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Research Article

Estimation of Changes in Mechanical and Color Properties from the Weight Loss Data of "Shine Muscat" Fruit during Storage

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"Shine Muscat" fruit is a table grape commonly consumed cultivar in Japan; however, the storage characteristics have not been investigated, especially physical properties. The objective of this study was to clarify changes in weight loss, mechanical, and color properties of Shine Muscat fruit during storage and the relationships between them. The storage tests were performed at 15°C under two relative humidity (RH) conditions, i.e., RH 95% and RH 40%. The weight loss of fruit was calculated from the mass changes during storage. The mechanical properties—stress, strain, and elasticity—at the break point were examined by compression tests. The color properties, color differences (ΔE), and chroma (C) were calculated from $L^*a^*b^*$ scale parameters. The breaking stress did not reflect changes in the mechanical characteristics of samples during storage. Weight loss was highly correlated with the breaking strain and elasticity, ΔE, and C. In addition, the physical properties could be estimated from weight loss data ($R^2 = 0.81$–0.94). We showed the changes in weight loss and other physical properties and proposed equations to estimate the physical properties based on weight loss data. The equations indicated the importance of inhibiting the weight loss to maintain the quality and could be used as a nondestructive and easy method for assessment of storage characteristics of Shine Muscat fruit.

1. Introduction

"Shine Muscat" fruit is a table grape derived from *Vitis labruscana* Bailey and *Vitis vinifera* L. is a commonly consumed cultivar in Japan with increasing demand [1, 2]. This cultivar has a Muscat flavor, large green berries, crisp flesh texture, high soluble solid concentration, low acidity, and edible skin. Because the fruit is distributed after harvest, it is necessary to study the storage characteristics of the fruit to prevent quality decline, such as texture and color; however, flavor and aroma volatile content are the only storage characteristics that have been investigated [3].

The texture of Shine Muscat fruit was reported by a breeding organization [1]. Nonetheless, the results were limited by simple sensory evaluations, including firmness (high or medium). Quantitative texture evaluation, especially of mechanical properties, is critical; therefore, many studies have explored the mechanical properties of several grape cultivars [4–7]. However, the changes in mechanical properties of Shine Muscat fruit during storage have not been investigated.

Because skin color is important for consumer acceptability of table grapes, the color characteristics of several grape cultivars were investigated [6]. In fact, the color of Shine Muscat fruit at the preharvesting stage was previously investigated [8, 9]; however, the changes in color properties of the fruit during storage were not investigated.

The objective of this study was to identify the changes in mechanical and color properties of Shine Muscat fruit during storage. Based on these data, we developed equations to estimate the changes in these physical properties from the weight loss data collected during storage. These results contributed as an assessment data of storage characteristics of the fruit; moreover, an easy estimating method for mechanical and color properties was proposed.

2. Materials and Methods

2.1. Samples. Shine Muscat bunches were purchased from a fruit sorting center in Yamanashi Prefecture, Japan. The bunches were immediately transported to the Food Research Institute NARO, Ibaraki, Japan. The bunches were subjected to storage tests, and when the physical property tests were performed, each individual fruit was used as a sample (Brix value: 18.75 ± 1.01 °Brix, pH value: 3.69 ± 0.16, diameter: 28.07 ± 2.08 mm, weight: 17.38 ± 2.11 g).

2.2. Storage Conditions. The storage tests were conducted using the FJ-TR-H240 incubator (Fuji Plant, Japan) and a custom incubator (Ebara, Japan). Generally, the temperature range for long-term fruit storage is 0–4°C; however, in this study, we employed 15°C to accelerate the changes in quality. Shin et al. [10] clarified the influence of humidity on the mechanical and color changes of the strawberry fruit during storage. In their study, the relative humidity (RH) was controlled at high or low conditions to investigate the influence of storage humidity on the physical properties of the samples. Therefore, the storage conditions in this study were 15°C, RH 95% (high-humidity storage: HHS) and 15°C, RH 40% (low-humidity storage: LHS). The actual temperature and RH during each storage test were 14.8 ± 0.2°C, 96.2 ± 1.5% (HHS) and 15.1 ± 0.2°C, 39.4 ± 5.3% (LHS). The storage period was 30 days, and the quality measurements were conducted for 5 or 10 days.

2.3. Weight Loss Measurement. Weight decrease may influence the mechanical properties of the fruit [11]. However, the changes in weight of berries only during storage cannot be continuously determined, because generally, Shine Muscat grapes are stored as bunches. For these reasons, in this study, the weight loss of bunches was measured.

Weight loss (%) was calculated using the following equation:

$$\text{Weight loss} = \frac{M_0 - M}{M_0} \times 100, \quad (1)$$

where M is the mass of bunches during storage and M_0 is the mass of nonstored bunches. Six bunches were used for the measurements.

2.4. Mechanical Measurement. Mechanical properties of the samples were measured by a compression test using a universal testing machine (Model 5542, Instron, USA) with a load cell of 50 N at 20°C. We performed the mechanical tests using a steel holder with a hole to place the sample and penetrated the equatorial side with a φ 1 mm stainless steel probe at a constant speed of 0.5 mm/s according to modified methods of Fava et al. [7] and Maury et al. [5]. We focused on breaking points in the compression tests and evaluated several mechanical parameters, namely, breaking force, breaking energy, breaking stress, breaking strain, and breaking elasticity. Stress was calculated as a ratio of the load to the area of the probe. Strain was calculated as the ratio of deformation to the initial height of the sample. Elasticity was calculated as a ratio of the stress and strain. Eighteen samples were used for the measurements.

2.5. Color Measurement. The color of samples was measured with a handheld color meter (Model CR-20, Konica Minolta, Japan). The $L^*a^*b^*$ data were recorded, where L^* indicates lightness or luminance, a^* indicates chromaticity on a green (−) to red (+) axis, and b^* indicates chromaticity on a blue (−) to yellow (+) axis [7]. We calculated color parameters, color difference (ΔE), and chroma (C) from the $L^*a^*b^*$ data. Ten to twelve samples were used for the measurements.

$$\begin{aligned} \Delta E &= \sqrt{\left(L_0^* - L^*\right)^2 + \left(a_0^* - a^*\right)^2 + \left(b_0^* - b^*\right)^2}, \\ C &= \sqrt{a^{*2} + b^{*2}}, \end{aligned} \quad (2)$$

where L_0^*, a_0^*, and b_0^* indicate the color data of nonstored samples.

3. Results and Discussion

3.1. Weight Loss. Figure 1 shows weight loss of the Shine Muscat bunches during storage. The weight loss in HHS was 3.05% after storage for 30 days; in contrast, that in LHS was 17.56%.

Weight loss was inhibited under high humidity, indicating that a main factor in maintenance of fruit quality during storage is transpiration of internal water. Because water loss may affect other physical properties of the samples, we investigated the relationships between them.

3.2. Changes in Mechanical Properties. Table 1 shows all calculated mechanical properties at the breaking point during compression tests. We evaluated the mechanical parameters normalized by probe area or individual differences of samples, including breaking stress, breaking strain, and breaking elasticity. Figures 2(a)–2(c) show the changes in mechanical properties of the samples during storage. The breaking stress of samples decreased for 10 days. Thereafter, the stress did not change in HHS. However, the stress in LHS increased to values similar to those of prestored (day 0) samples at 30 days (Figure 2(a)). The breaking strain of samples was unchanged in HHS but increased in LHS (Figure 2(b)), while the breaking elasticity of samples was unchanged in HHS but decreased in LHS (Figure 2(c)).

Under high humidity, degradation of the middle lamella and disintegration of the primary cell wall were the main factors influencing mechanical property changes. Nonetheless, the greater the water loss under low humidity, the lower the turgor pressure, and decreased turgor affects the mechanical properties [4, 12]. Decreased turgor pressure reflects increased breaking strain and decreased elasticity [13], which was corroborated by the current results (Figures 2(b) and 2(c)), suggesting that a primary factor influencing the mechanical property changes in LHS fruit was decreased turgor pressure by water loss under low humidity.

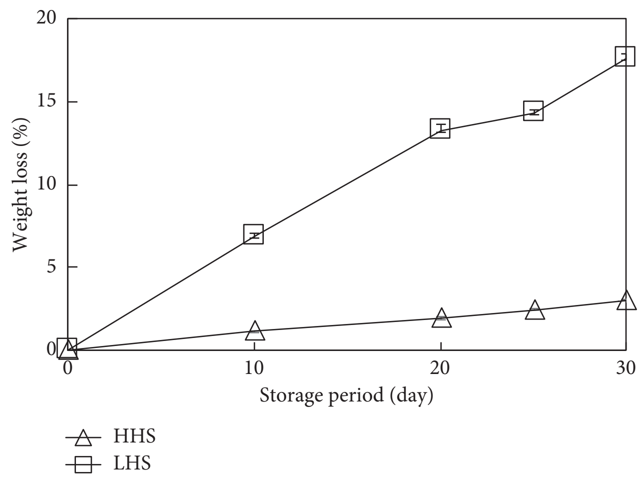

Figure 1: Weight loss of "Shine Muscat" bunches during storage. HHS: high storage humidity sections; LHS: low storage humidity sections. Error bar shows standard error ($n = 6$).

Table 1: Mechanical properties of "Shine Muscat" fruit at the breaking point during storage.

Storage period (days)	Force (N)	Energy (mJ)	Stress (N/mm^2)	Strain (–)	Elasticity (N/mm^2)
HHS					
0	1.95 ± 0.02	2.37 ± 0.07	2.49 ± 0.02	8.85 ± 0.39	29.07 ± 1.28
10	1.50 ± 0.05	1.52 ± 0.09	1.91 ± 0.05	7.22 ± 0.49	26.98 ± 1.17
20	1.47 ± 0.05	1.37 ± 0.08	1.88 ± 0.07	6.44 ± 0.41	29.63 ± 1.00
30	1.67 ± 0.07	1.80 ± 0.13	2.13 ± 0.09	7.64 ± 0.78	27.92 ± 0.63
LHS					
0	1.95 ± 0.02	2.37 ± 0.07	2.49 ± 0.02	8.85 ± 0.39	29.07 ± 1.28
10	1.49 ± 0.06	2.04 ± 0.16	1.89 ± 0.07	10.39 ± 0.49	18.37 ± 0.46
20	1.96 ± 0.03	3.36 ± 0.09	2.50 ± 0.04	16.70 ± 0.41	15.11 ± 0.40
30	1.98 ± 0.03	3.51 ± 0.15	2.52 ± 0.05	20.13 ± 0.78	12.77 ± 0.40

HHS: high storage humidity sections; LHS: low storage humidity sections.

The breaking stress of LHS samples at 10 days returned to values similar to those of prestored samples (Figure 2(a)). Nevertheless, the strain and elasticity revealed that the mechanical properties were not recovered (Figures 2(b) and 2(c)). Moreover, increased stress was observed after decreased stress in dehydrated fruit and vegetables [14, 15]. From these results, we assumed that the increased breaking stress was mainly caused by drying during storage.

3.3. Changes in Color Properties. Figures 3(a) and 3(b) show changes in color properties of samples during storage. The color difference, ΔE, of samples increased for 10 days and thereafter did not change in HHS. However, ΔE increased in LHS with increasing storage duration (Figure 3(a)). The chroma, C, of samples did not change in HHS but gradually decreased in LHS with increasing storage duration (Figure 3(b)). Komatsubara investigated the acceptability values of some color parameters for human [16] and showed that the ΔE can be used as an index of the allowable color differences for the visual perception. Therefore, it was assumed that the visual changes of samples in HHS were inhibited compare to that of LHS.

The color changes of samples were confirmed in LHS; therefore, it was assumed that the low humidity or water loss may reflect their colors. Grape contains many polyphenols and high oxidase activity, which contribute to browning [17]. Shine Muscat fruit also contains polyphenols [9] and may indicate that browning due to polyphenols occur during storage. In addition, chlorophyll degradation is one of the factors of the color changes in ripening fruit [18]. However, the relationships between polyphenol content, oxidase activity, chlorophyll degradation, and color of Shine Muscat fruit during storage under low humidity have not been studied. Therefore, these relationships will be investigated in further studies.

3.4. Equations for Estimation of Mechanical and Color Properties from Water Loss Data. Figures 4(a)–4(e) reveal the relationships between weight loss and mechanical or color properties of the sample.

These results clarified that the weight loss greatly influenced the mechanical and color characteristics of Shine Muscat fruit and the inhibition of weight loss, namely, water loss, was critical to maintain these characteristics after harvest. Moreover, the breaking stress was not suitable as an

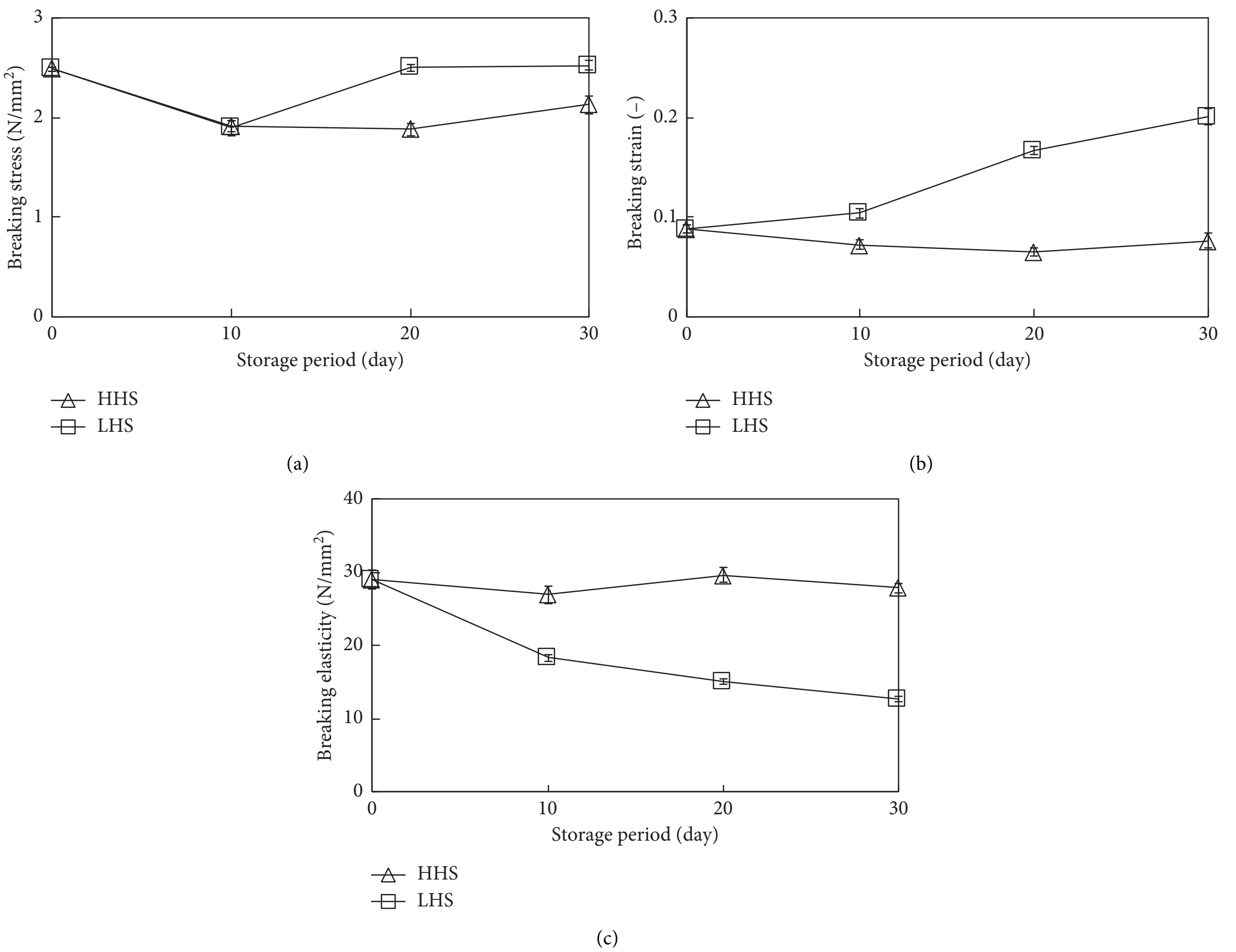

Figure 2: Changes in mechanical properties of "Shine Muscat" fruit during storage: (a) breaking stress; (b) breaking strain; (c) breaking elasticity. HHS: high storage humidity sections; LHS: low storage humidity sections. Error bar shows standard error ($n = 18$).

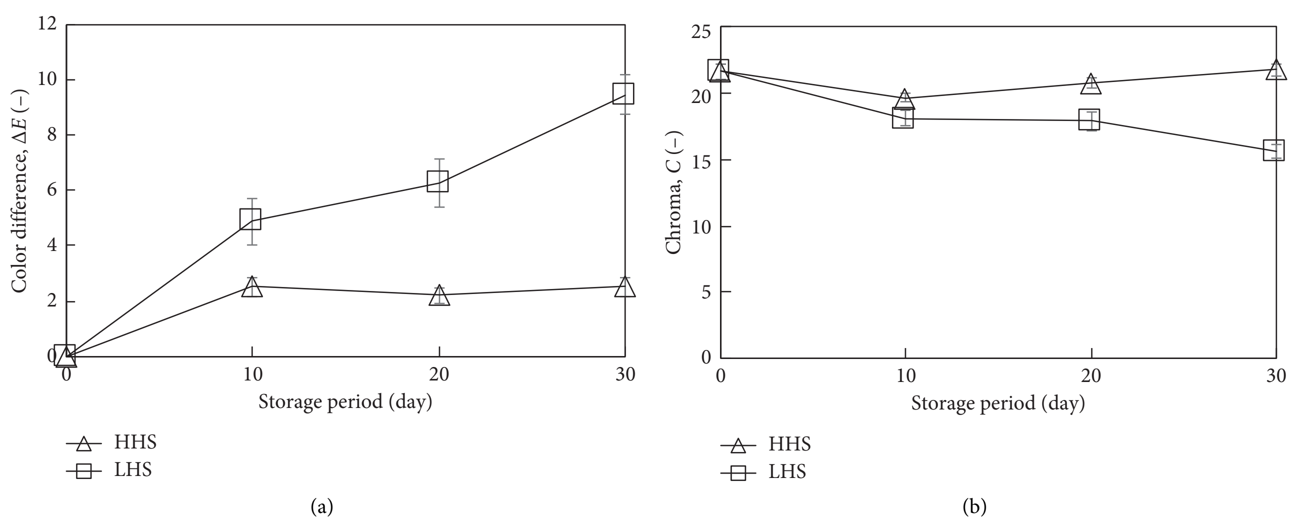

Figure 3: Changes in color properties of "Shine Muscat" fruit during storage: (a) color difference; (b) chroma. HHS: high storage humidity sections; LHS: low storage humidity sections. Error bar shows standard error ($n = 10 - 12$).

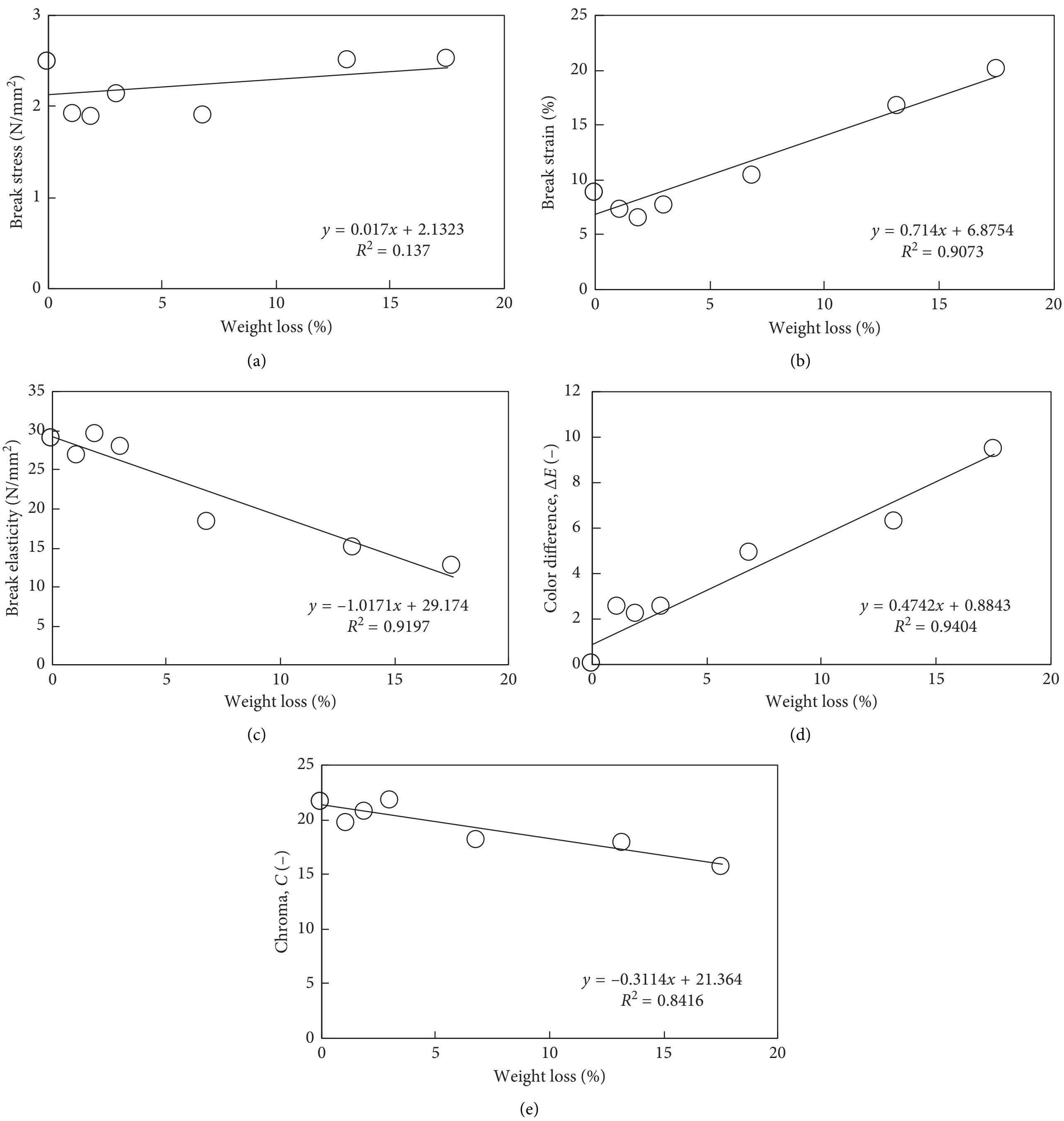

Figure 4: The relationships between the weight loss and mechanical or color properties of "Shine Muscat" fruit and the estimation equations of them: (a) breaking stress; (b) breaking strain; (c) breaking elasticity; (d) color difference; (e) chroma.

indicator of changes in mechanical characteristics of Shine Muscat fruit during storage when weight loss occurred.

Elucidation of the relationships between weight loss and mechanical and color properties, excluding breaking stress, resulted in the generation of simple equations, which can be used to estimate the changes in mechanical and color properties using the weight loss data and simple parameters shown in Figures 4(b)–4(e) (R^2 = 0.81–0.94). From these results, we concluded that the developed equations indicate the importance of inhibiting the weight loss and can be used as a tool for assessment of quality or storage conditions of Shine Muscat fruit after harvest.

4. Conclusions

We investigated the changes in weight loss, mechanical properties (breaking stress, strain, and elasticity), and color properties (color differences and chroma) of Shine Muscat fruit during storage. Under HHS, the weight loss of samples was inhibited, indicating that the weight loss was mainly influenced by internal transpiration of samples. The mechanical and color properties, excluding breaking stress, were correlated with increasing storage duration in LHS and weight loss. The breaking stress was not suitable for assessment of the mechanical characteristics of the fruit during storage when weight loss occurred. The other physical properties—breaking strain, elasticity, color differences, and chroma—could be estimated using the weight loss data and simple equations ($R^2 = 0.81–0.94$). The results indicated that the equations may be applied for easy assessment of these physical properties using only weight loss data as well as the importance of inhibiting weight loss of Shine Muscat fruit during storage. Moreover, we confirmed a strong correlation between the color and mechanical properties, excluding breaking stress, of samples. In further studies, we will investigate the relationships between these properties and nondestructive methods of estimation of mechanical properties using color parameters.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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