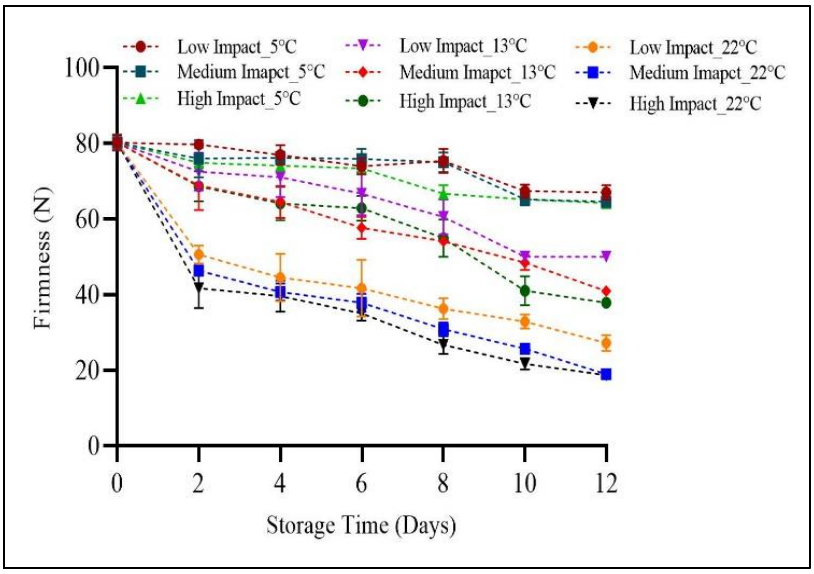

Figure 2. *Firmness* (*N*) of banana fruit bruised at low, medium, and high impact energy levels and stored 5 °C, 13 °C and 22 °C storage conditions for 12 days. Error bars represent standard deviation (SD) of the mean values ± S.D. of 6 replicates.

3.3. Color

Color is one of the primary visual attributes that highly affect consumers' choices at the market level [14]. The change in L^* of bruised banana fruit over 12 days was statistically affected by impact level ($p = 0.01822$), storage temperature ($p < 0.00001$), and storage temperature ($p < 0.00001$) (Table 1). Color lightness reduction was higher in banana fruit impacted at higher impact energy and stored at 5 °C and 22 °C, respectively (Figure 3A). The L^* value decreased from day 4 and day 6 in all bruised bananas stored at 5 °C and 22 °C, respectively. However, bruised bananas from all impact levels and stored at 10 °C showed a gradual increase of 40.78% after 12 day of storage.

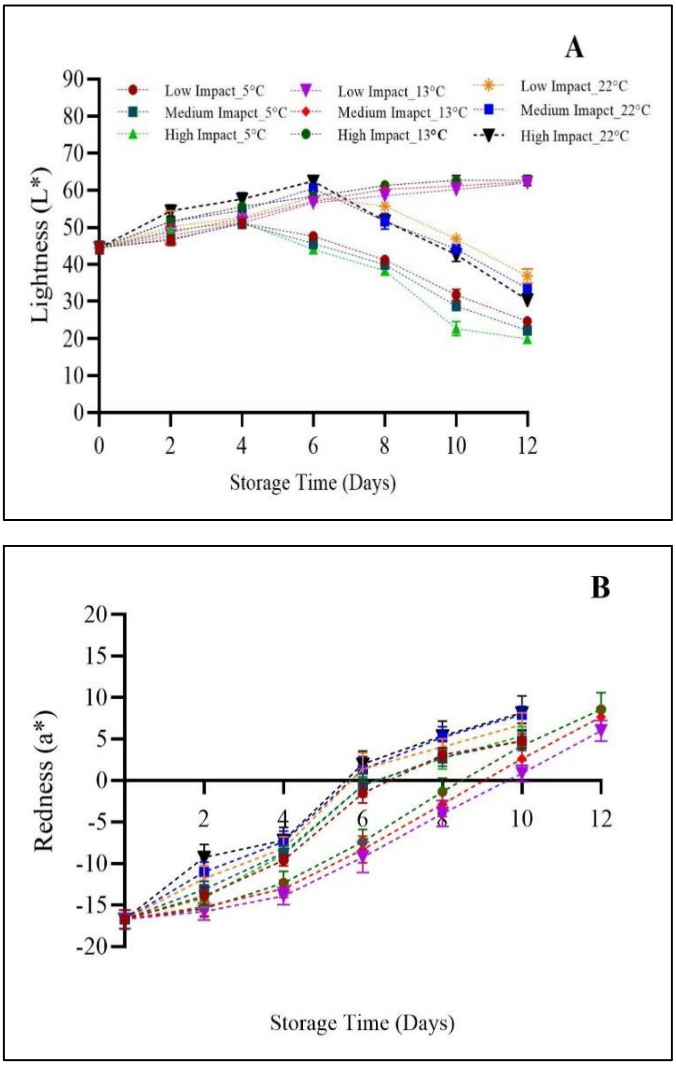

Figure 3. Lightness (L^*) (**A**) and redness (a^*) (**B**) of banana fruit bruised at low, medium, and high impact energy levels and stored 5 °C, 13 °C and 22 °C storage conditions for 12 days. Error bars represent standard deviation (SD) of the mean values ± S.D. of 15 readings of 3 replicates.

The redness (a^*) results differed ($p < 0.05$) significantly between the investigated factors (impact bruising, storage temperature, and storage duration) (Table 1). The a^* value increment was highly observed in all bruised banana fruit (from low, medium, and high impact levels) stored at 22 and 5 °C, respectively. As shown in Figure 3B, the a^* value measurements stopped on day 12. The a^* value development slightly increased in all damaged banana fruit stored at 10 °C until the last day of storage. Based on visual observations, the ideal storage temperature used to store bruised banana fruit was 10 °C. Storage at 5 °C showed chilling injuries after 3 days following bruising. Storage at 22 °C accelerated the process of ripening and increased bruise expansion on fruit. This was mainly attributed to carotenoid synthesis and chlorophyll degradation in the banana fruit peel after storage, thus, leading to the change of green color. In addition, mechanical damage (impact bruising) can hasten the peel color of banana fruit compared to non-bruised fruit [3].

4. Conclusions

Mechanical damage such as bruising induced the occurrence of weight loss reduction and color lightness changes over time, particularly at 22 °C. The firmness of bruised banana fruit reduced, as storage temperature and impact level increased during the experiment. Storage at 13 °C reduced the appearance of severe damage of bruising in banana fruit.

Increment of transpiration rate was associated with both storage temperature and bruising. Increasing the awareness of bruising mechanisms and better storage management during the postharvest supply chain can reduce food quality losses.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/IECHo2022-12483/s1.

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