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EVALUAREA CALITĂȚII MERELOR PĂSTRATE ÎN CONDIȚII DE FRIG
ASSESSMENT OF APPLE FRUITS UNDER COLD STORAGE

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Abstract

The cold storage of fruits for a long period of time without quantitative and qualitative depreciations is absolutely necessary to supply the market with fresh fruits. This study aimed to investigate the changes in apple fruits during cold storage in order to determine their optimal storage capacity and to know the optimal moment of market sale. Five apple cvs. ('Rumina', 'Rebra', 'Rustic', 'Generos' and 'Florina') grown in the Genetics and Breeding Department of Research Institute for Fruit Growing Pitesti, Romania were kept in the cold storage at 2-4ºC and 90-95% humidity for 4 months. Before and after storage in cold conditions, the following physical and chemical parameters of fruits were evaluated: weight, color, firmness, soluble solids content and acids content. After 4 months, the fruits weight decreased with 2.45 g. The lowest weight loss was recorded on 'Rumina' cv. (1.48 g) and the highest for 'Rebra' cv. (3.20 g). At the end of storage period (January) the fruits firmness decreases with 7.74 Bareiss HPE-II FFF units, the best results being recorded on Rumina cv. (loss of firmness by only 5.23 units). Also, after cold storage the taste of the fruits was improved (the soluble solids content increased with 0.29 % Brix and the acid content decreased with 0.22 g/100 g fresh weight). The fruits color has changed gradually during the storage, the fruits being more colorful and attractive.

Cuvinte cheie: greutate, fermitate, culoare, substanță uscată, aciditate.
Key words: weight, firmness, color parameters, soluble solids content, acidity.

1. Introduction

The apple is one of the most important and widespread tree species in the world. In 2019, world apple production was 87,236,221 tons (FAO, 2021). From this fruits production, only a small part is consumed immediately after harvesting, the most part, being necessary to keep for a few months in storage houses, to preserve the fruits quality until consumption (Ahmad et al., 2021; Kovac et al., 2010; Militaru et al., 2016).

Quality and appearance have an important role in the selections of fruits on the market (Ahmad et al., 2021). Therefore, the fruit quality is one of the major goals in apple breeding program, as well as keeping the fruit quality during the storage period (Militaru et al., 2011).

It is known that the quality of an apple or any fruit can be defined as the combination of the external (shape, size, gloss and color) and internal (firmness, density, acidity and soluble solids content) attributes (Ahmad et al., 2021; Kader, 2002; Militaru et al., 2011, 2016; Sestraș, 2004; Braniște et al., 2008).

The quality of apples depends on pre-harvest and post-harvest factors. Also, the time of fruits harvest has an important effect on the storage capacity of the fruits and on their quality during storage (Saei et al.; Costa et al., 2012; Nadulski et al., 2017).

The apple is climacteric fruit and it continue to ripen after harvest. So, fruits must be harvested before full ripeness and stored in cold conditions (2-4ºC temperature and 90–95% humidity) or controlled atmosphere (2-4ºC temperature, 90-95% humidity, 2-3% O_2 and 2-5% CO_2) in order to sell them on the market at a high price (Kader et al., 2002; Militaru et al., 2016; Mohebi et al., 2017).

During the storage time, fruits quality changes. Thus, it decreases the fruits weight, firmness and acids content, increases the sugar content and changes fruits color (Militaru et al., 2016; Mohebi et al., 2017).

The role of storage is to keep fruits fresh as long as possible after harvesting with minimum physical and chemical changes in their composition (Sumedrea et al., 2017).

This study aimed to investigate the changes in apple fruits during cold storage in order to determine their optimal storage capacity and to know the optimal moment of market sale.

2. Material and methods

Fruit samples from five apple cvs. ('Rumina', 'Rebra', 'Rustic', 'Generos', – Romanian cvs. and 'Florina' – French cv., as control), grown in experimental plots from Genetics and Breeding Department of Research Institute for Fruit Growing Pitesti, Romania, were stored four months in cold storage at low temperature (2-4ºC) and high humidity (90-95%).

The present study was performed during October 2020 - January 2021 period and the following measurements were carried out:

- the fruit weight was recorded with a scale in g/fruit;
- the fruit skin color parameters (CIE L*, a*, b*) were measured using a Konica Minolta CR 400 chromameter, where L* corresponds to Luminance or darkness, and a* and b* to the chromaticity coordinates. The CIELAB color scale is organized in a cube form. The L* axis runs from top to bottom. The maximum for L* is 100, which represents a perfect reflecting diffuser. The minimum for L* is zero, which represents black. The a* and b* axes have no specific numerical limits. Positive a* is red. Negative a* is green. Positive b* is yellow. Negative b* is blue;
- the fruit firmness was measured with non-destructive penetrometer Qualitest HPE-II-FFF equipped with a test anvil ball of ø5mm.
- the soluble solids content of fruits was measured with Digital Sucrose Refractometer – (Hanna Instrument 96801), in % Brix;
- the malic acid content of fruits was measured using the device Minititrator Hanna Instrument 84532. Titratable acidity was expressed as % or g/100 g fresh matter.

All measurements were performed in two moments: before storage (October) and after four months of storage (January).

After storage we also determined the weight loss, the firmness loss and changes of soluble solids and malic acid content of fruits (by difference between the initial and after storage values).

For the statistical interpretation of the results, the data were included in an Excel database and then statistically interpreted with the SPSS 14.0 program, which uses the multiple range Duncan's test for a 5% statistical assurance. The relationship between physical and chemical characteristics was evaluated by Pearson's correlation at P≤0.05.

3. Results and discussions

3.1. Fruits weight and weight loss

The average fruits weight before cold storage (October) was 197.11 g, varying between 174.83 g at 'Rebra' cv. and 211.70 g at 'Rustic' cv., with very significant differences between the cvs. studied. Compared with Florina cv. (control), 'Rumina' and 'Rustic' cvs., had much larger fruits (Table 1; Fig. 1).

After four months of cold storage (in January) the average fruits weight decreased at 192.27 g the weight loss being 2.45 % (Table 1; Fig. 1).

The weight loss of the fruits depends on the structure of the epidermis and nature and amount of wax on the surface of the fruits (Babos et al., 1984; Jan et al., 2012; Veravrbeke et al., 2003). The weight loss of fruits kept in cold storage up to 90 days is low because the wax layer is not damaged. After 90 days of storage the wax layer could be damage, and that could be the major reason for high weight loss of the fruits (Gavlheiro et al., 2003).

The loss of water from the fruit leads to a decrease of appearance and turgor of the fruits and contributes to the softening of the fruits (Vander – Beng, 1981)

In our study, the highest weight loss was recorded at 'Rebra' cv. (3.20 %), and the lowest weight loss at 'Rumina' cv. (1.48 %) (Fig. 1). Among the studied cvs., only 'Rumina' cv. had small loss regarding fruit weight. This cv. has rust on the epidermis that prevents water losses during storage and probably therefore weight loss of fruits is lower than of other cvs.

Regarding weight losses of the fruits after cold storage, many other authors have observed the same trend in other apple cvs.: Mohebi et al. (2017) at 'Fuji' cv., Jan et al. (2012) at 'Royal Gala', 'Mondial Gala', 'Red Delicious' and 'Golden Delicious' cvs., Sumedrea et al. (2017) at 'Idared', 'Goldrush', , 'Florina', 'Pinova' and 'Dalinette' cvs.

3.2. Fruits color

Color is also an important quality parameter that affects appearance of fruits (Ahmad, 2021).

Among the studied cvs., 'Rumina' cv. had a yellow rust skin, and the other cvs. had red color.

During storage, significant changes were observed regarding color parameters (CIE L*, a*, b*). The "L*" value indicates the darkness of the skin, "a*" and "b*" values indicate the red and yellow color of the skin. The "L*" value decreased slightly during the storage, from 61.15 to 49.24 due to appearance of redness of fruits. The "a*" value increased from 0.65 to 4.09 and the "b*" value decreased slightly from 26.62 to 20.08 (Table 2). During the storage period it was observed that the fruits become more colorful and attractive.

Other studies on different apple cvs., also observed the same evolution of fruits color (Militaru et al., 2016; Ahmad et al., 2021).

3.3. Fruits firmness

Firmness is an important factor for fruits quality and market value (Stow et al., 2000; Jan et al., 2012) and loss of firmness is a serious problem (Kov et al., 2005).

The fruits firmness depends on the evapo-transpiration and respiration, resulting in loss of solutions and water (Gavalheiro et al., 2003; Jan et al., 2012).

The firmness of apples is due to the flesh texture. Changes in texture during maturation are due to the destruction of primary cell wall and middle lamella structures (Jackman and Stanley, 1995) and result in fruits soft, which are less accepted by consumers (Gomez et al., 1998).

It is known that the fruits firmness significantly decreased with increasing storage duration (Jan et al., 2012).

Before the cold storage, the fruits firmness was on average 76.74 HPE units. After four months of cold storage, the fruits firmness decreased to 69.00 HPE units, ranged from 75.16 HPE units in 'Rumina' cv. to 63.90 HPE units in 'Generos' cv. The highest firmness loss was recorded at 'Generos' (10.71 HPE units) and 'Rustic' (9.58 HPE units) cvs., and the lowest firmness loss at 'Rumina' (4.45 HPE units), 'Rebra' (5.53 HPE units) and 'Florina' (5.25 HPE units) cvs. (Table 3; Fig. 2).

3.4. Fruits soluble solids content

The soluble solids content of apple is an important quality parameter which increased gradually with increasing the storage duration. The increase in soluble solids could be attributed to the breakdown of starch into sugars (Jan et al., 2012).

Before the cold storage, the soluble solids content of apple was on average 13.75% Brix. After four months of cold storage, the soluble solids content of fruits increased to 14.04% Brix, ranged from 16.26% Brix in 'Rumina' cv. to 12.46% Brix in 'Rebra' cv. (Table 4; Fig. 3).

The highest content of soluble solids was recorded at 'Rumina cv. immediately after harvest (15.83 % Brix) and also after 4 months of cold storage (16.26 % Brix) (Table 4; Fig. 3).

Compared with 'Florina' cv. (control), at all cvs. studied except 'Generos' cv. the soluble solids content of fruits increased during the storage.

Other authors reported the same results regarding the increasing the soluble solids content of the fruits during storage (Mahajan, 1994; Jan et al., 2012; Militaru et al., 2016; Ahmad et al., 2021).

3.5. Malic acid content of fruits

During the storage the acidity of the fruits juice decreased because the starch content decreases and sugar content increases (Jan et al., 2012; Ahmad et al., 2021).

The average malic acid content of fruits before cold storage (October) was 0.52%, varying between 0.37% at 'Rebra' cv. and 0.77% at 'Rumina' cv., with very significant differences between the cvs. studied (Table 4; Fig. 4). After four months of cold storage (in January) the average malic acid content of fruits decreased at 0.30%, varying between 0.23% at 'Rutic' cv. and 0.35% at 'Rumina' cv., with very significant differences between the cvs. studied (Table 4; Fig. 4).

The highest content in malic acid was recorded on 'Rumina' cv. immediately after harvest (0.77 g/100 g fresh weight) and also after 4 months of cold storage (0.35 g/100 g fresh weight) (Table 4; Fig. 4).

4. Conclusions

During the cold storage, all the apple fruits quality parameters changes significantly.

The average fruits weight before cold storage (October) was 197.11 g, varying between 174.83 g at 'Rebra' cv. and 211.70 g at 'Rustic' cv., with very significant differences between the cvs. studied. Compared with Florina cv. (control), 'Rumina' and 'Rustic' cvs., had much larger fruits. After 4 months of cold storage, the fruits weight decreased with 2.45 %. The lowest weight loss was recorded on 'Rumina' cv. (1.48 %) and the highest for 'Rebra' cv. (3.20 %).

At the end of storage (January), the fruits firmness decreases to 69.00 HPE-II_FFF Bareiss units (loss of firmness by 7.74 HPE-II-FFF Bareiss units, on average), ranged from 75.16 HPE units in 'Rumina' cv. to 63.90 HPE units in 'Generos' cv. The highest firmness loss was recorded at 'Generos' (10.71 HPE units) and 'Rustic' (9.58 HPE units) cvs., and the lowest firmness loss at 'Rumina' (4.45 HPE units), 'Rebra' (5.53 HPE units) and 'Florina' (5.25 HPE units) cvs.

Also, after cold storage the taste of the fruit improved (the soluble solids content increased with 0.29 % Brix and the malic acid content decreased with 0.22 g/100 g fresh weight).

Before the cold storage, the soluble solids content of apple was on average 13.75% Brix. After four months of cold storage, the soluble solids content of fruits increased to 14.04% Brix, ranged from 16.26% Brix in 'Rumina' cv. to 12.46% Brix in 'Rebra' cv.

The average malic acid content of fruits before cold storage (October) was 0.52%, varying between 0.37% at 'Rebra' cv. and 0.77% at 'Rumina' cv. After four months of cold storage (in January) the average malic acid content of fruits decreased at 0.30%, varying between 0.23% at 'Rutic' cv. and 0.35% at 'Rumina' cv.

The fruits color has changed gradually during the storage, the fruits being more colorful and attractive.

We investigate the changes in fruits during cold storage in order to determine their optimal storage capacity and to know the optimal moment of market sale. Thus, it can be said that the 'Rumina' cv. has

been storage very well and could be sale on the market in February. The other varieties studied had several changes during storage and therefore should be sale earlier, respectively in December.

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Tables and Figures

Table 1. The fruits weight (g) at five apple cultivars stored in cold conditions

No.	Cultivar	Fruit weight* (g)	
		Before storage (September)	After 4 months of storage (January)
1	Rumina	206.36 b	203.3 b
2	Rustic	211.70 a	206.23 a
3	Rebra	174.83 e	169.23 e
4	Generos	192.90 d	187.63 d
5	Florina (Control)	199.80 c	195.00 c
	Average	**197,11**	**192,27**

*Different letter(s) in columns indicate significantly different values at P≤0.05 by Duncan test.

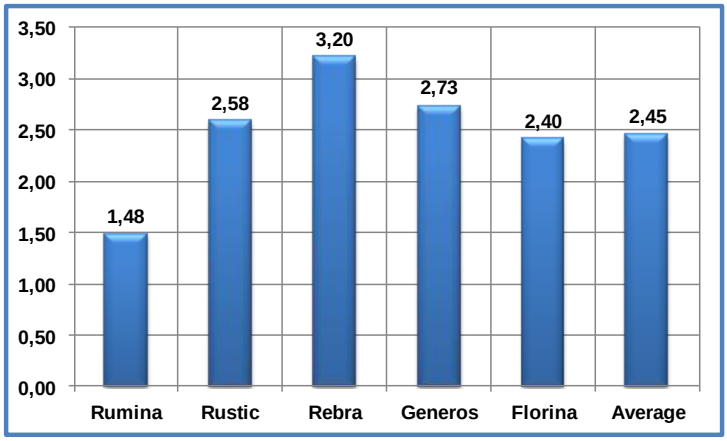

Fig. 1. Weight losses of fruits (%) after cold storage

Table 2. The fruits color of five apple cultivars stored in cold conditions

No.	Cultivar	CIELAB color values*					
		Before storage			After 4 months storage		
		L*	***a****	***b****	***L****	***a****	***b****
1	Rumina	56.61 c	-1.83 b	27.34 a	20.04 c	9.75 a	12.97 c
2	Rustic	60.19 b	-1.76 b	27.58 a	55.44 b	2.16 b	24.05 a
3	Rebra	65.27 a	-1.95 b	26.79 a	55.97 b	1.76 b	22.39 a
4	Generos	68.03 a	-3.87 b	27.67 a	60.46 a	0.89 b	22.31 a
5	Florina (Control)	55.68 c	8.99 a	23.72 b	54.29 b	5,90 b	18.71 b
	Average	**61.15**	**0.65**	**26.62**	**49.24**	**4.09**	**20.08**

*Different letter(s) in columns indicate significantly different values at P≤0.05 by Duncan test.

Table 3. The fruits firmness of five apple cultivars stored in cold conditions

No.	Cultivar	Firmness* (HPE-II-FFF Bareiss units)	
		Before storage	After 4 months of storage
1	Rumina	79.61 a	75.16 a
2	Rustic	78.58 ab	69.00 b
3	Rebra	72.46 b	66.93 bc
4	Generos	74.61 ab	63.90 c
5	Florina (Control)	78.46 ab	73.23 ab
	Average	**76.74**	**69.00**

*Different letter(s) in columns indicate significantly different values at P≤0.05 by Duncan test.

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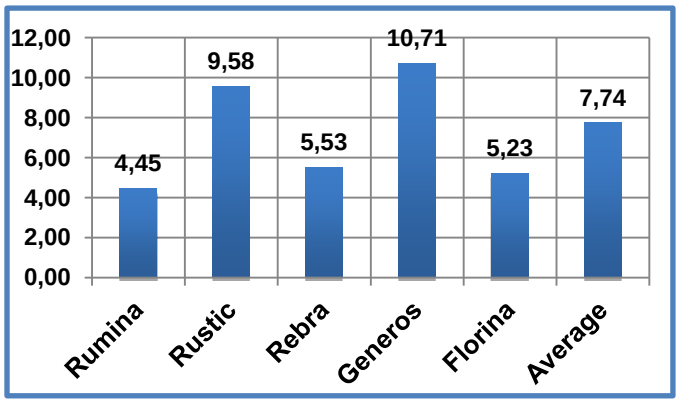

Fig. 2. Firmness loss of fruits (HPE units) after cold storage

Table 4. Fruits content in soluble solids and malic acid of five apple cultivars stored in cold conditions

Cultivar	SSC* (%Brix)		Malic acid* (g / 100 g fresh weight)	
	After harvest	After 3 months storage	After harvest	After 4 months storage
Rumina	15.83 a	16.26 a	0.77 a	0.35 a
Rustic	12.30 b	12.70 b	0.49 b	0.23 d
Rebra	12.13 b	12.46 b	0.37 c	0.31 b
Generos	13.30 b	13.16 b	0.48 b	0.28 c
Florina (Control)	15.20 a	15.26 a	0.50 b	0.33 b
Average	**13.75**	**14.04**	**0.52**	**0.30**

*Different letter(s) in columns indicate significantly different values at P≤0.05 by Duncan test.

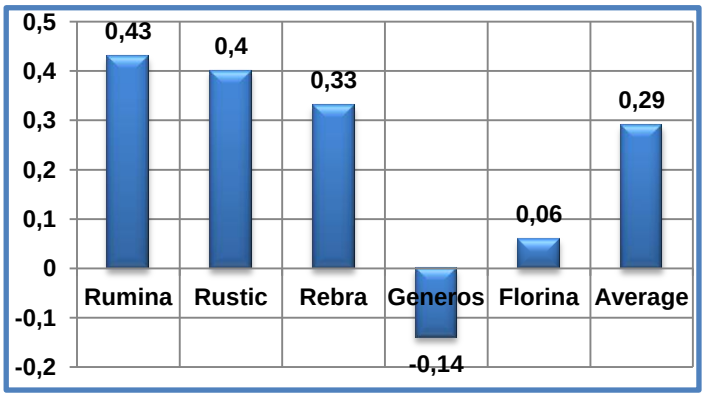

Fig. 3. Changes (increases and decreases) in fruits soluble solids content during the cold storage

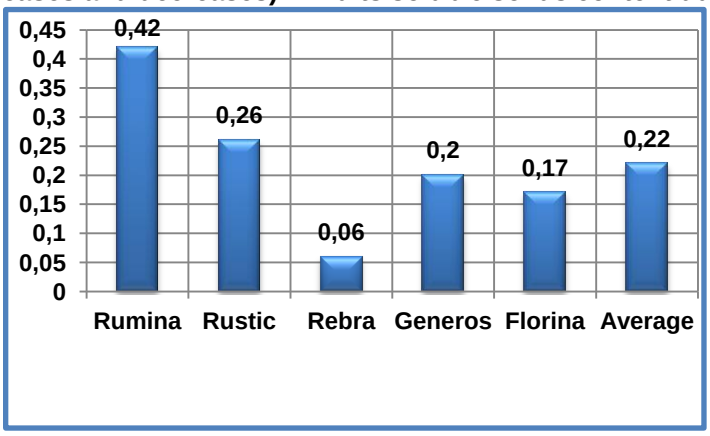

Fig. 4. Decreases of malic acid content of fruits during the storage