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INFLUENCE OF AMBIENT STORAGE ON WEIGHT, COLOR, AND TSS IN GOLDEN DELICIOUS APPLES: A CORRELATIONAL STUDY

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Abstract: This research explores the interplay between weight loss, color transformation, and total soluble solids (TSS) in Golden Delicious apples during storage at room temperature. Across six weeks, a freshly harvested batch of Golden Delicious apples underwent scrutiny in a controlled environment, maintaining around 24ºC and 60% humidity. The study aimed to unravel the post-harvest physiological shifts in apples, explicitly focusing on factors affecting consumer appeal and shelf life. Methodologically, weight loss was precisely tracked using a high-precision scale, while color alterations were quantified via a portable colorimeter, yielding CIELAB L*, a*, and b* values. A refractometer was used to assess TSS, which indicated sweetness and ripeness. Correlation analysis revealed a strong link between weight loss and color shift, with a less pronounced yet significant connection between TSS and the other variables. These findings enrich our comprehension of the post-harvest dynamics of Golden Delicious apples, carrying implications for adequate storage and marketing tactics. This research supports the principles of the circular economy by enhancing the efficiency of post-harvest processes and minimizing waste through better storage practices. By understanding these factors, producers can reduce spoilage and extend the shelf life of apples, contributing to more sustainable food systems.

Keywords: Apple, post-harvest changes, storage impact, correlation, mass loss

1. Introduction

Due to limited storage capacity compared to production levels, the costs associated with cold storage can increase. As a result, many consumers choose to purchase fruits that have been stored at room temperature in local markets. Therefore, assessing the quality of apples at room temperature is crucial, and non-destructive color measurement is a valuable indicator at purchase [1], [2]. A fruit's vibrant and fresh appearance is a consumer's initial interaction with it, significantly influencing their sensory experience. Traditionally, fruit quality assessment relied on visual inspection and destructive testing [3]. However, advancements in spectroscopic and imaging techniques offer effective and non-destructive alternatives that address the limitations of traditional methods [4].

The levels of total soluble solids (TSS) in apples are crucial in determining their texture and flavor, which in turn impact their overall quality and appeal to consumers [5], [6], [7].

Additionally, weight loss in fruits, mainly due to dehydration, affects their quality and economic value. The natural wax coating on apples plays a significant role in retaining moisture, and the structure and composition of the skin's wax are essential factors in mitigating weight loss [8]. Weight loss affects the fruit's visual appeal and textural quality, leading to softening and reduced turgor pressure. Therefore, measuring fruit weight is essential for fruit quality assessment [9], [10].

While there is existing research on fruit storage, further investigation is needed into color changes in fruits and the classification of ripening stages during shelf life [11] demonstrated that color changes during storage could serve as a classification criterion for ripening stages. Apple quality deteriorates significantly during storage, which affects consumer acceptance [12], [13], [14]. This study highlights the relationship between weight loss, TSS and colorimetry data.

2. Materials and Methods

Fresh Golden Delicious apples were harvested from a farm near Kecskemét, Hungary. Three measurements were made for each sample to determine the weight and geometry. The average weight of the entire fruit sample was 150 ±12 g. The apples were kept for six weeks at room temperature (24 ± 1 C) with 60% relative humidity.

2.1. Measurement of Weight Loss

The samples of apple fruits were weighed using a precision scale type KERN (KERN & SHON GmbH, Balingen, Germany, KERN PCB 3500-2, max.: 3500 g ± 0.01 g).

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

$$\mathbf{Weight\ loss} = \frac{\mathbf{m_0 - m}}{m_0} \cdot \mathbf{100}, [\%] \quad (1)$$

where:

m – the mass of apples during storage (g),

m_0 – the initial mass of apples (g).

2.2. Measurement of Color

The color characteristics of samples were measured with a wireless Nix Pro color sensor (Nix Sensor Ltd., Hamilton, Ontario, Canada, NixPro Mini).

Color parameters, precisely color difference (ΔE), and chroma (C) were calculated from the L*a*b* data. Chroma describes the saturation of a fruit's color, while Delta E is used to measure and compare color differences.

$$\mathbf{\Delta E} = \sqrt{(\mathbf{L_0^*} - \mathbf{L^*})^2 + (\mathbf{a_0^*} - \mathbf{a^*})^2 + (\mathbf{b_0^*} - \mathbf{b^*})^2}, \quad (2)$$

$$\mathbf{C^*} = \sqrt{\mathbf{a^{*2}} + \mathbf{b^{*2}}}, \quad (3)$$

where L_0^*, a_0^*, and b_0^* represent the initial color data based on the samples.

2.3. Measurement of Total Soluble Solids (TSS)

The TSS of extracted juice was determined with a digital hand refractometer (Ebro Electronic GmbH, Ingolstadt, Germany, Model: DR-10). The TSS values of the juice were measured in triplicate and the results were expressed in ^{0}Brix (±0.2).

3. Results and Discussion

3.1. Correlation between weight loss and color parameters

Correlation analysis can assist in comprehending the connection between two variables. A significant linear trend can be identified by analyzing Golden Delicious apples' weight loss and L* value (lightness) stored at room temperature over six weeks. This trend indicates a link between increased weight loss and decreased lightness. The negative correlation between weight loss and the L* value suggests that as the apples lose water weight and undergo transformations during storage, they become less reflective or appear darker. The correlation also points to a change in color in the apples as they lose weight, which is linked to increased ethylene production and respiration [15]. Therefore, it is critical to understand how storage time influences the apples' quality and marketability in terms of their visual appeal, which directly impacts how consumers perceive their freshness and quality. The solid linear correlation, with an R^2 value of 0.9075, indicates a robust connection, where the linear model explains most of the variance in the L* values. It implies that, by understanding the percentage of weight loss of the apples, their L* value can be predicted with a high degree of accuracy using this model. By understanding the correlation between weight loss and L* value in Golden Delicious apples, the quality and marketability of the fruit can be predicted based on its visual appeal. (Fig. 1.)

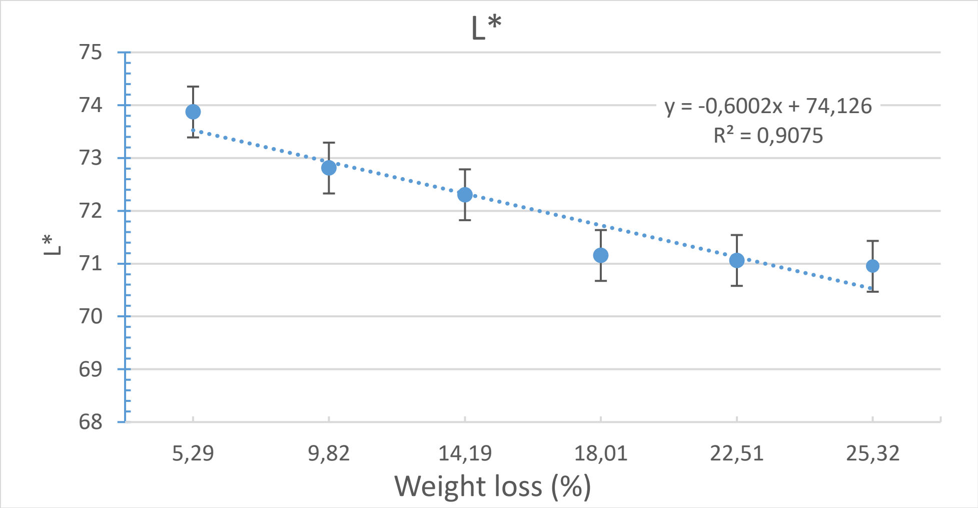

Figure 1. Correlation between Weight Loss and L* Values in Stored Golden Delicious Apples.

Fig. 2 shows the relationship between weight loss and the a* value (representing chromaticity on a green-to-red axis) of apples stored at room temperature over six weeks. The graph exhibits a positive correlation between weight loss and the a* value. As the weight loss percentage increases, the a* value increases, suggesting that the apples become redder as they lose weight and start rotting. The R^2 value of 0.9423 demonstrates a robust correlation between these two variables. As apples lose weight, mainly through water loss, there may be a concentration of pigments such as anthocyanins and carotenoids, which can cause the color to shift towards red [16]. Apples can undergo enzymatic reactions that may lead to a change in skin color. In the case of Golden Delicious apples, this might mean a shift from a greener to a redder hue as the weight loss progresses and red spots appear as a sign of rotten. The strong correlation between weight loss and color change affects apples' perceived freshness and quality. As the color shifts towards red, it may affect consumer preference significantly. In the case of Golden Delicious apples, a redder color is associated with ripeness and rottenness. This correlation is statistically robust, as indicated by the high R^2 value, and could be valuable for the agricultural industry to predict and assess color changes in apples due to weight loss during storage.

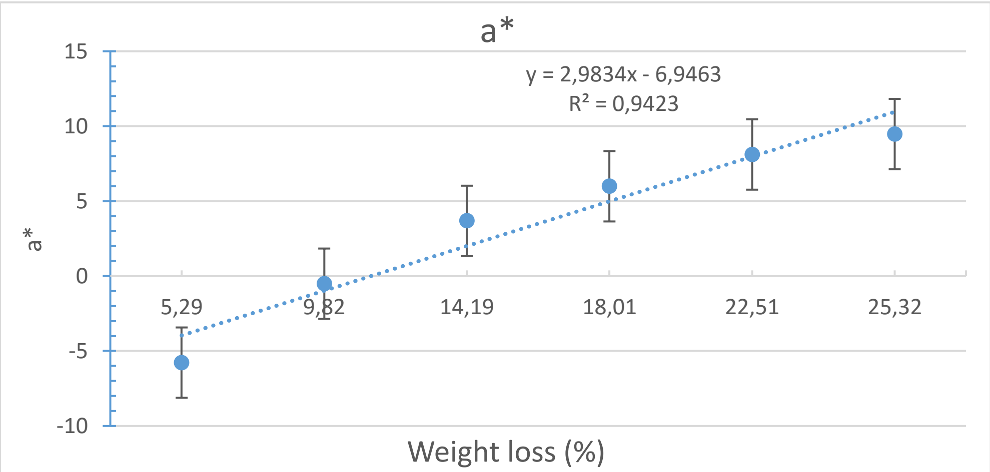

Figure 2. Correlation Between Weight Loss and Chromaticity (a*) of Golden Delicious Apples During Six Weeks of Room Temperature Storage.

Fig. 3 shows a positive correlation between weight loss and the b* value. As weight loss increases, the b* value increases, suggesting that the apples become more yellow as they lose weight. The R^2 value is 0.8523, which indicates a robust correlation between weight loss and b* value.

The increase in b* value with weight loss might be due to the natural ripening process, where chlorophyll breakdown and the synthesis of carotenoids can make the fruit appear more yellow over time [17].

Water loss may lead to a concentration of pigments within the apple, making the yellow color more pronounced. This is especially true if the water loss is more from the surface, where the color change is most noticeable. As they age and lose water, apples may undergo non-enzymatic browning reactions that can contribute to a change in color, potentially leading to an increase in the yellow component [18]. The strong correlation captured by the linear model and the high R^2 value suggests that this color change is consistent and can be reliably predicted by the extent of weight loss.

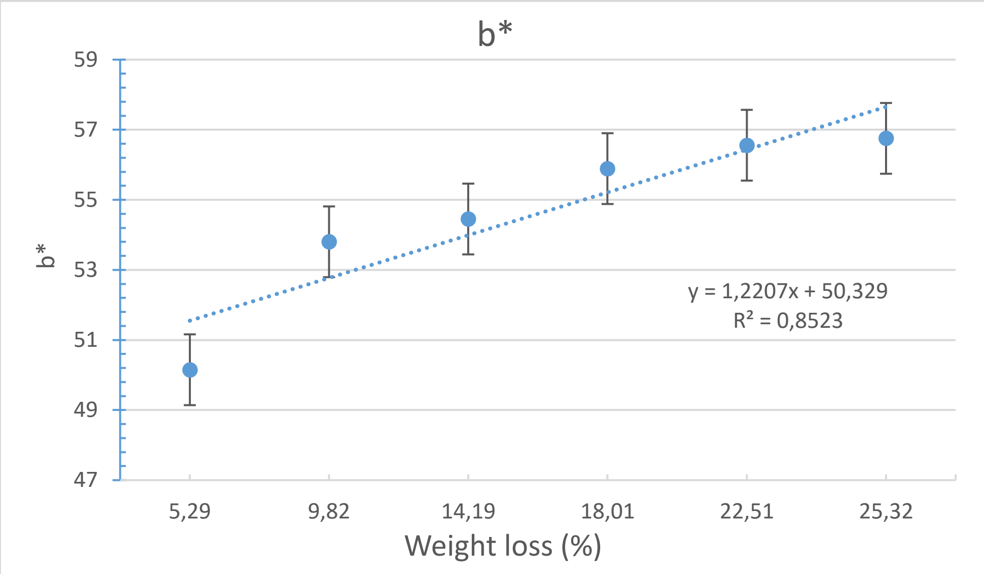

Figure 3. Correlation Between Weight Loss and Chromaticity (b*) of Golden Delicious Apples During Six Weeks of Room Temperature Storage

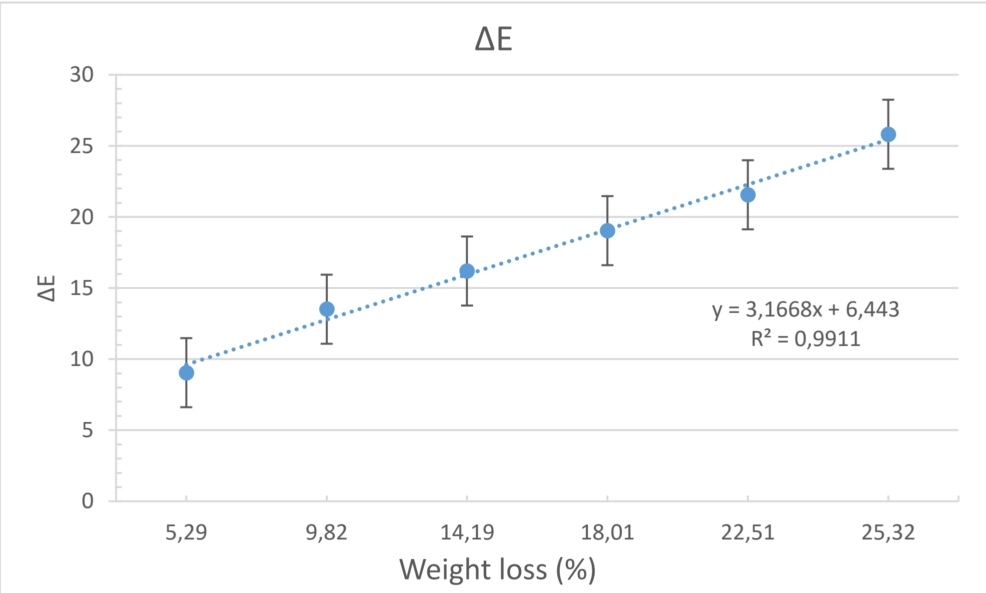

Figure 4. Relationship Between Weight Loss and Total Color Change (ΔE) in Golden Delicious Apples Over Six Weeks of Storage.

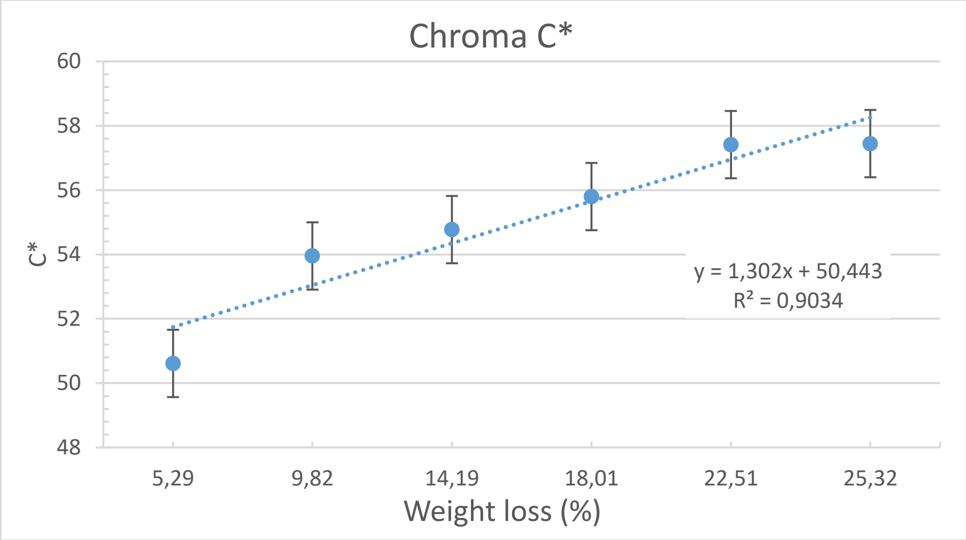

Figure 5. Impact of Weight Loss on Chroma Intensity (C*) in Golden Delicious Apples During Six Weeks at Ambient Temperature

The graphical analysis (Fig. 4) indicates a robust positive correlation between the weight loss of and ΔE, with an R^2 value of 0.9911. This strong correlation suggests that color changes are significant and directly related to the degree of weight loss.

In conjunction with ΔE, Chroma (C*) also exhibits a positive correlation with weight loss, as reflected by an R^2 value of 0.9034 (Fig. 5). This correlation demonstrates that as the apples lose weight, there is a concurrent increase in color intensity, leading to a more vivid and saturated appearance [11]. The initial weight loss stages are the most significant Chroma alterations, a trend consistent with the changes observed in ΔE.

The observed increase in both ΔE and Chroma during the early phase of weight loss can be attributed to the concentration of pigments due to moisture reduction and the potential degradation of chlorophyll. As a result, the apples exhibit a more pronounced color change, becoming noticeably different and more intense.

When apples ripen, the chlorophyll in their flesh and skin turns green. Chlorophyll is constantly renewed prior to maturation; however, once development starts, the rate of chlorophyll production slows down, initially leading to a loss of green tint. When more chlorophyll is lost, other pigmentation – typically yellow – takes centre stage. [19], [20].

3.2. Correlation between weight loss and Total Soluble Solids

Fig. 6 presents a correlation between the weight loss percentage of Golden Delicious apples and their Total Soluble Solids (TSS) measured during storage at room temperature. The graph illustrates a linear increase in TSS as the weight loss percentage rises. The pattern of change suggests that as apples lose moisture over time, the concentration of soluble solids like sugars increases [21]. The R^2 value of 0.9624 is very high, which means that the linear model can explain approximately 96.24% of the variance in TSS based on weight loss. This indicates a solid predictive relationship.

During storage, apples lose weight primarily due to water loss. As water content decreases, the components that make up the TSS, such as sugars, become more concentrated. TSS is a measure often associated with the sweetness and flavor intensity of the fruit. The increase in TSS as weight loss occurs may indicate that the apples could taste sweeter and have a more pronounced flavor as they dehydrate.

Given their perishable nature and high metabolic and respiratory rates, apples typically have a limited storage duration. Post-harvest losses, which can account for up to 25–28% of total yield [22], underscore the importance of enhancing post-harvest fruit management to bolster the food supply [23]. While apples are nutritionally rich, this value diminishes after harvest due to various factors.

Internal and external factors influence these losses during storage, with temperature and relative humidity playing a pivotal role [24]. The correlation between the weight loss of Golden Delicious apples and other parameters during post-harvest handling is particularly noteworthy. This weight loss is closely linked to changes in firmness, color, and total soluble solids content, reflecting the fruit's overall quality and shelf life.

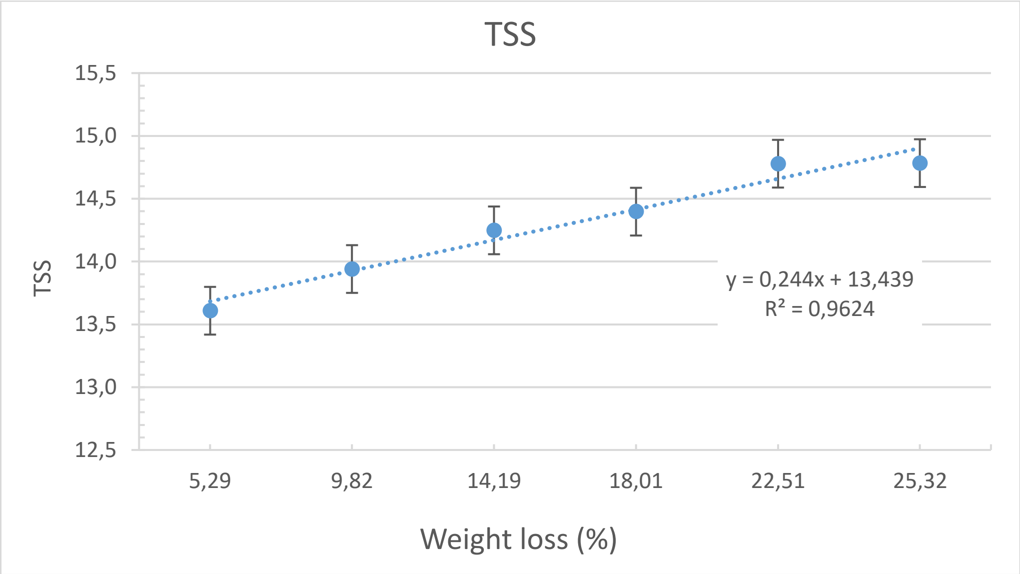

Figure 6. Correlation Between Weight Loss and TSS of Golden Delicious Apples During Six Weeks of Room Temperature Storage

The correlation between weight loss and total soluble solids (TSS) of Golden Delicious apples stored at room temperature has been a subject of interest in several studies. Juhnevica et al. assessed the impact of different storage conditions on apple quality [25]. This study provided insights into the various factors that influence the quality of apples during storage, including changes in TSS levels. Another study focused on the effect of post-harvest storage on the weight of Golden Delicious apples [26], highlighting the impact of storage conditions on weight loss, which can, in turn, influence TSS levels. Additionally, non-destructive methods for measuring chlorophyll content in the skin of Golden Delicious apples and evaluating quality were explored in a separate study by Rutkowski et al. shedding light on the potential indicators of apple quality beyond weight loss and TSS [27]. These findings collectively emphasize the multifaceted nature of apple quality during storage and the importance of considering various factors, including weight loss and TSS, in assessing and managing post-harvest apple quality.

4. Conclusions

This study established a definitive linear correlation between weight loss in Golden Delicious apples and critical quality attributes such as lightness, chromaticity, total color change, chroma intensity, and total soluble solids over a six-week storage period at room temperature. Analytical models explain most of the variability in these quality indicators, highlighting weight loss as a powerful predictive tool for assessing post-harvest quality deterioration. The implications for post-harvest apple management are substantial, presenting a metric for anticipatory quality control and increasing marketability through more informed storage strategies. This study highlights the importance of weight loss monitoring as a non-invasive but informative indicator of shelf life and sensory quality of Golden Delicious apples, offering real benefits to producers and consumers in the context of room-temperature storage. Some researchers have even modelled the indoor temperature of the containers, while others have analyzed the air quality in fruit storage facilities. [28], [29]. In this article, the temperature was kept constant, and the air quality was not analyzed. These insights are crucial for advancing the circular economy by reducing food waste and enhancing resource efficiency in the supply chain. Furthermore, these insights can encourage more sustainable farming methods, contributing to a more resilient food supply. Future studies could also investigate the impact of different storage strategies, such as modified atmosphere packaging, on the quality of Golden Delicious apples during storage.

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