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Proceeding Paper

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

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Abstract: Loss in fresh fruits mainly occurs due to their susceptibility to mechanical damage during the postharvest supply chain. Mechanical damages can reduce the quality of fresh produce during handling, especially if they are not consumed directly, which is critical food safety challenge and economic issue. Therefore, food security and agricultural efficiency require vital action to minimize such losses. The possible mitigation includes reducing the occurrence of damage by investigating the effects of the application of external forces during handling fresh fruits. Hence, this study aims to evaluate the local banana quality changes affected by impact energy and forces resulting from the simulated handling practices during storage at three different temperature conditions for 12 days. By using the pendulum technique, local banana fruits were damaged by low (0.074 ± 0.003 J), medium (0.160 ± 0.008 J), and high (0.27 ± 0.016 J) impact forces. Fruits from each impact energy were divided 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 % in high, medium, and low impact bruised bananas at all storage conditions. The highest recorded weight loss % was found in high impact (0.27 ± 0.016 J) injured banana fruits (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 transpiration rate (2.031 mg kg^{-1} s^{-1}) on banana fruits on day-12 of storage. Furthermore, high impact bruising and storage at ambient temperature condition resulted in 76.69% firmness reduction of banana fruits after 12-days of storage. Storage at 13 °C showed the least changes in visual properties, like the 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 fruits stored at 5 °C in all damaged fruits. One of the most critical factors that reduce the incidence of severe damages due to mechanical damages are (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 highly produced and consumed fruit globally. It contains various types of nutrients, unique flavors and is rich in benefits 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, fruits may be damaged through several physical effects like 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 fruit's impact damage is more severe than compression and vibration. Impact damage can occur when fruits fall with a particular and sufficient force against another fruit or surface [5].

Mechanical damages have the potential to reduce fresh produce quality, which leads to decrease the market value. This makes mechanical damage a significant issue in the fresh produce industry [6]. Mechanical damage can influence fresh produce's physical structure and chemical properties [7]. In bananas, mechanical damage can reduce the shelf-life and the visual appearance of the fruit. Banana fruit subjected to bruising/mechanical damage showed different physical and physiological alterations. It increased the ripening rate attributed to respiration rate and ethylene production rate, mass loss, and enzymatic activity increment [3]. Bruising increases firmness loss and total color change and reduces pear fruit's lightness [8]. Also, it increased the weight loss and increased the red color development of tomatoes [9]. Besides, mechanical damage increased pomegranate fruits' respiration rate, sugar, and acidity [10]. In recent years, many studies have been conducted to identify the relationship and the enormous negative contribution between impact force and the resulted 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) into fixed banana fruits. The contribution of impact on the quality changes of banana stored at three different storage conditions for 12 days.

2. Methods

2.1. Plant Sample and Impact/Storage Treatments

The banana fruits (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, and free from any damages 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 energy, the fruits (cheek side) were hit by a known weight (97.3 g) connected to the pendulum arm from three different angles, 30°, 45°, and 60°, which represent the 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 with a total amount of 162 banana fruits. Thus, a total of 54 bananas were utilized for each impact level. After each impact, the damaged area was marked by a marker. Later, impacted banana fruits from each impact level were equally divided 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 days interval. Three fruits 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 measurements of weight loss %. The transpiration rate was calculated per unit of initial banana fruits mass in mg kg^{-1} s^{-1} by following 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, 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 bananas.

2.2.3. Peel Color

A total of 15 external readings were taken from three ($n = 3$) banana fruits per treatment (group) per day by 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 donates for lightness and darkness and a* value for redness and greenness.

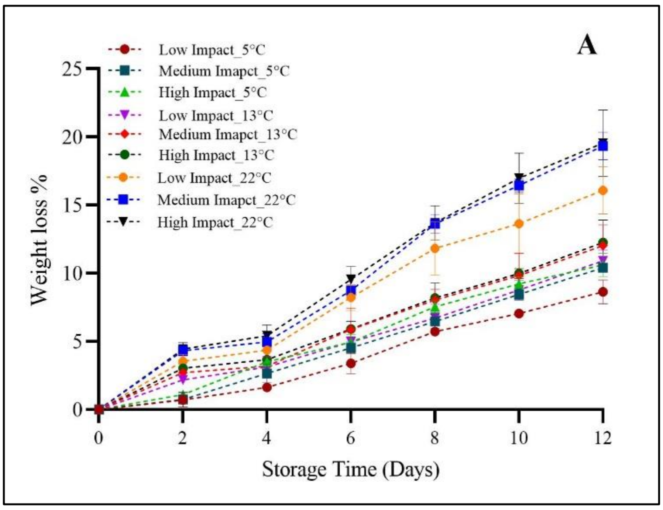
2.3. Statistical Analysis

The resulted data were analyzed by the 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 like 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 fruits 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 levels 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 banana fruits bruised by low, medium, and high impact levels at 13 °C, respectively. This is mainly attributed to the alterations in the permeability of the cell wall and tissue damage in banana fruits resulting in higher moisture content reduction through the fruit's cell wall. Besides, mechanical injuries that cause bruising can cause severe dehydration, thus reducing the bruised/damaged bananas [3].



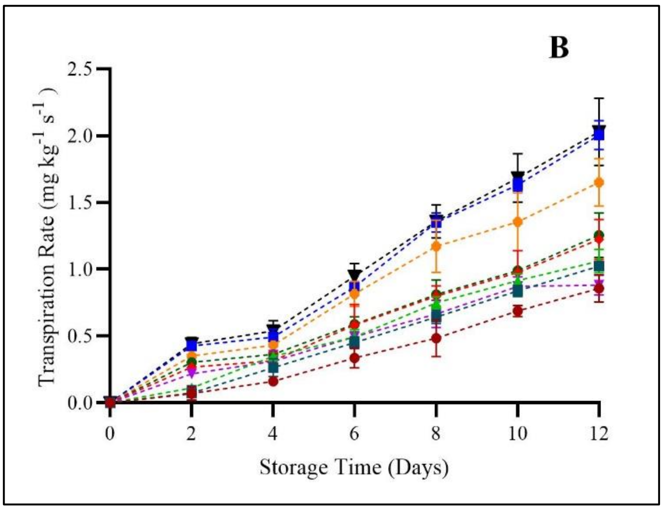


Figure 1. Weight loss % (**A**) and transpiration rate mg kg^{-1} s^{-1} (**B**) of banana fruit bruised at low, medium, and high impact energy levels and stored 5 °C, 13 °C and 22 °C storage conditions for 12 days. Error bars represent standard deviation (SD) of the mean values ± S.D. of 3 replicates.

Similarly, the analysis of variance showed that the storage conditions 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) of the banana fruit was in the range of 0.073 to 2.031 mg kg^{-1} s^{-1} over all bruised banana fruits (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 has been discussed by [15], where banana fruits are highly prone to water 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 fruits (Table 1). With storage time, a remarkable decrease in the firmness of bruised banana fruits stored at all storage conditions was observed on fruits stored at 22 °C damaged from a high impact level (Figure 2). For instance, as impact level increased, the firmness tended to reduce for low (66.06%), medium (76.40%), and high (76.69%) impact levels bruised banana fruit stored at 22 °C compared to those stored at 13 and 5 °C, respectively. Firmness reduction could be attributed to the changes in the content of structural starch, polysaccharides, and pectin substances associated with banana fruits which are highly increased as storage temperature and bruising impact increase [16]. Also, Li et al. [17] found that bruising is a vital parameter that led to the decrease in the firm state of pear due to polysaccharides activity increment. Besides, Pathare et al. [18] revealed that bruised pears from 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.

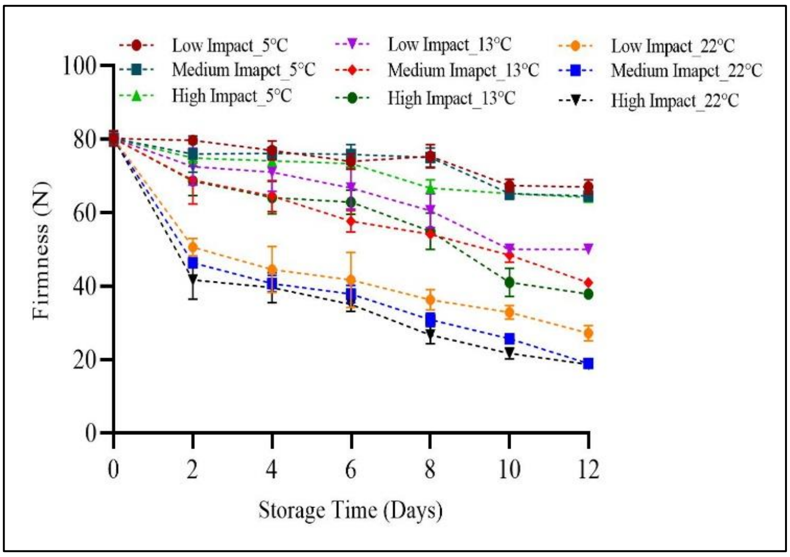


Figure 2. Firmness (N) of banana fruit bruised at low, medium, and high impact energy levels and stored 5 °C, 13 °C and 22 °C storage conditions for 12 days. Error bars represent standard deviation (SD) of the mean values ± S.D. of 6 replicates.

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 fruits 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

3.3. Color

Color is one of the primary visual attributes that highly affect consumers' choices at the market level [14]. The changes in L* of bruised banana fruits for 12 days were 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). L* value reduced 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 till the last day of storage by 40.78%.

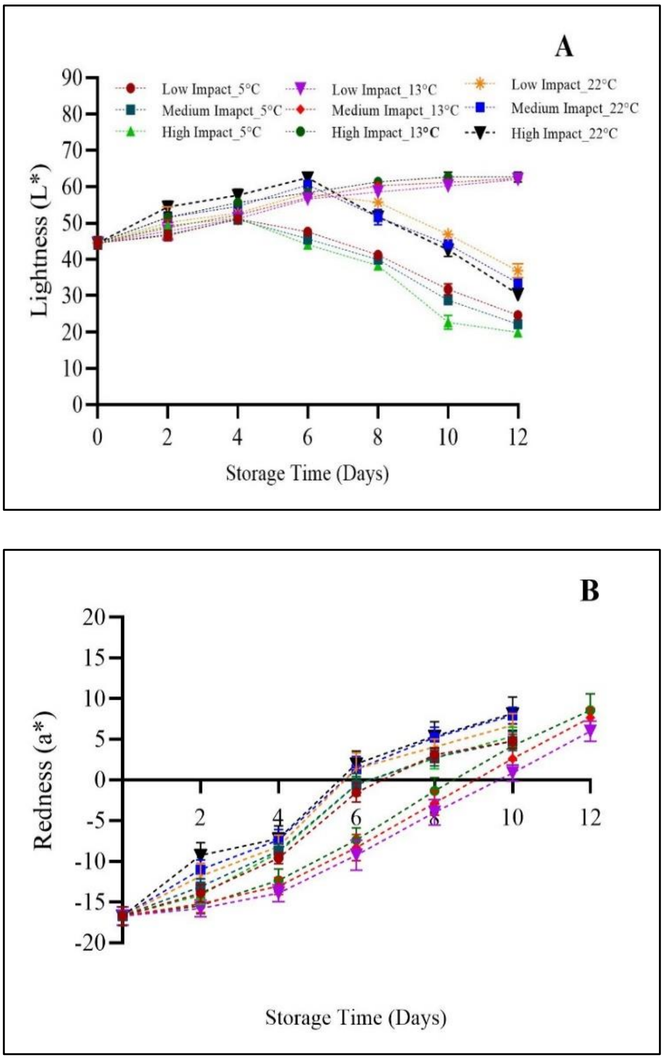


Figure 3. Lightness (L*) (**A**) and redness (a*) (**B**) of banana fruit bruised at low, medium, and high impact energy levels and stored 5 °C, 13 °C and 22 °C storage conditions for 12 days. Error bars represent standard deviation (SD) of the mean values ± S.D. of 15 readings of 3 replicates.

The redness (a*) was 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 fruits stored at 10 °C till the last day of storage. Based on the visual observations, the ideal storage temperature used to store bruised banana fruits was 10 °C. Storage at 5 °C showed chilling injuries after 3 days of the bruising test. Storage at 22 °C accelerated the process of ripening and increased bruise expansion on fruits. This is mainly attributed to the carotenoid's synthesis and chlorophyll degradation in the banana fruits peels after storage, thus leading to the change of color of green color. Besides, mechanical damage (impact bruising) can hasten the peel color of banana fruits compared to the non-bruised fruits [3].

4. Conclusions

Mechanical damage like bruising induced the occurrence of weight loss reduction and color lightness changes over time, particularly at 22 °C. The firmness of bruised banana fruits reduced as storage temperature and impact level increased during experimental days. Storage at 13 °C reduced the appearance of severe damages of bruising in banana fruits. Increment of transpiration rate was kindly 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.

Institutional Review Board Statement:

Informed Consent Statement:

Data Availability Statement:

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