

VARIATION AND CORRELATION OF TEXTURAL AND FRUIT MATURITY PARAMETERS DURING STORAGE OF DALINBEL, JONAFREE, AND REAL APPLE CULTIVARS

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Abstract

The paper aims to identify the influence of 82 days of storage of the Dalinbel, Jonafree, and Real apple cultivars on their textural parameters: hardness, fracture force, cohesiveness, and chewiness. It also aims to identify a possible correlation between the textural parameters and fruits' maturity, characterized by chlorophyll absorbance index IAD (index of absorbance difference), glucose, and fructose concentrations. Textural parameters were measured by puncture test and texture profile analysis (TPA). Dalinbel, Jonafree, and Real apples cultivars had particular variations of textural properties during storage. No significant differences were found for cortex (pulp) tissue's hardness, cohesiveness, chewiness, and fracture force (measured by TPA) for Dalinbel apples from day 47 to 82 of storage and from day 1 to day 82 of storage for the Jonafree apples. Linear correlation analysis over all apple cultivars revealed that after 47 days of storage, there was a negative correlation between glucose concentration and fracture force ($r = -0.9995$; $p = 0.0196$). Additionally, a linear correlation was observed for IAD and fruits hardness ($r = 0.9878$, $p = 0.0028$) measured by TPA.

Key words: apple cultivars, storage, textural parameters, fruit maturity parameters, correlation.

INTRODUCTION

Textural properties are among the most critical attributes of apples, alongside their appearance, aroma, and nutritional properties, playing a significant role in consumer acceptance and preference and play an important role in the development and selection of cultivars for commercialization as fresh fruit.

In addition to aroma and color, attributes such as juiciness and crispiness are essential factors influencing consumer acceptability for different apple varieties (Tudoreanu, 2014).

The primary textural characteristics of apples that are valued and expected by consumers are commonly described as "crisp," "juicy," and "firm." (Bourne, 2002).

'Dalinbel' (DL 11/Antares) apple cultivar originates from France and is characterized by high vigor, late flowering, and pink floral buds. The fruit reaches maturity at the end of September and has a medium-to-large size with a flattened-conical shape.

Its skin features a yellow background color with a red over-color (Braniște & Uncheașu, 2011).

'Jonafree' (Coop 22) cultivar originates from the United States and exhibits medium vigor, late flowering, and pink floral buds. The fruit reaches maturity at the end of September, has a medium size, and a spherical shape. Its skin features a greenish-yellow background color with a red over-color (Braniște & Uncheașu, 2011).

'Real' (V9/78-92) cultivar originates from Romania and is characterized by medium vigor, intermediate flowering, and pink floral buds. The fruit matures in September, has a large size, and an oblong shape. Its skin features a greenish-yellow background color with a red over-color (Braniște & Uncheașu, 2011).

Fruit ripening is a complex process governed by physiological, biochemical, and genetic factors that influence apple's firmness, crispness, and juiciness. Firmness, often referred to as hardness, is a critical attribute of apple texture, reflecting the fruit's resistance to deformation and fracture. It is commonly measured using penetrometers, which evaluates the force required to puncture the fruit's flesh. Several studies (Bily et al., 2009) have shown that firmness is closely related to the fruit's storage

potential and consumer preference, with firmer apples generally being associated with longer shelf life and better texture retention. Postharvest treatments such as 1-methylcyclopropene (1-MCP) have been shown to maintain firmness by inhibiting ethylene action, thereby delaying softening (Li et al., 2019). Pre-harvest factors, including cultivar selection and growing conditions, also significantly impact firmness, as demonstrated by studies on 'Cripps Pink' apples treated with aminoethoxyvinylglycine (AVG) (Khan & Singh, 2009).

Cohesiveness refers to the degree to which the apple tissue withstands deformation before breaking. It is a measure of the fruit's intercellular adhesion strength. Cohesiveness is often evaluated using texture profile analysis (TPA), which simulates the compression and decompression of the fruit. Apples with high cohesiveness tend to have a more uniform and resilient texture, which is desirable for both fresh consumption and processing. Furthermore, the composition of cell wall polysaccharides, particularly pectin, plays a crucial role in determining cohesiveness. Studies have shown that changes in pectin composition during storage can significantly alter cohesiveness, with higher pectin content generally associated with better tissue integrity (Billy et al., 2008).

Multivariate statistical analyses of textural parameters have demonstrated that cohesiveness is influenced by the fruit's rheological properties, such as compression/extension strength, and is closely linked to texture attributes like firmness and chewiness (Ballabio et al., 2012). Chewiness is a texture attribute that describes the energy required to masticate the apple flesh to a state ready for swallowing. It is a composite parameter derived from firmness, cohesiveness, and springiness. Apples with high chewiness are often perceived as having a denser and more satisfying texture. This attribute is particularly important for consumer acceptance, as it directly impacts the sensory experience during consumption. Studies have shown that chewiness is influenced by the fruit's structural integrity and the composition of cell wall polysaccharides, which can vary significantly among different apple cultivars (Zhao et al., 2017). Additionally, sensory evaluations have demonstrated a strong correlation between chewiness and instrumental measurements of

texture, highlighting the importance of this attribute in determining overall fruit quality (Brookfield et al., 2011).

Fracture force is the maximum force required to break or rupture the apple tissue, reflecting its mechanical strength. This parameter is often measured using compression tests and is closely related to the fruit's structural properties, such as cell wall thickness and intercellular adhesion. Fracture force is a critical indicator of apple quality, as it affects both handling and processing. Apples with higher fracture force are less prone to bruising and mechanical damage during harvest and transport. Research has shown that fracture force is influenced by pre-harvest factors, including cultivar, growing conditions, and maturity at harvest (Musacchi & Serra, 2018). Additionally, postharvest storage conditions, such as temperature and humidity, can significantly impact fracture force, with improper storage leading to a rapid decline in mechanical strength (Johnston et al., 2002).

Glucose and fructose are the primary sugars in apples, contributing significantly to their sweetness and overall flavor profile. The ratio of glucose to fructose can vary among apple cultivars, influencing the fruit's taste and consumer preference. Studies have shown that glucose and fructose levels are influenced by factors such as cultivar, growing conditions, and post-harvest storage. Additionally, developmental changes in sugar content have been observed, and glucose and fructose levels increasing as the fruit matures (Zhang et al., 2010, Filip et al., 2016). The aim of the present study is to study the key textural parameters relevant to understanding consumer response (first compression hardness, fracture force, and chewiness) and to examine how these parameters may be influenced by storage duration prior to commercialization. Furthermore, the study explores the potential relationship between textural properties and the ripening stage of the fruit, as indicated by chlorophyll b content (IAD absorbance index), as well as glucose and fructose concentrations.

MATERIALS AND METHODS

The samples consist of 150 apples (50 apples /variety) from three cultivars of "*Malus domestica*": 'Dalinbel,' 'Jonafree,' and 'Real' which are cultivated in the experimental orchard

of the Faculty of Horticulture of the University of Agronomic Sciences and Veterinary Medicine of Bucharest (USAMVB).

After harvest the apples were stored for 82 days in the cold storage room of the Research Center for the Study of Agri-Food Products – HORTINVEST of USAMVB at a temperature between 1°C and 3°C. All analysis were made in day 1, day 47 and day 82 after harvest.

Textural analysis and statistical analysis were carried out in the Interdisciplinary Laboratory for the Study of Heavy Metal Accumulation and Transport in the Food Chain – HEVMETFOOD, within the Faculty of Veterinary Medicine of USAMVB. The analysis of chlorophyll, glucose and fructose concentrations were carried out in the Laboratory of Integrated Pomology of the Faculty of Horticulture of USAMVB.

Rheological Analysis

The universal testing machine Texture Analyser TAPlus, Lloyd Instruments and Nexigen Plus software were used to analyse apple's textural profile. Textural profile analysis (TPA) is a double compression test which was performed on peeled apple pulp. TPA analysis was made using 5 apples from each cultivar for each of the storage period.

The apples samples were cut as cylinders (approximatively 3cm height and 1 cm diameter). 4 cylindrical samples were cut from each fruit. The cutting was made radially, from the outer surface of the fruit towards the seed cavity. The working parameters for the TPA test were: compression speed 1 mm/s for a compression of 50% of the sample height. The height of each sample was measured using a calliper with a precision of 0.02mm. The following parameters were measured: hardness (firmness) at the first compression, chewiness, fracture force, and cohesiveness.

Chlorophyll, Fructose, and Glucose Concentrations Analysis

The chlorophyll concentration was measured by using the DA-meter on each apple, with the peel intact. The analysis was conducted at two distinct points on the fruit—one at the lightest-colored area and the other at the darkest-colored area—recording the average of these two measurements for each apple.

The analysis of glucose and fructose was performed using glucose and fructose refractometers.

Chlorophyll, fructose, and glucose concentration analysis were made on three different fruits from each cultivar.

Statistical Data Analysis

Statistical data analysis was conducted using the MedCalc software.

Since multiple apple cultivars were compared for each textural parameter, the statistical analysis employed was either one-way ANOVA or its non-parametric equivalent, the Kruskal-Wallis test, with the storage period considered as the main factor for each cultivar. One-way ANOVA was applied when the data followed a normal distribution. In cases of ANOVA significant result ($p < 0.05$), post-hoc comparisons were performed using the Tukey-Kramer test to identify significantly different values of the parameters analysed. If the normality check indicated a non-normal data distribution, the Kruskal-Wallis test was used. When the Kruskal-Wallis test yielded a significant result ($p < 0.05$), post-hoc analysis was conducted using the Conover test.

The relationships between firmness and chlorophyll concentration, as well as between chewiness and glucose and fructose concentrations, were analysed using linear correlation analysis. Pearson's correlation coefficient was used when the data followed a normal distribution, while Spearman's rank correlation coefficient was used to study the correlation between non-normally distributed data.

RESULTS AND DISCUSSIONS

Dalinbel apples

It was observed that the first compression hardness (firmness) for the Dalinbel cultivar does not change significantly after 47 days of storage. Firmness is influenced by factors such as cell wall composition, turgor pressure, and the arrangement of parenchyma cells. Genetic factors also play a significant role in determining firmness, as highlighted by genome-wide association studies (GWAS) that identify specific loci associated with texture traits (Farneti et al., 2017).

For the Dalinbel cultivar, the fracture force at the cortex tissue level do not change significantly after 47 days. The chewiness of the cortex tissue in the Dalinbel cultivar does not change significantly between 47 and 82 days of storage.

Khan and Vincent (1993) showed that the cortex apples cells and intercellular spaces are radially oriented. They identified that if the apple sample is compressed radially, along the cell rows the fracture is generated by the collapse of a single layer of cells. In rheology toughness is a mechanical parameter measuring the ability of a material to absorb energy and plastically deform without fracturing, it is a measure of the strength with which the material opposes rupture (Villasenor-Ochoa, 2017). In apples rupture might occur through cell membrane and /or through the intercellular space (Ng et al., 2013). Due to the molecular cell arrangement in the apple cortex, a compression exerted radially on the cortex will generate a smaller toughness and requires a smaller deformation to fracture (Khan and Vincent, 1993) compared to a sample compressed tangentially. For the apple cortex the stiffness (the ability of a material to return to its original form after being subjected to a force) of samples compressed radially is larger compared to samples compressed tangentially, (Khan and Vincent, 1993). The cohesiveness of the cortex tissue in the Dalinbel cultivar does not change significantly between 47 and 82 days of storage, indicating that the modifications at cellular level occur mainly in the first 47 days of storage.

Jonafree apples

The compressive mechanical properties of fruits parenchyma are related to the size, shape and orientation of cells and intercellular spaces, and cellular adhesion. Moreover apple parenchyma is mechanically very anisotropic due to their elongated cells and intercellular spaces (Khan and Vincent, 1993). There are no significant differences for hardness (Table 1) throughout the entire storage period for Jonafree apples, meaning that their hardness remains constant over the 82-day period (Table 1). However, after 47 days, Jonafree apples exhibit a significant different cortex fracture force compared to day 82. (Table 1). Softening of apples is dependent of cortical microstructure and cell adhesion as well as of cell shape and size (Ng et al., 2014). Fracture may be generated by cell rupture or by cel-to-cell separation, the later being characteristic for apples with a softer behavior during the first bight and less juiciness (Ng et al., 2014). Modification of Jonafree

fracture force after 82 days, but no firmness modification might be explained by a modification in cell adhesion after 47 days of storage.

Table 1. Variation of hardnes at first compression (firmness), Cohesiveness (Coh); Chewiness (Chew); Fracture force (Ff) in apples cultivars. P values for one-way ANOVA/ Khruskal-Wallis test. Data are presented as **mean** ±standard deviation. Comparison can be made only between values associated to storage period. No comparison between apple varieties can be made

Cultivar	Day	Hardness (N)	Coh $\times 10^{-2}$	Chew (J) $\times 10^{-2}$	Ff (N)
Dalinbel	1	124.61a ±26.80	1.995a ±1.132	1.110a ±0.869	94.765a ±62.899
	47	52.922b ±13.66	0.95b ±0.757	0.26b ±0.53	21.516b ±25.024
	82	58.014b ±10.264	1.04b ±1.24	0.31b ±0.64	19.608b ±27.455
	P	0.001	*0.005	*0.001	*0.004
Jonafree	1	92.416a ±48.637	2.84a ±1.97	0.90a ±0.82	13.172a ±14.877
	47	65.110a ±18.082	4.59a ±6.65	1.96a ±3.42	17.580b ±24.827
	82	69.278a ±14.062	1.27b ±1.10	0.46a ±0.62	24.649a ±31.823
	P	*0.001	*0.004	*0.001	*0.003
Real	1	183.17a ±31.291	2.60a ±1.16	1.99a ±1.10	33.806a ±76.203
	47	92.119b ±24.449	4.85a ±12.18	1.26b ±1.15	28.208b ±44.828
	82	89.967b ±12.852	0.80b ±1.15	0.38c ±0.60	20.103b ±30.642
	P	*0.001	*0.175	*0.001	*0.755

*Significant value for the Khruskal-Wallis test- data not normally distributed

The choice of performing the compression radially on the apples' cortex was in order to identify the possible modifications of the cell walls mechanical properties during storage. The cohesiveness of the cortex in Jonafree apples does not change significantly after 47 days compared to day 1, but has a significant change after 82 days (Table 1). The intercellular links by which the apples' cortex mass is held together determine its cohesiveness. The cohesiveness value of a sample is directly related to the compression strength of the apple cortex. The Jonafree low cohesiveness after 82 day, which is significantly lower compared with the cohesiveness in day 1 and 47 (table 1) suggest that the intercellular links of the cortex cells becomes weaker after 82 days. The intercellular space is the continuum consisting of all voids or pores between the cells and may encompass as much as 30% of the total volume of an apple fruit depending on the cultivar (Herremans et al., 2015, Li et al., 2019, Li et al., 2023.). In the perception of cohesiveness, the

intracellular space is playing an important role alongside rheological properties of cell walls and membranes. The cohesiveness indicates how well a food retains its form between the first and the second chew. When stored at temperatures between 1°C to 3°C the Jonafree apples showed no cohesiveness modification which is an indicator that their crispiness is stable for at least 47 days. In this situation the stability of the cohesiveness might be explained by no modifications in cell adhesion during the 47 days of storage.

Data from table 1 show that there are no significant differences in chewiness throughout the 82 storage period for Jonafree apples.

Real apples

For the Real cultivar, first compression hardness does not differ significantly between days 47 and 82 of storage (Table 1).

The fracture force of the cortex does not differ significantly between days 47 and 82 of storage for the Real cultivar (Table 1).

The Table 1 shows that there are no significant differences in cortex cohesiveness between days 1 and 47 of storage for Real apples; in other words, Real apple cohesiveness changes after 47 days. The chewiness of the Real cultivar differs significantly between day 47 and day 82.

The variations of glucose and fructose concentrations (Table 2) may be due to the inter-individual differences and to a lesser extent to the storage period.

Table 2. Mean values and standard deviations (mean ±standard deviation) of Chlorophyll, Glucose, and Fructose. No comparison between cultivars or chemical parameters can be made

Cultivar	Day	Glucose (%)	Fructose (%)	Chlorophyll (AU)
Dalinbel	1	12.7a ±1.2	13.1a ±1.1	1.16a ±0.72
	47	12.2a ±0.8	12.7a ±0.7	2.41b ±1.20
	82	14.3a ±1.1	14.36a ±1.01	0.86a ±1.57
Jonafree	1	12.46a ±1.15	12.7a ±1.3	4.22 ±0.87
	47	13.43a ±1.89	13.16a ±1.76	4.52 ±1.96
	82	10.16a ±0.96	9.8b ±2.5	3.58 ±2.42
Real	1	11.73a ±0.45	11.7a ±0.2	5.08a ±0.70
	47	11.83a ±1.32	11.53a ±1.49	4.49a ±2.32
	82	11.3a ±0.3	11.4a ±0.4	3.7a ±0.8

No significant variation of glucose and fructose was found over time for the three cultivars.

This result may be due to the small number of apples tested (only 3 fruit /cultivar).

The linear correlation study (Table 3) between selected quality parameters revealed that after 47 days, there is an inverse significant ($p=0.0196$) very good correlation between glucose concentration and fracture force ($r=-0.9995$).

This result should be interpreted with caution, as the correlation was based on a very small sample size (three cultivars). It serves as an indication for potential future research, therefore increasing the number of analyzed cultivars may either confirm or contradict the present results.

Table 3. Study of the Correlation Between Quality Parameters of Dalinbel, Jonafree, and Real Apple Cultivars. Pearson correlation coefficient (PCC) and significance level (P) are indicated. Chlorophyll (Cph); Glucose (Gl); Fructose (Fr). Cohesiveness (Coh); Chewiness (Chew); Fracture force (Ff)

Storage duration			Hardness	Coh.	Chew.	Ff
Day 1	Cph	PCC	0.19	0.51	0.98	-0.91
		P	0.87	0.65	0.12	0.26
	Gl	PCC	-0.71	0.062	-0.70	0.52
		P	0.48	0.96	0.50	0.64
	Fr	PCC	-0.67	-0.0005	-0.74	0.58
		P	0.52	0.99	0.46	0.60
Day 47	Cph	PCC	0.98	0.84	0.92	-0.33
		P	0.002	0.35	0.24	0.78
	Gl	PCC	0.30	-0.24	-0.07	-0.99
		P	0.80	0.84	0.95	0.01
	Fr	PCC	0.23	-0.71	-0.57	-0.83
		P	0.84	0.49	0.60	0.36
Day 82	Cph	PCC	0.79	-0.04	0.80	0.54
		P	0.41	0.97	0.40	0.63
	Gl	PCC	-0.57	-0.25	-0.94	-0.77
		P	0.61	0.83	0.21	0.43
	Fr	PCC	-0.50	-0.33	-0.96	-0.82
		P	0.66	0.78	0.16	0.38

After 47 days, a highly significant ($p=0.0028$) strong linear correlation ($r=0.9878$) and was observed between the IAD absorbance index and first compression hardness (table3). However, this correlation should also be validated by expanding the study to include a larger number of cultivars (10-15 cultivars).

CONCLUSIONS

The Jonafree apples cortex's firmness and chewiness showed no significant differences throughout 82 days of storage. Additionally, cortex cohesiveness remained unchanged after

47 days compared to Day 1 but showed a significant difference after 82 days.

The Dalinbel apples showed no statistically significant changes in firmness (hardness at first compression), cohesiveness, chewiness, and fracture force between 47 and 82 days of storage.

The Real apples' cortex firmness, and fracture force, was not significantly different between 47 and 82 days of storage however it significantly changed between day 1 and 47. Moreover no significant differences were observed in pulp cohesiveness between day1 and 47 of storage, but significant differences was observed after 82 days of storage.

Using data from the three cultivars studied, an inverse linear correlation was found between glucose concentration and fracture force ($r = -0.9995$; $p = 0.0196$) after 47 days of storage, a linear correlation between the IAD absorbance index and first compression hardness ($r = 0.9878$; $p = 0.0028$).

Although linear correlations were tested for 3 storage times and three quality parameters for all textural parameters, only 2 significant linear correlations were obtained, the rest of linear correlations were not significant. Further investigation is needed to identify other possible correlations between textural and quality parameters of apples and to confirm the present findings.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to Professor Florin Stănică, Vice-Rector of the University of Agronomic Sciences and Veterinary medicine of Bucharest (UASVMB), and Dr. Ana-Cornelia Butcaru for their invaluable support and permission to use samples from the experimental orchard of the Faculty of Horticulture of UASVMB. Additionally, I am deeply thankful to them for the opportunity to conduct analyses at the Integrated Pomology Laboratory of the Faculty of Horticulture Bucharest

I am also grateful to my colleagues, the students Ana-Antonia Moșteanu and Roxana Mihalache, from the University of Agronomical Sciences and Veterinary Medicine of Bucharest for helping me during the harvest period.

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