HUNGARIAN UNIVERSITY OF AGRICULTURE AND LIFE SCIENCES

# Non-destructive testing of the relationship between apple storage technologies and physical parameters

PhD Thesis

by

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## CONTENTS

# 1. INTRODUCTION, OBJECTIVES

Over the years, fruits have been appreciated as an essential component of the human diet because of their excellent sensory qualities and positive impact on human health. Fruit quality, appearance, and mechanical qualities under various conditions, especially temperature and shelf life, have been the primary focus of post-harvest fruit preservation research.

In the past, fruit was usually consumed fresh at the place of production. However, technological advances in post-harvest and storage have made transporting fruit to different regions possible. As a result, they are consumed a few days, or even several days, after their harvest date.

One of the most challenging issues facing the globe today is how to store fruit after harvest. Storing fruit at low temperatures immediately after harvest reduces its respiration rate. As a result, shelf life increases while preserving nutritional and sensory qualities and reducing post-harvest losses.

This research will lead to a better understanding and optimisation of the storage process, which will help extend fruit shelf life. It will provide an overview analysis of changes in parameters, namely weight loss percentage and colour, during storage at different temperatures of Golden Delicious apples.

The general objective of this study is to investigate the change in weight loss percentage and colour parameters of Golden Delicious apples as a function of storage conditions.

The detailed research objectives can be described as follows:

1. To assess how different storage temperatures affect the weight loss percentage of Golden Delicious apples during storage.
2. To assess how different storage temperatures affect the colour change of Golden Delicious apples during storage.
3. To assess how different storage temperatures affect the hue angle of Golden Delicious apples during storage.
4. To assess how the same storage temperatures affect the weight loss percentage of Golden Delicious apples, changes in the dark chamber and the light chamber.
5. To assess how the same storage temperatures affect the hue angle of Golden Delicious apples, changes in the dark chamber and the light chamber.
6. To establish whether the measurement data generated by the performed experimental series show a significant difference based on statistical analysis.

# 2. MATERIALS AND METHODS

This chapter presents the experimental methodology, materials, instrumentation, procedures, and processes employed in the research, including the scientific methods used in the experimental measurements and a description of the test systems designed to achieve the research objectives.

## 2.1. Measured parameters during apple storage

### *2.1.1. Temperature*

The Ebro EBI 300 TE (Xylem Analytics Germany GmbH, Weilheim, Germany, EBI 300 + TPH 400, T=-20→+40℃ ± 0.5℃) multi-purpose USB data logger was fitted with an external temperature sensor to record the data. They were placed in various locations within each storage room, including the centre, the entrance door, the cooling unit, and the crates containing the fruit samples, as shown in Fig.1.

Fig. 1. The Ebro EBI 300 TE multi-use USB datalogger with external temperature probe

### *2.1.2. Storage Relative humidity*

Relative humidity and variations inside the storage rooms were registered to maintain stable conditions. The Ebro EBI 300 TH multi-purpose USB data logger (Xylem Analytics Germany GmbH, Weilheim, Germany, EBI 300 + TPH 400, T=-20→+40℃ ± 0.5℃) was utilised to measure this parameter in real-time during storage. The software used to analyse the recorded relative humidity data is Ebro Winlog Pro software. External probes were placed in the sample boxes to continuously monitor the relative humidity, as shown in Fig.2.

Fig. 2. The Ebro EBI 300 TH Multi-Use USB Data Logger for temperature and humidity measurement

#### *2.1.3. Weight and weight loss percentage measurement*

Weight loss percentage was measured throughout the storage experiment to understand the physiological responses of apples to different storage temperatures under normal atmospheric conditions. The change in weight of each apple over time ($\Delta m_a$) was calculated using the following formula:

$$\Delta \mathrm{m}_a = m_0 - m \text{ (g)}$$

The weight loss percentage Δm (%) was calculated using the following equation:

$$\Delta \mathrm{m} = \frac{m_0 - m}{m_0} \cdot 100, \text{ (\%)}$$

where,

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

$m_0$ – the initial mass of the apples (g).

The apple fruit samples were weighed weekly using a precise scale type KERN (KERN&SHON GmbH, Germany, KERN PCB 3500-2, max.: 3500 g ± 0.01 g) to calculate the average fruit weight as shown in Fig. 3.

Fig. 3. The scale type KERN

### *2.1.4. Measurement of Apple colour parameters*

A NixPro wireless colour sensor (Nix Sensor Ltd., Hamilton, Ont, Canada, NixPro Mini) was utilised to assess the colour parameters of Golden Delicious apples throughout the experiment, as depicted in Fig. 4.

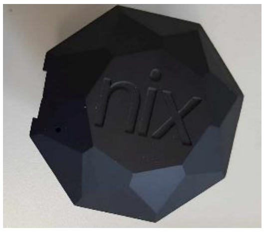



Fig. 4. The NixPro wireless colour sensor

The colour was recorded in the CIELAB uniform colour space.

The value of ΔE can be calculated using the following equation:

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

$L^*_0$, $a^*_0$ and $b^*_0$ a represent the colour data of the initial samples, and $L^*$, $a^*$ and $b^*$ are the measured real-time data.

The following relationship describes the definition of Chroma:

$$C^* = \sqrt{a^{*2} + b^{*2}},$$

The conversion of $a^*$ and $b^*$ to h° (hue angle) is performed as follows:
$Hue\ angle = 180 + \arctan(b^*/a^*)/2\pi \cdot 360\ ;\ a^* < 0, b^* > 0$ and $a^* > 0, b^* > 0$

### *2.1.5. Control parameters measurement methods*

Destructive analyses were conducted to measure total soluble solids (TSS) and pH at the beginning and end of the storage period to characterize the physiological state of Golden Delicious apples throughout the storage experiment. The TSS content was measured in triplicate for each sample with a digital refractometer (Ebro Electronic GmbH, Germany; Model: DR-10, range: 0–54% Brix, accuracy: ±0.2%) as depicted in Fig. 5, and results were expressed as a percentage Brix.

Fig. 5. DR-10 type digital refractometer

The same juice extracts were used for pH analysis, which was conducted with a calibrated benchtop pH meter (Electronic Temperature Instruments Ltd., UK; Model: ETI 8100 Plus) as shown in Fig. 6.

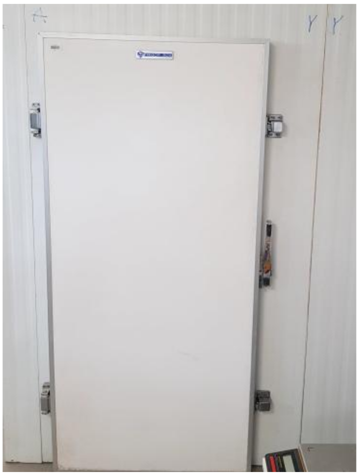
Fig. 6. ETI 8100 Plus type pH measurement equipment

## 2.2. Preparing apple samples for storage

A batch of Golden Delicious apples was sourced directly from a local farm near Kecskemét, Hungary, in November 2022. The apples had been harvested at the optimal level of maturity, which corresponded to the typical harvest date for marketing. Every apple has an identity code (e.g., D03A1, where D03 denotes the darkroom storage at 3°C and A1 represents the specific apple), allowing for simple tracking throughout the experiment.

## 2.3. Storage conditions of apples during the experiment

Golden Delicious apples were placed in 4 plastic boxes, each containing 12 apples. 48 apples were stored under various temperature conditions for 12 weeks. The first box (box ID is D24) was placed in darkroom storage at ambient temperature (24±1℃) under air relative humidity (RH 60±5%), the second box (box ID is D03) was placed in darkroom cold storage at 3±1°C, under air relative humidity (RH 85±5%) the third box ( box ID is D15) was placed at 15±1°C in darkroom storage under air relative humidity (RH 85±5%) and the last box (box ID is L03) was stored at 3±1°C in lightroom cold storage under air relative humidity (RH 85±5%) with a continuous illumination provided by a T8 36W/840 NW fluorescent tube (Kanlux Kft., Győr, Hungary, T8 36W/840 NW, Useful luminous flux of the light source 3350lm, Colour temperature 4000K) as shown in Fig.7.



a) D03 - Dark chamber, +3°C

b) D24 - Dark chamber, +24°C

c) L03 - Light chamber, +3°C

d) D15 - Dark chamber, +15°C

Fig. 7. Different storage conditions

## 2.4. Statistical analysis methods

The aim of the study was to observe how the parameters (e.g., $\Delta m$, $\Delta E$, and Hue angle) of apples change under different storage conditions (D03, L03, D15, and D24) over 12 weeks. The apples were assigned unique identifiers to ensure no random differences between the individual samples.

To analyse the effect of time and storage conditions on the parameters of apples, we applied a Linear Mixed Model (LMM). This approach extends the classic Linear Model (LM) by incorporating both fixed and random effects, making it well-suited for handling complex, hierarchical datasets. Fixed effects represent the overall parameter trend across weeks and storage conditions, while random effects account for variability between individual apples. LMMs are particularly advantageous for repeated-measures data, as they handle unbalanced datasets and missing values more robustly than traditional methods.

Applying ANOVA to the residuals of a linear or mixed model, we are testing if any remaining unexplained variation can be attributed to the factors in the model, such as storage method or week.

In the context of applying ANOVA to a linear mixed model, the null hypothesis tests whether the fixed factors (such as storage condition or week) significantly improve the model fit.

$H_0$: The fixed effect(s) do not explain a significant amount of variation in the response variable beyond what is captured by the random effects and baseline model.

$H_1$: The fixed effect(s) significantly improve the model by explaining additional variation in the response variable.

Post-hoc analyses are essential for examining the specific pairwise differences between the levels of a factor after a significant overall effect has been found in an ANOVA.

In the context of post-hoc tests, EMMs are used to calculate pairwise comparisons between levels of a factor, such as the different storage conditions in the current study, while accounting for the effects of other variables (e.g., week of measurement).

When linear regression is used, the nature of the trends is confirmed by the $R^2$ and p-values. All analyses were conducted using Excel and R-studio 3.6.0+ software.

# 3. RESULTS AND DISCUSSION

This chapter presents the most important results obtained from the experimentation and their discussions.

## 3.1. Effect of storage temperature on Golden Delicious apple properties

### *3.1.1. Effect of storage temperature on weight loss percentage*

A database was created from the measured data and prepared appropriately for the analysis. During the LMM statistical analyses, the change in the percentage of weight loss (Δm) was examined as a function of the number of weeks of storage (w). The analysis was completed using the Analysis of Variance Table with Satterthwaite's method. The analysis results for the change in weight loss percentage are presented in Table 1. at different storage temperatures (D03, D15, D24), with constant relative humidity.

Table 1. Results of ANOVA analysis of the change in Δm value as a function of storage temperature

| | Sum Sq | Mean Sq | NumDF | DenDF | F value | Pr(>F) | p |
|---|---|---|---|---|---|---|---|
| **Storage** | 510.2 | 255.09 | 2 | 32.94 | 166.56 | < 2.2e-16*** | <0.01 |
| **Week** | 13046.2 | 1087.18 | 12 | 372.09 | 709.87 | < 2.2e-16*** | <0.01 |
| **Storage: Week** | 4100.8 | 170.87 | 24 | 372.08 | 111.57 | < 2.2e-16*** | <0.01 |

Signif. codes : 0 ***, 0.001 **, 0.01 *, 0.05.

The results showed a significant difference (F=709.87, p<0.01) in the weight loss percentage during the storage duration. Conversely, the highest weight loss percentage, recorded at 31.99%, was observed in apples stored at D24, followed by those stored at D15, which exhibited an 18.77% reduction by the end of the storage period. The minimum weight loss percentage (5.99%) was recorded for D03. There is a significant difference (F=166.56, p<0.01) between D03, D15, and D24 storages. The analysis demonstrated a significant interaction between storage conditions and time. (F=111.57, p<0.01), which indicates that the weight loss percentage of apples was not the same for D03, D15, and D24 storage, and the influence of storage conditions on weight loss percentage changed throughout the weeks

Based on the post-hoc tests performed, it can be stated that the calculated values differ significantly (p<0.0001) for all three storage methods (D03; D15; D24). During 12 weeks of storage, percentage weight loss increased for apples stored in the dark chamber at T=3°C (D03), T=15°C (D15) and T=24°C (D24), as shown in Fig. 8.

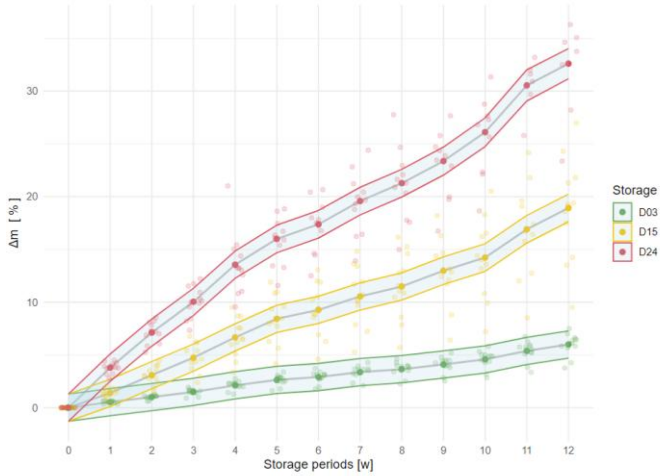



Fig. 8. Weight loss (%) of apples stored in a dark chamber (D) at temperatures T=24°C, T=3°C and T=15°C

The relationship between storage duration (w=weeks) and weight loss percentage (Δm) of apples stored at different temperatures is presented by the following equations:

D03; T= 3°C; Δm (%) = 0.4931·w where $R^2$ = 0.9865; w ∈ [0-12] weeks; RH85±5%
D15; T= 15°C;Δm (%) = 1.5216·w where $R^2$ = 0.9911; w ∈ [0-12] weeks; RH85±5%
D24; T= 24°C;Δm (%) = 2.7253·w where $R^2$ = 0.9772; w ∈ [0-12] weeks; RH60±5%
(D03; T= 3°C; w=12; RH85±5% / D15; T= 15°C; w=12; RH85±5% / D24; T= 24°C; w=12; RH60±5%)

To specifically compare storage temperatures (D03, D15) under constant relative humidity, the D24 setting was excluded from this analysis. The analysis was performed using the Satterthwaite method within an analysis of variance framework. The results showed a significant difference (F=78.995, p<0.01) in weight loss percentage between D03 and D15 during the 12-week storage period.

Our results show that storing Golden Delicious apples at 3°C with 85±5 % relative humidity can extend shelf life. Conversely, storing apples at higher temperatures, such as 24°C under 60±5%RH, results in faster ripening, lower quality, and higher vulnerability to spoilage.

### *3.1.2. Effect of storage temperature on colour parameters (ΔE, C*, h°)*

The C* values increased rapidly for apples stored at D15, from 51.60 to 57.98 from week 0 to week 12, and from 51.58 to 58.30 from week 0 to week 12 for apples stored at D24. Over the weeks, the statistical analysis showed a significant (F=41.5106, p<0.01) difference in chroma values. These findings show that, independent of storage temperature, the period of storage has a significant impact on the intensity of apple colouration. On the other hand, I found that differences in storage temperature lead to notable variations in the intensity of colouration; the storage at different temperatures, 3°C, 15°C, and 24°C, showed a significant ($F=27.6008$, $p<0.01$) difference in the chroma. For apples stored at 3°C, the highest chroma value was recorded in week 12 of cold storage, with 55.19, as shown in Fig. 9. The higher the chroma values, the more intense the colour of the samples will appear to humans. I found that cold storage can delay the increase in chroma value and the development of physiological peel disorders. The analysis demonstrates that storage duration and temperature independently affect the chroma of apples, while the difference between them is significant ($F= 4.0858$, $p<0.01$) and further influences how colouration evolves. The analysis results for the change in C* are presented in the following Table 2. at different storage temperatures (D03, D15, D24), with constant and identical relative humidity.

Table 2. Results of ANOVA analysis of the change in C* values as a function of storage temperature

| | Sum Sq | Mean Sq | NumDF | DenDF | F value | Pr(>F) | p |
|---|---|---|---|---|---|---|---|
| **Storage** | 139.28 | 69.640 | 2 | 33.05 | 27.6008 | 8.937e-08 *** | <0.01 |
| **Week** | 1256.83 | 104.736 | 12 | 373.48 | 41.5106 | < 2.2e-16 *** | <0.01 |
| **Storage: Week** | 247.41 | 10.309 | 24 | 373.44 | 4.0858 | 1.697e-09 *** | <0.01 |

Signif. codes : 0 ***, 0.001 **, 0.01 *, 0.05.

The difference must be checked with post-hoc tests.
Based on the post-hoc tests performed, it can be stated that the calculated values differ significantly ($p<0.05$) for all three storage methods (D03, D15, D24).

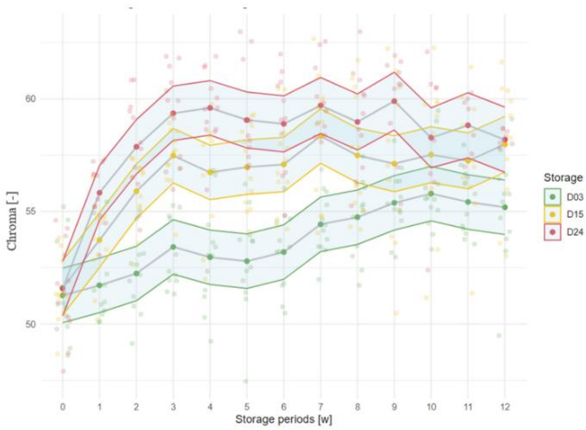



Fig. 9. Estimated marginal means of chroma (C*) over storage weeks in a dark chamber (D) at temperatures T=24°C, T=3°C and T=15°C

The evolution of Chroma (C*) of apples stored at different temperatures as a function of storage duration is described by the following equations:

D03; T= 3°C; $C^* = -0.0091 \cdot w^2 + 0.4839 \cdot w + 51.3$ where $R^2 = 0.9237$; $w \in [0\text{-}12]$ weeks
D15;T= 15°C; $C^* = -0.064 \cdot w^2 + 1.1507 \cdot w + 52.912$ where $R^2 = 0.8019$; $w \in [0\text{-}12]$ weeks
D24; T= 24°C; $C^* = -0.1222 \cdot w^2 + 1.7929 \cdot w + 53.582$ where $R^2 = 0.8001$; $w \in [0\text{-}12]$ weeks
(D03; T= 3°C; w=12; RH85±5% / D15; T= 15°C; w=12; RH85±5% / D24; T= 24°C; w=12; RH60±5%)

I calculated the colour difference (ΔE) for the three storages once a week until the end of the storage process, as shown in Fig. 10. The obtained results clearly show an increased and visible colour difference in the colour of Golden Delicious apples there is a significant (F=194.917, p<0.01) difference in the measured ΔE over time. For D03 and D15, ΔE increased from 0 to 6.62. and from 0 to 14.07, respectively, from week 0 to week 12. For apples stored at D24, an increase in ΔE was observed from week 0 to week 12, from 0 to 18.93. The statistical analysis showed a significant (F=113.930, p<0.01) difference in the ΔE values between apples stored in D03, D15, and D24.
For apples stored at D03, (ΔE > 3) was noticed from week 3 of the storage period. For apples stored at D15, (ΔE > 3) was seen starting from week 1. However, for D24 storage, from the first week, ΔE > 5. This study statistically validated a significant (F=14.897, p<0.01) interaction between storage temperatures and time.
The analysis results for the change in ΔE are presented in the Table 3. at different storage temperatures (D03, D15, D24), with constant and identical relative humidity.

Table 3. Results of ANOVA analysis of the change in ΔE values as a function of storage temperature

| | Sum Sq | Mean Sq | NumDF | DenDF | F value | Pr(>F) | p |
|---|---|---|---|---|---|---|---|
| **Storage** | 477.2 | 238.62 | 2 | 33.37 | 113.930 | 1.231e-15 *** | <0.01 |
| **Week** | 4898.9 | 408.24 | 12 | 374.83 | 194.917 | < 2.2e-16 *** | <0.01 |
| **Storage: Week** | 748.8 | 31.20 | 24 | 374.78 | 14.897 | < 2.2e-16 *** | <0.01 |

Signif. codes : 0 ***, 0.001 **, 0.01 *, 0.05.

Based on the post-hoc tests performed, it can be stated that the calculated values differ significantly (p<0.001) for all three storage methods (D03, D15, D24).

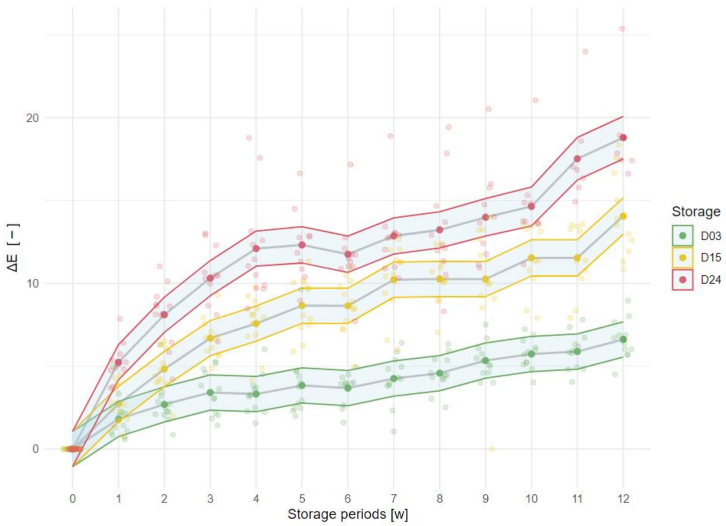



Fig. 10. Estimated marginal means of ΔE over storage weeks in a dark chamber (D) at temperatures T=24°C, T=3°C and T=15°C

The relationship between the storage period (w-week) and ΔE of apples stored at D03, D15, and D24 is described by the following equations:

| | | | |
|---|---|---|---|
| D03; T= 3°C; | $\Delta E = 0.5975 \cdot w$ | where $R^2 = 0.819$; | $w \in [0\text{-}12]$ weeks |
| D15; T= 15°C; | $\Delta E = 1.2768 \cdot w$ | where $R^2 = 0.8075$; | $w \in [0\text{-}12]$ weeks |
| D24; T= 24°C; | $\Delta E = 1.6842 \cdot w$ | where $R^2 = 0.7189$; | $w \in [0\text{-}12]$ weeks |

(D03; T= 3°C; w=12; RH85±5% / D15; T= 15°C; w=12; RH85±5% / D24; T= 24°C; w=12; RH60±5%)

To specifically compare storage temperatures (D03, D15) under constant relative humidity, the D24 setting was excluded from this analysis. The analysis was performed using the Satterthwaite method within an analysis of variance framework. The results showed a significant difference ($F=130.942$, $p<0.01$) in ΔE between D03 and D15 during the 12-week storage period.

The hue angle decreased for D03, D15, and D24 over time, as shown in Fig. 11. From week 0 to week 12, the values decreased from 94.34 to 90.94 for D03 and 93.66 to 83.30 for D15, respectively. For apples stored at D24, the hue angle decreased from week 0 to week 12 from 93.46 to 78.37. The change in Hue angle values over the storage (w) weeks was analysed using Linear Mixed Models (LMM) with Satterthwaite's method to analyse variance. The results, which examine the relationship between Hue angle and storage time at different temperatures (D03, D15, D24) under constant and identical relative humidity, are summarised in Table 4.

Table 4. Results of ANOVA analysis of the change in h° value as a function of storage temperature

| | Sum Sq | Mean Sq | NumDF | DenDF | F value | Pr(>F) | p |
|---|---|---|---|---|---|---|---|
| **Storage** | 117.2 | 58.583 | 2 | 33.11 | 49.933 | 1.009e-10 *** | <0.01 |
| **Week** | 3207.9 | 267.321 | 12 | 373.23 | 227.848 | < 2.2e-16*** | <0.01 |
| **Storage: Week** | 732.1 | 30.502 | 24 | 373.22 | 25.998 | < 2.2e-16*** | <0.01 |

Signif. codes : 0 ***, 0.001 **, 0.01 *, 0.05.

The statistical results showed that the storage duration significantly (F= 227.07, $p < 0.01$) impacts the hue angle of stored apples, and the storage temperature (3°C, 15°C, or 24°C) significantly (F=49.933, $p < 0.01$) impacts hue angle. On the other hand, the interaction between storage duration and storage temperature is statistically significant (F= 25.998, $p<0.01$), and the changes in hue angle over time are temperature-dependent.
Based on the post-hoc tests performed, it can be stated that the calculated values differ significantly ($p<0.001$) for all three storage methods (D03, D15, D24).

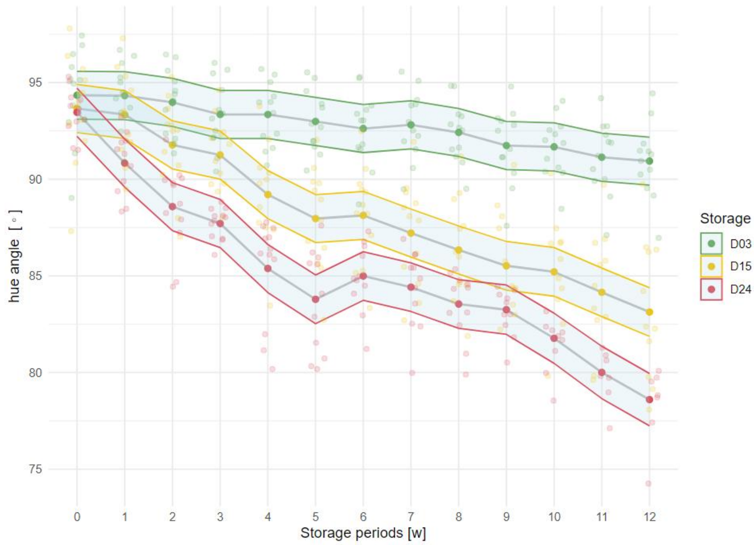



Fig. 11. Estimated marginal means of hue angle over storage weeks at different temperatures (3°C, 15°C, 24°C)

The relationship between the storage period (w-week) and hue angle (h°) of apples stored at D03, D15, and D24 is described by the following equations:

| | | | |
|---|---|---|---|
| D03; T= 3°C; | $h° = -0.2913\ w + 94.484$ | where $R^2 = 0.9804$; | $w \in [0\text{-}12]$ weeks |
| D15; T= 15°C; | $h° = -0.842\ w + 93.356$ | where $R^2 = 0.9784$; | $w \in [0\text{-}12]$ weeks |
| D24; T= 24°C; | $h° = -1.0515\ w + 91.315$ | where $R^2 = 0.9239$; | $w \in [0\text{-}12]$ weeks |

(D03; T= 3°C; w=12; RH85±5% / D15; T= 15°C; w=12; RH85±5% / D24; T= 24°C; w=12; RH60±5%)

To specifically compare storage temperatures (D03, D15) under constant relative humidity, the D24 setting was excluded from this analysis. The analysis was performed using the Satterthwaite method within an analysis of variance framework. The results showed a significant difference ($F=22.00$, $p<0.01$) in the hue angle (h°) between D03 and D15 during the 12-week storage period.

Apples' visual attractiveness and nutritional value can be affected by variations in the concentration and distribution of pigments, such as chlorophyll and carotenoids, when stored at different temperatures. As apples are climacteric fruits, they continue to ripen even during storage, losing their green colour due to chlorophyll reduction. Chlorophyll synthesis begins to slow down during storage, while new pigments take their place. As a result, the apples start to lose their vibrant green colour and shift toward yellow. Higher temperatures could accelerate colour changes over time, while lower temperatures might moderate them. Our findings indicated that D03 storage is more effective in preserving the apple's colour for prolonged periods and helps to prevent significant colour changes. In contrast, D15 and D24 cause rapid colour changes, quickly making the apples less visually attractive.

## 3.2. Effect of light and dark storage on Golden Delicious apple properties

### *3.2.1. Effect of light and dark conditions on weight loss percentage*

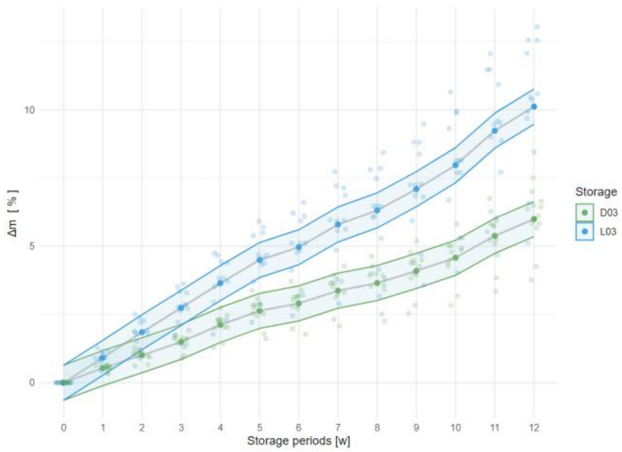



Fig. 12. Estimated marginal means of apple weight loss percentage over storage weeks under D03 and L03

The apples were stored in a refrigerated chamber under normal atmospheric conditions where measurements monitored temperature and humidity values.

The weight loss percentage increased in storage D03 and L03, as shown in Fig.12. The results showed significant ($F=441.041$, $p<0.01$) differences for D03 and L03 in the weight loss percentage throughout the storage weeks.

On the other hand, the weight loss percentage was noticeably more significant for apples stored at L03, with a maximum weight loss percentage of 10.11%, while the maximum weight loss percentage for apples stored at D03 attained 5.99%. A fluorescent light source did not significantly affect the stored apples' temperature, as the cooling system maintained the required conditions with its efficient air circulation. The statistical analysis, using Linear Mixed Models (LMM) with Satterthwaite's method to analyse variance, showed significant ($F=29.660$, $p<0.01$) differences in apple weight loss percentage stored at D03 and L03 during the experiment. The storage under light exposure L03 affects more $\Delta m$ [%] than D03. The latter retained the weight of apples for a more extended period. The weight loss percentage of apples was not the same for L03 and D03 storage, and the impact of storage conditions on weight loss percentage changed each week. This study demonstrated a statistically significant interaction between storage condition and time ($F=29.666$, $p<0.01$). The results, which examine the relationship between $\Delta m$ and storage conditions (light L03 and dark D03) at 3°C under constant and identical relative humidity, are summarised in Table 5.

Table 5. Results of ANOVA analysis of the change in $\Delta m$ value as a function of storage condition (D03 and L03)

| | **Sum Sq** | **Mean Sq** | **NumDF** | **DenDF** | **F value** | **Pr(>F)** | **p** |
|---|---|---|---|---|---|---|---|
| **Storage** | 10.04 | 10.043 | 1 | 22 | 29.660 | 1.802e-05 *** | <0.01 |
| **Week** | 1792.04 | 149.336 | 12 | 264 | 441.041 | < 2.2e-16 *** | <0.01 |
| **Storage: Week** | 120.54 | 10.045 | 12 | 264 | 29.666 | < 2.2e-16 *** | <0.01 |

Signif. codes : 0 ***, 0.001 **, 0.01 *, 0.05.

The following equations describe the relationship between $\Delta m$ and storage duration for apples kept at 3°C in two different conditions: light (L03) and dark (D03):

L03; T=3°C; $\Delta m\ (\%) = 0.8443 \cdot w$ where $R^2 = 0.9894$; $w \in [0-12]$ weeks

D03; T=3°C; $\Delta m\ (\%) = 0.4931 \cdot w$ where $R^2 = 0.9865$; $w \in [0-12]$ weeks

(L03; T= 3°C; w=12; RH85±5% / D03; T= 3°C; w=12; RH85±5%)

Our findings indicate that the efficacy of storage conditions may change over time. Therefore, it is critical to consider storage conditions and duration when preserving Golden Delicious apples.

### *3.2.2. Effect of light and dark conditions on colour parameters ($\Delta E$, $C^*$, $h°$)*

The highest chroma values were recorded in week 12, measuring 55.82 and 55.19 for apples stored under L03 and D03 conditions, respectively, as illustrated in Fig.13.

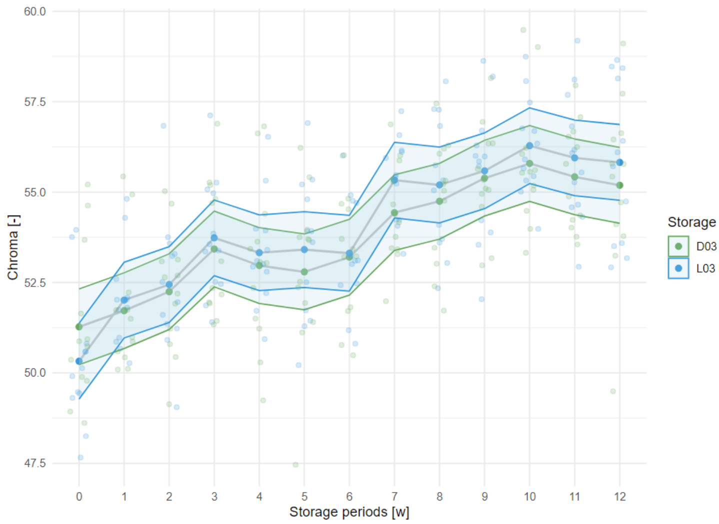



Fig. 13. Estimated marginal means of C* over storage weeks under D03 and L03 for apples

Table 6. presents the analysis results for the change in C* at different storage conditions (D03, L03), with constant and identical relative humidity and temperature (3°C RH85±5%).

Table 6. Results of ANOVA analysis of the change in C* values as a function of storage conditions (D03 and L03)

| | Sum Sq | Mean Sq | NumDF | DenDF | F value | Pr(>F) | p |
|---|---|---|---|---|---|---|---|
| **Storage** | 0.36 | 0.357 | 1 | 22 | 0.2864 | 0.5979 | 0.5979 |
| **Week** | 788.30 | 65.692 | 12 | 264 | 52.7169 | < 2.2e-16 *** | <0.001 |
| **Storage: Week** | 13.81 | 1.151 | 12 | 264 | 0.9236 | 0.5238 | 0.5238 |

Signif. codes : 0 ***, 0.001 **, 0.01 *, 0.05

The ANOVA results demonstrated that storage duration significantly (F =52.7169, p<0.01) impacts the chroma of apples stored at 3°C, which undergoes pronounced changes over time. However, there was no significant difference in chroma (F=0.2864, p=0.5979) between apples stored in light (L03) and dark (D03) conditions. Furthermore, the interaction between storage conditions and time was not significant (F=0.9236, p=0.5238), which indicates that the influence of time on chroma is independent of storage conditions. The results indicate that chroma values exhibit a similar pattern over time, regardless of the storage conditions. The relationship between C* and storage duration for apples kept at L03 and D03 is described by the following equations:

L03; T= 3°C; $C^* = -0.015 \cdot w2 + 0.6389 \cdot w + 51.018$ where $R^2 = 0.9163$; $w \in [0\text{-}12]$ weeks

D03; T= 3°C; $C^* = -0.0091 \cdot w2 + 0.4839 \cdot w + 51.3$ where $R^2 = 0.9237$; $w \in [0\text{-}12]$ weeks

(L03; T= 3°C; w=12; RH85±5% / D03; T= 3°C; w=12; RH85±5%)

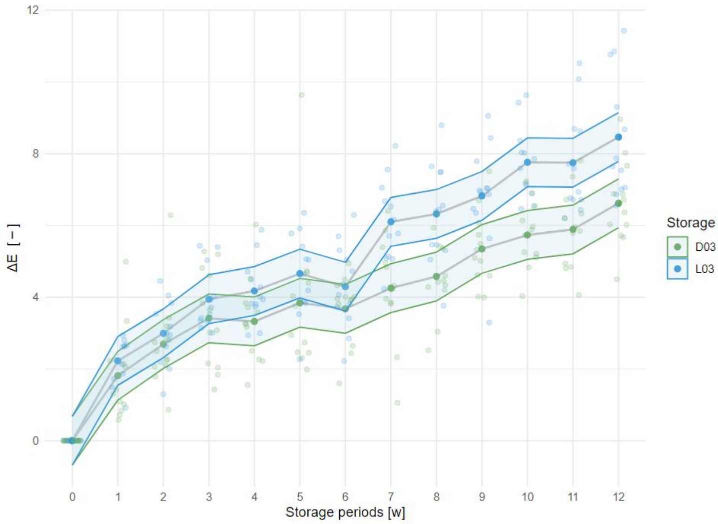



Fig. 14. Estimated marginal means of ΔE over storage weeks under D03 and L03 for apples

Fig. 14 illustrates that the ΔE increased for apples stored in the lightroom and darkroom. The highest ΔE values, 8.46 and 6.62 for apples kept at L03 and D03, respectively, were noted in week 12.
The analysis results for the change in ΔE are presented in Table 7.

Table 7. Results of ANOVA analysis of the change in ΔE values as a function of storage conditions (D03 and L03) for apples

| | Sum Sq | Mean Sq | NumDF | DenDF | F value | Pr(>F) | p |
|---|---|---|---|---|---|---|---|
| **Storage** | 10.19 | 10.187 | 1 | 22 | 11.837 | 0.002334 ** | <0.01 |
| **Week** | 1302.36 | 108.530 | 12 | 264 | 126.118 | < 2.2e-16 *** | <0.01 |
| **Storage: Week** | 36.78 | 3.065 | 12 | 264 | 3.562 | 6.278e-05 *** | <0.01 |

Signif. codes : 0 ***, 0.001 **, 0.01 *, 0.05.

The findings indicate a statistically significant difference ($F=11.837$, $p<0.01$) in ΔE values between apples stored in D03 and L03. According to the statistical findings, time has a significant effect on how the apples' colour changes over weeks, independent of storage conditions ($F=126.118$, $p<0.01$). There are three categories for differences in visible colour: highly noticeable when $\Delta E > 3$, noticeable when $1.5 < \Delta E < 3$, and subtle differences when $\Delta E < 1.5$. For apples stored at L03, the colour difference ($\Delta E > 3$) is noticeable from the second week of storage. However, for apples stored at D03, a distinct colour difference ($\Delta E > 3$) is observed starting from the third week of storage.

The present study statistically validated a significant interaction ($F=3.562$, $p<0.01$) between storage conditions and time. Storing the apples in L03 or

D03 affects how this parameter changes over time.

The following equations describe the correlation between ΔE and the storage period for apples stored at L03 and D03:

L03; T= 3°C; $\Delta E = 0.7767 \cdot w$ where $R^2 = 0.8555$; $w \in [0\text{-}12]$ weeks

D03; T= 3°C; $\Delta E = 0.5975 \cdot w$ where $R^2 = 0.819$; $w \in [0\text{-}12]$ weeks

(L03; T= 3°C; w=12; RH85±5% / D03; T= 3°C; w=12; RH85±5%)

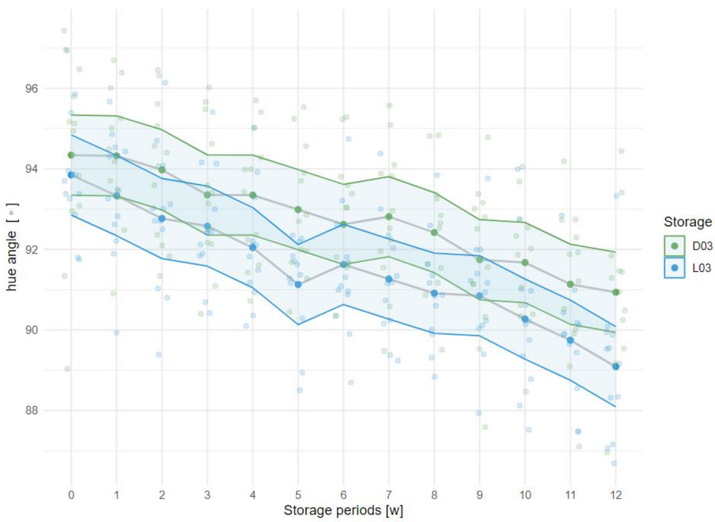



Fig. 15. Estimated marginal means of hue angle over storage weeks under D03 and L03 for apples

As shown in Fig.15, the hue angle values for apples stored at L03 and D03 decreased from 93.85 to 89.09 and 94.34 to 90.94, respectively, from week 1 to week 12. This decrease reflected variations in the apple's shade, which changed from light green to yellow during storage. The analysis results for the change in Hue angle are presented in Table 8.

Table 8. Results of ANOVA analysis of the change in Hue angle ($h^o$) values as a function of storage conditions (D03 and L03) for apples

| | Sum Sq | Mean Sq | NumDF | DenDF | F value | Pr(>F) | p |
|---|---|---|---|---|---|---|---|
| **Storage** | 1.98 | 1.983 | 1 | 22 | 3.9037 | 0.06085 | 0.06 |
| **Week** | 453.43 | 37.785 | 12 | 264 | 74.3659 | < 2e-16 *** | <0.01 |
| **Storage: Week** | 11.94 | 0.995 | 12 | 264 | 1.9581 | 0.02832 * | <0.05 |

Signif. codes : 0 ***, 0.001 **, 0.01 *, 0.05

The statistical analysis indicated a significant difference ($F=4.3659$, $p<0.01$) between the $h^o$ measured in the first and last weeks, regardless of whether the apples were in the dark or the presence of light. On the other hand, the statistical analysis indicated that storage conditions (light vs.

dark) had a non-significant effect ($F=3.9037$, $p=0.06085$) on the hue angle. Additionally, the interaction between storage duration and storage condition is statistically significant ($F=1.9581$, $p<0.05$), indicating that the effect of storage duration on the hue angle varies slightly between light and dark conditions.

The following equations describe the relationship between the hue angle and the storage period for apples stored at L03 and D03:

L03; T=3°C; $h^o = -0.3461\ w + 93.582$ where $R^2 = 0.9654$; $w \in [0\text{-}12]$ weeks

D03; T=3°C; $h^o = -0.2913\ w + 94.484$ where $R^2 = 0.9804$; $w \in [0\text{-}12]$ weeks

(L03; T= 3°C; w=12; RH85±5% / D03; T= 3°C; w=12; RH85±5%)

### 3.3. Relationship between weight loss percentage and colour parameters

A linear regression model was employed to examine the relationship between the two variables as part of the data analysis. The findings from the linear regression analysis are presented in Table 9.

Table 9. The results of the linear regression for the independent variables $h^o$ and $\Delta m$ in the case of apple storage

| | **$R^2$** | **F** | **Pr(>F)** | **p** | **m** | **b** |
|---|---|---|---|---|---|---|
| **L03** | 0.969 | 373.3 | 2E-10 | <0.01 | -0.411 | 93.59 |
| **D03** | 0.976 | 484.7 | 5E-11 | <0.01 | -0.582 | 94.45 |
| **D15** | 0.978 | 546.1 | 2E-11 | <0.01 | -0,553 | 93.36 |
| **D24** | 0.966 | 316.8 | 2E-09 | <0.01 | -0,426 | 92.17 |

(L03; T= 3°C; w=12; RH85±5% / D03; T= 3°C; w=12; RH85±5% / D15; T= 15°C; w=12; RH85±5% / D24; T= 24°C; w=12; RH60±5%)

A correlation study was conducted to investigate the relationship between these factors and the interaction between physical alterations and visual quality after storage. A linear correlation was found between weight loss percentage and hue angle under varying storage temperatures. The high $R^2$ values of the coefficient of determination indicated the strong correlation between weight loss percentage and hue angle. Our results show a good correlation between weight loss percentage and hue angle during storage, which suggests that as the fruit loses weight, possibly due to water loss, respiration, and transpiration processes, there are concurrent changes in its colour. During the data analysis, the linear relationship between the two variables was explored using linear regression. The results of the linear regression are summarised in Table 10.

Table 10. Results of the linear regression for the independent variables $\Delta E$ and $\Delta m$ in the case of apple storage

| | **$R^2$** | **F** | **Pr(>F)** | **p** | **m** | **b** |
|---|---|---|---|---|---|---|
| **L03** | 0.972 | 377.4 | 7E-10 | <0.01 | 0.672 | 1.789 |
| **D03** | 0.973 | 393.4 | 6E-10 | <0.01 | 0.848 | 1.614 |
| **D15** | 0.96 | 264.3 | 5E-09 | <0.01 | 0.579 | 3.294 |
| **D24** | 0.936 | 145.2 | 3E-07 | <0.01 | 0.414 | 4.766 |

(L03; T= 3°C; w=12; RH85±5% / D03; T= 3°C; w=12; RH85±5% / D15; T= 15°C; w=12; RH85±5% / D24; T= 24°C; w=12; RH60±5%)

The slopes of the trendlines indicate the rate of colour change per unit of weight loss percentage. The highest slope was observed under D03 storage (0.848), indicating that weight loss percentage correlates most strongly with colour change in dark storage at 3°C. Weight loss percentage is less significantly correlated with colour change in D24 storage, where the slope was lowest (0.414)

D24 and D15 storages had higher intercepts compared to L03 and D03. Apples kept at higher temperatures changed colour more and lost less weight. The temperature has a significant effect on how quickly colour deteriorates. Weight loss percentage was more directly correlated with L03 and D03 storage, which was also strongly correlated with colour changes. Even at reduced rates of weight loss percentage, D24 storage, however, resulted in much quicker and more significant colour change.

### 3.4. Control parameters results

Apples stored at D03 showed a moderate TSS increase from 12.00 to 13.13 °Brix. In comparison, those in L03 exhibited a slightly higher rise from 12.00 to 13.63 °Brix, suggesting that light exposure may accelerate sugar accumulation even at low temperatures. After storage at D15, TSS increased significantly from 12.00 to 14.70 °Brix, which indicates an increased metabolic activity at this intermediate temperature. The most notable change occurred at D24, when the TSS rose to 16.67 °Brix due to moisture loss at high temperatures and rapid starch-to-sugar conversion.

Table 11. pH and TSS at the beginning and end of storage

| | **pH [-]** | | **TSS [°Brix]** | |
|---|---|---|---|---|
| **Storage** | week 0 | week 12 | week 0 | week 12 |
| **D03** | 3.88 | 3.89 | 12.00 | 13.13 |
| **L03** | 3.88 | 3.94 | 12.00 | 13.63 |
| **D24** | 3.88 | 5.00 | 12.00 | 16.67 |
| **D15** | 3.88 | 4.18 | 12.00 | 14.7 |

(L03; T= 3°C; w=12; RH85±5% / D03; T= 3°C; w=12; RH85±5% / D15; T= 15°C; w=12; RH85±5% / D24; T= 24°C; w=12; RH60±5%)

Table 11. shows pH measurements in Golden Delicious apples under four distinct storage conditions at the beginning and end of storage over 12 weeks. All treatments began with identical initial pH values (3.88). However, the final pH measurements showed significant changes based on storage conditions. D24 storage showed the most significant pH elevation, which could be related to accelerated metabolic consumption of organic acids. On the other hand, D03 storage maintained near-stable pH level

# 4. NEW SCIENTIFIC RESULTS

In this chapter, I present new scientific findings based on the results obtained during my research.

1. *Changes in weight loss percentage (Δm) of stored apples depending on the storage temperature*

Based on the experimental results, I have established new linear correlations that can be used to predict the weight loss percentage (Δm) of Golden Delicious apples during storage as a function of the number of weeks elapsed (w), considering different storage temperatures (T) at the same relative humidity (RH).

D03; T=3°C; $\Delta m\ (\%) = 0.4931 \cdot w$ where $R^2 = 0.9865$; $w \in [0\text{-}12]$ weeks; RH85±5%
D15; T=15°C; $\Delta m\ (\%) = 1.5216 \cdot w$ where $R^2 = 0.9911$; $w \in [0\text{-}12]$ weeks; RH85±5%

I found that the weight loss percentage (Δm) of Golden Delicious apples during 12 weeks of storage increases linearly from the beginning of storage at both 3°C and 15°C, under constant relative humidity (RH 85 ± 5%) and in dark storage. The slope of the linear relationship is 0.4931 for apples stored at 3°C and 1.5216 for those stored at 15°C, with coefficients of determination $R^2=0.9865$ and $R^2=0.9911$, respectively. During the statistical analysis, I used linear mixed model (LMM) and ANOVA, and the results showed a significant ($F=78.995$, $p<0.01$) difference in weight loss percentage (Δm) at different storage temperatures (D03, D15).

2. *Changes in weight loss percentage (Δm) of stored apples depending on the light and dark conditions*

Based on the experimental findings, I developed new linear equations that could be utilised for estimating the weight loss percentage (Δm) of Golden Delicious apples during storage as a function of the elapsed weeks (w), considering light (L) and dark (D) storage conditions at the same temperature (T) and relative humidity (RH).

L03; T=3°C; $\Delta m\ (\%) = 0.8443 \cdot w$ where $R^2 = 0.9894$; $w \in [0\text{-}12]$ weeks; RH85±5%
D03; T=3°C; $\Delta m\ (\%) = 0.4931 \cdot w$ where $R^2 = 0.9865$; $w \in [0\text{-}12]$ weeks; RH85±5%;

I found that the weight loss percentage (Δm) of Golden Delicious apples during 12 weeks of storage increases linearly from the beginning of storage under both light and dark conditions, at a constant temperature of 3 °C and relative humidity (RH 85 ± 5%). The slope of the linear relationship is 0.8443 for apples stored in a light room storage and 0.4931 for those stored in a dark room storage, with coefficients of determination $R^2=0.9894$ and

$R^2$=0.9865, respectively. During the statistical analysis, I used a linear mixed model (LMM) and ANOVA, and the results showed a significant ($F$=29.660, $p$<0.01) difference in weight loss percentage ($\Delta m$) for apples stored in light and dark rooms (D03, L03).

3. *Changes in colour change ($\Delta E$) of stored apples depending on the storage temperatures*

Based on the experimental results, I developed new linear relationships that can be used to predict the change in the colour change ($\Delta E$) of Golden Delicious apples during storage as a function of the elapsed weeks (w), considering different storage temperatures (T) at the same relative humidity (RH).

D03; T=3°C; $\Delta E = 0.5975 \cdot w$ where $R^2 = 0.819$; $w \in [0\text{-}12]$ weeks; RH85±5%;
D15; T=15°C; $\Delta E = 1.2768 \cdot w$ where $R^2 = 0.8075$; $w \in [0\text{-}12]$ weeks; RH85±5%;

I found that the colour change ($\Delta E$) of Golden Delicious apples during 12 weeks of storage increases linearly at both 3 °C and 15 °C, under constant relative humidity (RH 85 ± 5%) and in a light-protected environment. For the linear models, the coefficient of determination was $R^2$=0.819 for apples stored at 3 °C and $R^2$=0.8075 for those stored at 15 °C. During the statistical analysis, I used a linear mixed model (LMM) and ANOVA, and the results showed a significant ($F$=130.942, $p$<0.01) difference in colour change ($\Delta E$) between the two different storage temperatures (D03, D15).

4. *Changes in hue angle (h°) of stored apples depending on the storage temperature*

Based on the experimental results, I developed new linear relationships that can be used to predict the change in the hue angle of Golden Delicious apples during storage as a function of the elapsed weeks (w), considering different storage temperatures (T) at the same relative humidity (RH).

D03; T=3°C; $h° = -0.2913 \cdot w + 94.484$ where $R^2 = 0.9804$; $w \in [0\text{-}12]$ weeks; RH85±5%;
D15; T=15°C; $h° = -0.842 \cdot w + 93.356$ where $R^2 = 0.9784$; $w \in [0\text{-}12]$ weeks; RH85±5%;

I found that the hue angle (h°) of Golden Delicious apples changes linearly over 12 weeks of storage at both 3°C and 15°C, under constant relative humidity (RH 85 ± 5%) and in a light-protected environment. For the linear models, the coefficient of determination was $R^2$=0.9804 for apples stored at 3°C and $R^2$=0.9784 for those stored at 15°C. During the statistical analysis, I used a linear mixed model (LMM) and ANOVA, and the results showed a significant ($F$=28.228, $p$<0.01) difference in hue angle ($h^0$) between the different storage temperatures (D03, D15).

*5. Changes in hue angle (h°) of stored apples depending on the light and dark conditions*

Based on the experimental results, I developed new linear relationships that can be used to predict the hue angle of Golden Delicious apples during storage as a function of the elapsed weeks (w), considering light (L) and dark (D) storage conditions at the same temperature (T=3°C) and relative humidity (RH).

L03; T=3°C; $h° = -0.3461 \cdot w + 93.582$ where $R^2 = 0.9654$; $w \in [0-12]$ weeks; RH85±5%;
D03; T=3°C; $h° = -0.2913 \cdot w + 94.484$ where $R^2 = 0.9804$; $w \in [0-12]$ weeks; RH85±5%;

I found that the hue angle (h°) of Golden Delicious apples during 12 weeks of storage changed linearly under light and dark conditions, at a constant temperature of 3 °C and relative humidity (RH 85 ± 5%). For the linear models, the coefficient of determination was $R^2$=0.9654 for apples stored under light conditions and $R^2$=0.9804 for those stored in darkness. During the statistical analysis, I used a linear mixed model (LMM) and ANOVA, and the results showed no significant ($F=3.903$, $p=0.06$) difference in hue angle (h°) between samples stored in light and dark rooms (D03, L03).

## 5. CONCLUSION AND SUGGESTIONS

The study investigated the effects of different storage temperatures: 3℃ (D03; RH 85±5%), 15℃ (D15; RH 85±5%), and 24℃ (D24; RH 60±5%) and the impact of storage under light (L03) and dark (D03) conditions on the state of Golden Delicious apples during 12 weeks, using non-destructive methods. Based on the experimental results, the following conclusions can be drawn for Golden Delicious apples during storage:

- New linear correlations were developed to predict apple weight loss percentage (Δm) as a function of storage time, showing high reliability with $R^2$ values exceeding 0.97 for different temperature conditions.
- Statistical analysis using a linear mixed model and ANOVA confirmed significant differences ($p<0.01$) among the three temperature conditions, and post-hoc tests confirmed the effect of temperature on the apple weight loss percentage during the 12-week apple storage experiment. For D03 and D15, the weight loss percentage rate at 15°C is higher than at 3°C ($F=78.995$, $p<0.01$).
- Apples stored at 3℃ under light (L03) experienced more significant weight loss percentage (Δm) than those stored in darkness (D03), a difference supported by statistical analysis.
- Statistical analysis confirmed significant differences in ΔE across apple storage temperatures, with post-hoc tests supporting the temperature-dependent effects.
- Apples stored under light exhibited a slightly higher rate of colour change (ΔE) compared to dark storage.
- Apple hue angle (h°) decreased with advancing storage, and higher temperatures accelerated the rate of change.
- Under constant RH (85±5%) and dark conditions, h° decreases linearly with storage time (w-weeks) at both temperatures D03 and D15, and ANOVA confirms significantly faster colour shift at 15°C than at 3°C.
- ANOVA confirmed significant differences ($p<0.01$) between apple storage temperatures, and the post-hoc test indicated that all temperature treatments significantly affected hue angle ($p<0.001$).
- No significant difference was observed in hue angle (h°) change between apples stored in light and dark.

Finally, further studies can explore integrating advanced non-destructive monitoring techniques, such as hyperspectral imaging or machine vision systems, with statistical modelling in R that could enable real-time quality tracking and predictive analysis.

# 6. SUMMARY

## NON-DESTRUCTIVE TESTING OF THE RELATIONSHIP BETWEEN APPLE STORAGE TECHNOLOGIES AND PHYSICAL PARAMETERS

In this work, comprehensive experimental and numerical investigations were conducted to evaluate the quality of Golden Delicious apples during storage under various conditions. To achieve the aims of this research, Golden Delicious apples were obtained, grouped, and stored for 12 weeks under four storage conditions: darkroom at 3℃ (D03; RH 85±5%), darkroom at 15℃ (D15; RH 85±5%), darkroom at 24℃ (D24; RH 60±5%), and lightroom at 3℃ (L03; RH 85±5%). The experiment utilised non-destructive methods to measure weight loss percentage (Δm) and colour parameters, including L*, a*, b*, chroma (C*), hue angle (h°), and ΔE.

The research was divided into two parts: (1) First, apples were stored in a dark chamber at three different temperatures (D03, D15 and D24) for 12 weeks, and then (2) the properties of apples stored under dark D03 and light L03 conditions were examined at the same temperature. The Nix Pro wireless colour sensor and its associated application were used to measure colour parameters. All experimental investigations were conducted in the Machinery and Food Technology Laboratory at the Hungarian University of Agriculture and Life Sciences (MATE) in Gödöllő, Hungary. Statistical analyses, including ANOVA and correlation analysis, were performed using R-Studio software to identify significant differences and relationships among the parameters. The experiment outcomes revealed a significant difference ($p<0.01$) between the values measured at the start and end states for all parameters across the four storage conditions over the 12 weeks. Results showed that storage conditions, such as higher temperatures, significantly increased weight loss percentage (Δm). The D24 exhibited the highest loss, at 31.98%. Also, higher temperatures accelerated changes in colour parameters. Storing Golden Delicious apples at D03 exhibited the least colour degradation, slowed down respiration and transpiration processes, and extended shelf life. Storing apples at higher temperatures results in faster ripening, lower quality, and increased vulnerability to spoilage.

The study also revealed that weight loss percentage increased in both D03 and L03 storage conditions, with L03 causing more significant weight loss percentage. The comparison between D03 and L03 indicated that light exposure at 3℃ resulted in a slightly higher rate of colour change than dark storage, though the effect was less impactful than temperature elevation.

## 7. MOST IMPORTANT PUBLICATIONS RELATED TO THE THESIS

Refereed papers in foreign languages:


1. **Kassebi, S**., Korzenszky, P. (2024): Examination of weight loss and colour changes in Golden Delicious apples under light and dark storage conditions. Progress in Agricultural Engineering Sciences, Vol. 20(1), pp. 199–215.https://doi.org/10.1556/446.2024.00135 **(Scopus: Q2)**
2. **Kassebi, S.**, Korzenszky, P. (2024): Influence of ambient storage on weight, color, and TSS in Golden Delicious apples: A correlational study. *Hungarian Agricultural Engineering*, Vol. 43, pp. 18–25. https://doi.org/10.17676/HAE.2024.43.18
3. **Kassebi, S.**, Korzenszky, P. (2024): Cold storage effects on ethylene emission, $CO_2$ accumulation, and TSS variation in Golden Delicious apples at 3°C. *Journal of Central European Green Innovation*, Vol. 12(3), pp. 199–215. https://doi.org/10.33038/jcegi.6441
4. **Kassebi, S.**, Farkas, C., Székely, L., Géczy, A., Korzenszky, P. (2023): Late shelf life saturation of Golden Delicious apple parameters: TSS, weight, and colorimetry. *Applied Sciences*, Vol. 13(1), Paper No. 159. https://doi.org/10.3390/app13010159 **(Scopus: Q2, IF: 2.5)**
5. **Kassebi, S.**, Korzenszky, P. (2022): The Influence of Storage Temperature on the Weight of Golden Delicious Apples. *Hungarian Agricultural Engineering*, Vol. 41, pp. 5–10. https://doi.org/10.17676/HAE.2022.41.5
6. Ghabour, R., **Kassebi, S**., Korzenszky, P. (2021): Simulation and experiment of apple fruits in domestic fridge. *Hungarian Agricultural Research: Environmental Management, Land Use, Biodiversity*, Vol. 30(2), pp. 11–14.
7. **Kassebi, S**., Korzenszky, P. (2021): The effect of post-harvest storage on the weight of Golden Delicious apples. *Science, Technology and Innovation*, Vol. 13(2), pp. 7–11. https://doi.org/10.5604/01.3001.0015.5265
8. **Kassebi, S.**, Ghabour, R., Korzenszky, P. (2021): Monitoring the preservation of apples in a domestic fridge. *Mechanical Engineering Letters: R&D: Research and Development*, Vol. 21, pp. 178–184.
9. Ben Rejeb, I., Dhen, N., **Kassebi, S.**, Gargouri, M. (2020): Quality evaluation and functional properties of reduced sugar jellies formulated from citrus fruits. *Journal of Chemistry*, Vol. 2020, pp. 1–8. https://doi.org/10.1155/2020/5476872 **(Scopus: Q2, IF: 2.8)**
10. Korzenszky, P. E., **Kassebi, S.** (2021): A tömegcsökkenés vizsgálata Golden Delicious alma tárolása esetén. *Acta Agronomica Óváriensis*, Vol. 62 (Ksz 1), pp. 128–139.