



ASSESSMENT OF SHELF-LIFE ABILITY OF APPLES CV. 'AUKSIS' AFTER LONG-TERM STORAGE UNDER DIFFERENT CONDITIONS

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ABSTRACT

The objective of the current research was to ascertain the shelf-life ability of apple 'Auksis' after 6 months of cold storage under different conditions. The effect of storage conditions such as: cold storage under normal atmosphere (NA), 1-methylcyclopropene (1-MCP) + cold storage, and ultra-low oxygen (ULO)-controlled atmosphere (CA) [2.0% CO₂ and 1.0% O₂ (ULO1) and 2.5% CO₂ and 1.5% O₂ (ULO2)] on the quality of apples during shelf-life was evaluated. Apple fruits immediately after cold storage and after 25 days of maintaining at market condition had been evaluated. The physical (firmness, weight losses), chemical (total soluble solids and acid contents), and sensory (aroma, taste, acidity, sweetness, juiciness, and color) characteristics of apples had been evaluated after 5, 10, 15, 20, and 25 days to ascertain maximal shelf-life. Results from sensory evaluation indicated that apples treated with 1-MCP and stored at NA were characterized with distinctive aroma, whereas apples stored under CA were poor in sweetness and had remarkable acidity and juiciness. Apples that were stored in cold had pronounced aroma and color but without taste. Based on the evaluation by panelist, maximum shelf-life of apples that were kept under cold storage and ULO1 was 15 days, whereas that of apples that had been treated with 1-MCP and stored at NA and those stored in ULO2 was 25 days.

Key words: controlled atmosphere, 1-Methylcyclopropene, cultivar Auksis, post-harvest quality

INTRODUCTION

Apples available throughout the food chain have different quality. Fruit quality is determined by several factors, including length of storage period, storage temperature, the composition of the storage atmosphere, treatment with 1-methylcyclopropene (1-MCP), shelf-life conditions, etc. The dominant attributes of fruit quality influencing consumer preference are generally associated with appearance, firmness, and taste of the fruit (Harker et al. 2008). The apples that had been stored under controlled atmosphere (CA) were perceived by consumers as green and unready to eat. In spite of the beneficial effects of CA storage on a number of quality attributes (firmness, acidity, and sweetness), detrimental effect on apple color development has also been re-

ported. It is because CA storage reduces the chlorophyll degradation by suppressing ripening processes (Lara et al. 2006) and the green color remains intact throughout the shelf-life of fruit (Tijskens et al. 2008). On the contrary, results obtained by Brackmann et al. (2005) and López et al. (2007) indicate that storage of apples under CA not only ensures extended storage time but also maintains good sensory attributes and quality of fruits.

Shelf-life ability of apples depends on a number of factors such as chemical composition, especially water and sugar content, surface structure of the cuticular layer, and the specific surface area (Soliva-Fortuny et al. 2002). Winter cultivar apples, which have lower water content compared with summer fruits, can always be stored for a longer period.

Degree of maturity of apples at harvest strongly affects the shelf-life period. For instance, ‘Granny Smith’, harvested at slightly green stage and stored under CA for about a year, can be kept on shelf for approximately 6–8 weeks, although it is connected with loosing of taste and aroma. According to Raffo et al. (2009), the storage of apples in CA extends the shelf-life up to 60 days but decreased sensory attributes. CA storage conditions alter the synthesis of volatile compounds, which are responsible for the development of fruit aroma (Juhņevica-Radenkova et al. 2014). The maintaining of apples in shelf condition affects biochemical and physiological changes during typical climacteric processes.

The quality of apples that had been removed from the long-term storage and then maintained at +2–4 °C in marketing conditions can be kept within 6–8 weeks. However, the quality of apples stored under conditions with ambient temperature about +20 °C shortens instantly this period to 1–2 weeks (Juhņevica-Radenkova et al. 2014).

Varela et al. (2005, 2008) has determined the maximum of shelf-life at +20 °C for apples ‘Fuji’ that had been assessed recently after harvest or stored at +1 °C in controlled atmosphere. The results have shown that shelf-life of the apples stored for 7 months under CA would be 23 days with a 50% rejection probability and 17 days with a 25% probability of rejection by consumers. In turn, shelf-life of apples assessed without long-term storage could be even stored for 61 days with a 30% rejection probability by consumers, while after 70 days of storage, apples became shriveled.

One of the possibility for controlling of the ethylene synthesis aimed to decrease ripening and softening processes in climacteric fruits is the application of 1-MCP (SmartFresh™), which is broadly documented as an ethylene inhibitor (Abdi et al. 1998; Martínez-Romero et al. 2003; Candan et al. 2006; Watkins 2006). The apples treated with 1-MCP allows maintaining their shelf-life ability up to 4–6 weeks (Bizjak et al. 2012). However, there is still a risk that during fruit storage, ethylene receptors will be able to recover activity and gain susceptibility to molecules of ethylene (Abadi et al. 2009). The aim of the current research was to ascertain the

optimal length of shelf-life period of apples ‘Auksis’ stored for 6 months in different conditions: cold storage under normal atmosphere (NA), cold storage preceded by MCP treatment, and ultra-low oxygen (ULO) CA [2.0% CO₂ and 1.0% O₂ (ULO1) and 2.5% CO₂ and 1.5% O₂ (ULO2)].

MATERIALS AND METHODS

This study took place in years 2013 and 2014 at the Experimental Processing Department of the Latvia State Institute of Fruit-Growing (currently, Institute of Horticulture, Latvia University of Agriculture) in Dobele. Apple trees ‘Auksis’ [trees vigor medium to strong, midseason harvest time, good resistance to all diseases (Rubauskis et al. 2011)], grafted on the rootstock B9, were grown in the orchard according to the principles of integrated system.

During vegetative season, trees were treated twice with 6 kg·ha⁻¹ CaCl₂ (on July 13, 2013, and August 01, 2013, respectively). Apples were harvested twice: September 10 (A1) and September 14 (A2). The ripening characteristic is given in Table 1.

Table 1. Parameters characterizing the maturity stage of ‘Auksis’ apples

| Degree of maturity assessed by | Harvesting date | |
|--|-----------------|-----------------|
| | 2013/10/09 (A1) | 2013/14/09 (A2) |
| Starch–iodine test (from 1 to 10 points) | 3.50 | 6.50 |
| Streif Index | 0.16 | 0.07 |

A1 – first harvesting; A2 – second harvesting

Ripening stage of the apples was assessed by starch index using starch–iodine test and the Streif Index (SI) $F/(R \cdot S)$ (Streif 1996), where F is the firmness (in kg·cm⁻²), R the soluble solids content (TSS, in °Bx), and S the starch index (on a scale from 1 to 10). Harvested apples met the Latvian requirements for fruit intended for long-term storage in Latvia (Drudze 2003; 2005). Shortly after harvesting, apples were air cooled for 24 h in a cooling chamber at up to +4 ± 0.5 °C. Thirty kilograms of apples was sampled for each storage technology and placed by 10 kg in polypropylene, perforated boxes. The

cooled down apples were divided into four groups for post-harvest storage: (1) cold storage at 2 ± 1 °C, under NA; (2) 1-MCP treatment after harvest and cold stored at 2 ± 1 °C under NA; (3) ULO1, 2.0% CO₂ and 1.0% O₂; and (4) ULO2, 2.5% CO₂ and 1.5% O₂. Storage in ULO was implemented in Fruit Control Equipment (Italy) by selecting two different gas compositions. Apples were maintained in the above experimental conditions for 6 months.

Fruit treatment with 1-methylcyclopropene

1-MCP powdery substance (purchased from RandH: Rohm and Haas Company, Italy) was dissolved in warm water $+50 \pm 2$ °C by ratio of 1 : 30, the concentration of the obtained solution was $0.625 \mu\text{l dm}^{-3}$ according to Wawrzyńczak et al. (2007). The solution was prepared in an Erlenmeyer flask and placed in an air-tight processing container with apples intended for storage. The treatment with 1-MCP was performed at a temperature of 4 ± 0.5 °C for 24 h. After treatment, fruit samples were stored in cold storage under NA conditions.

Ascertaining of optimal shelf-life

Shelf-life is defined as the maximum period of time that food product can be stored under specific environmental conditions without any appreciable deterioration in quality and acceptability (Jena & Das 2012). In this study, shelf-life of the apple samples was determined using direct (real-time) shelf-life testing (Singh & Cadwallader 2004). After the completion of storage, fruit samples were transferred to the ambient conditions at 18 ± 1 °C and analyzed every 5 days up to 25 days. They had been weighed and transferred to the laboratory and subjected to sensory evaluation. On the basis of the results, if the sample was evaluated as acceptable without any deterioration in quality, physical and chemical parameters has been assessed.

Sensory evaluation

Fifteen well-trained panelists (5 men and 10 women) aged between 25 and 50 years participated in the current study. The sensory attributes of apples were evaluated using Line scale evaluation by the standard method ISO 4121:2003 (Sensory analysis – Guidelines) for the use of quantitative response scales. Each sample was coded randomly with three digit numbers to reduce any possible bias. The panelists were provided with five slices of apples for

every experimental sample and asked to score them for different sensory attributes. To avoid unwanted browning, the apples were cut just before being served and placed on each serving tray in a randomized order. To evaluate the overall acceptability of apple (external quality), whole uncut apple sample was also provided with the slices. To evaluate the sensory attributes such as color, aroma, taste, acidity, sweetness, and juiciness, all apple samples were assessed using 12-point Line scale, where 12 denotes “like extremely”, 6 denotes “neither like nor dislike”, and 0 denotes “dislike extremely”.

Physicochemical analyses

Fresh weight loss was determined with scaling method provided by Billiard (1999). This method was based on the differences between initial and final weight. Each sample was weighted before shelf-life and after 5, 10, 15, 20, and 25 days. Fresh weight loss have been expressed in percentage.

Ten fruits were used individually for the analysis of flesh firmness (N), soluble solids content (°Brix), and titratable acidity (%) after removal from storage. It was measured on two opposite sides of each apple without skin, using digital penetrometer (model TR 53205, Italy), which was equipped with 11-mm diameter probe; peak destructive force was expressed in newton's (N).

Titratable acidity was determined using Latvian standard method (LVS EN 12147:2001) and quantified by titration of 1 ml of juice (automatic titration DL 21, Mettler Toledo, Swiss) with 0.1 M NaOH to a pH 8.1. Expended amount of NaOH was expressed in percentage of malic acid.

Soluble solids content was determined using standard method (LVS EN 12143:2001). Ten fruits were selected and grinded with hand blender Bamix® (Switzerland, model SwissLine, Liechtenstein) into puree, and further, the content of soluble solids (in °Brix) was determined using a digital electronic refractometer (type Pal-1, Tokyo, Japan).

Statistical analysis

Data analysis was carried out using the general linear model functions in the IBM® SPSS® Statistics program 20.0 (SPSS Inc., Chicago, Illinois). The obtained data were analyzed using descriptive statistics. Significant differences were determined using UNIANOVA by least significant difference

(LSD) criteria. The significance of differences was determined at $p < 0.05$. Mean and standard deviation values were calculated for all parameters.

In order to compare sensory data that were obtained from Line scale evaluation, obtained results were processed by PanelCheck V1.4.2 programmed by Oliver Tomic and Henning Risvik software using principal component analysis (PCA) (Næs et al. 2010). PCA provides a representation of the dataset in a small number of dimensions, called principal components, which explain the majority of the variance of the dataset. In the current research, PCA represents the similarities and differences among the samples as well as their relationship with the evaluated sensory attributes. For instance, if the average score of a particular attribute will be equal to another score, points will be located on the plot close to each other and will be enclosed in ellipse. Besides, if a particular attribute strongly correlate with the particular sample its location will be near the sample and enclosed in ellipse (Piqueras-Fiszman et al. 2015).

RESULTS AND DISCUSSION

Sensory evaluation is the main criterion for determining the apple post-harvest shelf-life. Purchase decision is mainly influenced by external appearance (size, shape, and color) of fruit.

PCA (Fig. 1) was performed on the sensory data of the commonly grown 'Auksis' apples that had been stored for 6 months under different conditions. Principle component 1 (PC1 and PC2 together) explains the samples' variance starting from 87.2% to 100%. Biplot data in Figure 1 shows three well-separated groups in which storage conditions were responsible for the main differences between the samples. In general, those apple samples that were stored under NA (A1_N and A2_N) had the most pronounced aroma (8.36 and 8.96 points, respectively) compared with those stored under CA conditions in ULO. However, the lowest points have been assigned to those apples that had been treated with 1-MCP (A1_1-MCP_N – 1.78 and A2_1-MCP_N – 2.20 points) before long-term storage as well as those stored under CA conditions in

ULO1 (3.20 points) and ULO2 (2.66 points). During shelf-life of samples that had been kept under cold storage A1_N and A2_N, aroma was significantly ($p < 0.05$) decreased. In turn, after 20 days of shelf-life, samples that were treated with 1-MCP before cold storage were considerably enriched in aroma, resulting with a higher score – 4.76 points (A2_MCP_N). It should be noted that maximal shelf-life period of apples that were stored under NA conditions was 15 days (first harvesting time, A1) and 20 days (second harvesting time, A2). This period has been chosen based on the results from sensory evaluation. This agrees with the results of Mitcham et al. (2001) who underlined that one of the most important negative aspects of 1-MCP is the reduction of volatile compounds responsible for fruit flavor, resulted from eliminating sensitivity to ethylene. However, during shelf-life, flavor of fruit was significantly improved because of the metabolic processes. Juhneviča-Radenkova et al. (2014) proved a partial recovering of aroma during 2 weeks of shelf-life.

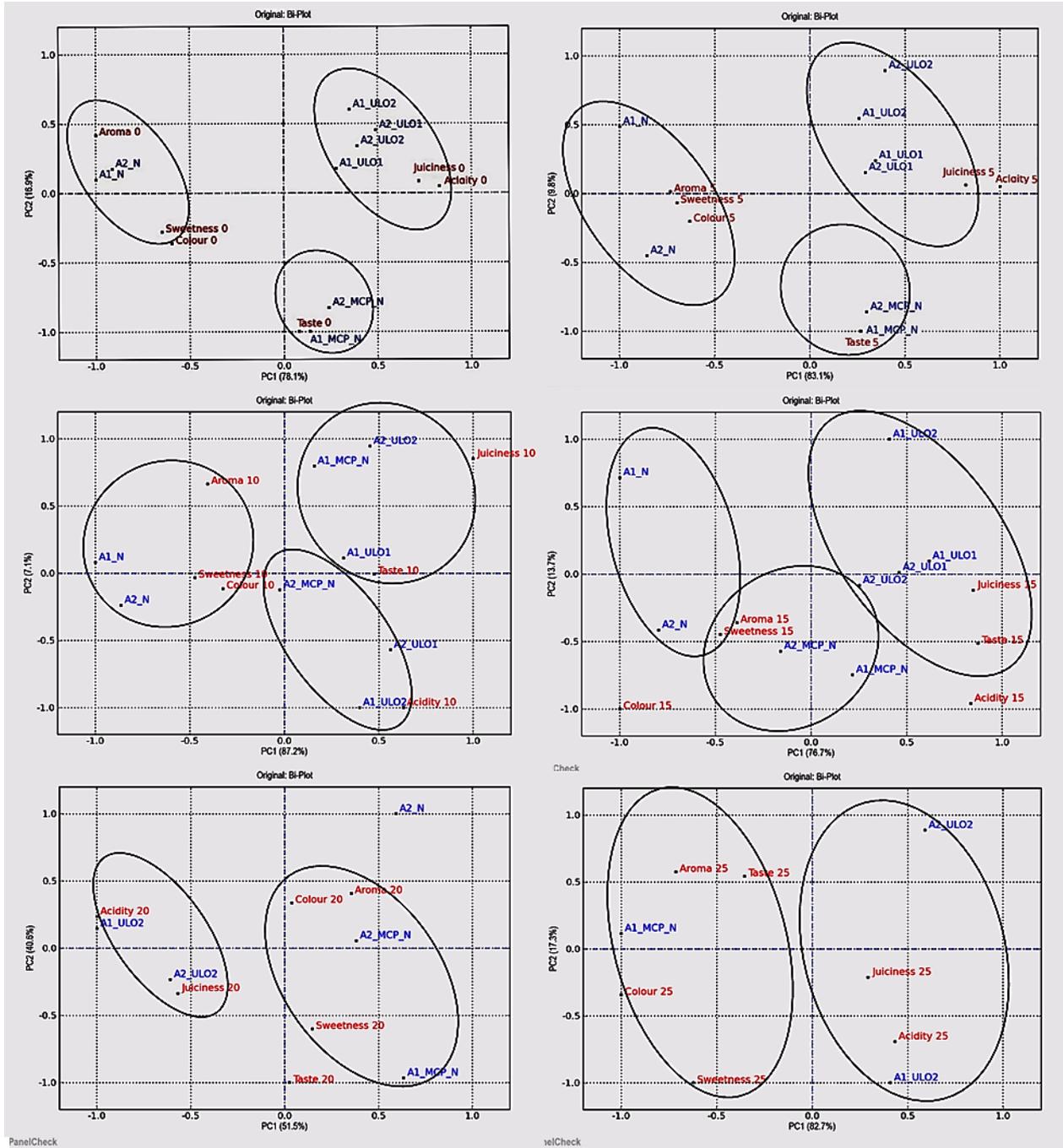
Taste of the apples treated with 1-MCP was most intense at the beginning of shelf-life period compared with other samples (8.22 points). After 5 days of shelf-life, panelists highlighted a remarkable taste – 8.88 and 8.94 points for A1_MCP_N and A2_MCP_N, respectively. However, after 20 days of shelf-life at 18 °C, taste of apples A1_MCP_N and A2_MCP_N was considerably depleted (6.30 and 5.20 points, respectively). After 25 days of shelf-life, it has been noted that the sample A1_MCP_N (6.60 points) has got the highest score in terms of taste, whereas sample A2_MCP_N was evaluated as with no distinctive taste. Therefore, maximal shelf-life period for this type of storage was 25 days (first harvesting time, A1) and 20 days (second harvesting time, A2).

Taste of the apples stored under ULO1 and ULO2 conditions that initially was rated as poor throughout 10 days of storage was remarkably improved (7.88 points for A1_ULO1). However, with the subsequent shelf-life period, taste was considerably worsened and not evaluated as "ideal taste."

According to Heyn (2009), apples that were treated with 1-MCP remain sour within long-term

storage and shelf-life. Our results were in agreement with the findings of Rizzolo et al. (2010) that apples stored under CA conditions at the commencement of shelf-life were sourer, firmer, less

mealy, more crispy, and juicy than those stored under NA. However, throughout shelf-life of apples, acidity has been substantially reduced.



A2_ULO2 – ‘Auksis’ 2x ULO2; A1_MCP_N – ‘Auksis’ 1x cold storage + 1-MCP; A2_MCP_N – ‘Auksis’ 2x cold storage + 1-MCP; A1_N – ‘Auksis’ 1x cold storage; A2_N – ‘Auksis’ 2x cold storage.
 0 – Shortly after long-term storage; 5 – after 5 days of shelf-life; 10 – after 10 days of shelf-life; 15 – after 15 days of shelf-life; 20 – after 20 days of shelf-life; 25 – after 25 days of shelf-life.

Fig. 1. Biplot presents scores and loadings of the first two principal components for apple sensory data for cultivar ‘Auksis’

The samples that were stored under NA conditions had the most pronounced sweetness after storage (A1_N – 8.26 points and A2_N – 8.56 points) but during shelf-life period, sweetness of these samples was decreased considerably; after 15 days, sample A1_N has been assessed at 4.92 points, whereas after twenty days of storage, A2_N has been assessed on 4.50 points. In turn, the samples that were stored under CA conditions were initially poor in sweetness (2.60, A2_ULO1; and 4.42, A1_ULO2), however, sweetness of these samples remained intact (4.20 points). Panelists noted that A1_1-MCP and A2_1-MCP were not pronounced in sweetness after storage and it was not recovered, throughout shelf-life period.

Juiciness of apple samples MCP_N, ULO1, and ULO2 was most intense for both harvesting terms at the beginning and remained constant even after 25 days of shelf-life. In turn, less pronounced juiciness was observed for apple samples A1_N and A2_N, and during shelf-life period, it did not change considerably.

Data depicted in Fig. 1 show a low color intensity for A1_ULO2 and A2_ULO2 samples shortly after removing from ULO, while after 25 days of shelf-life at 18 °C, it becomes intensive. However, most pronounced color of apples was recorded on those that were held under A1_N and A2_N conditions. It was classified for 7.06 and 8.02 points and 8.02 and 6.02 points after 15 and 20 days of shelf-life period (A1_N and A2_N, respectively). In turn, the samples that were treated with 1-MCP at the beginning of shelf-life did not had pronounced color compared with other samples, while after 25 days of shelf-life, A1_1-MCP was scored as the sample with the most intensive color (7.94 points). Our results coincide with the findings of Heyn (2009), who pointed out that treatment with 1-MCP as well as storage under ULO conditions strongly impaired color development of apples. In turn, sensory evaluation shows that color of apples characterized as “freshly picked from the tree,” after apple storage at ambient condition, can be partially renewed.

To sum up, it can be concluded that storage technology has a strong impact on sensory quality of apples (aroma, taste, acidity, sweetness, juiciness,

and color), while harvesting time on physicochemical characteristics. The treatment with 1-MCP in general did not cause significant differences at 0 day of shelf-life for ‘Auksis’. In turn, in accordance with panelist comments, after 25 days of shelf-life, A1_MCP_N and A2_MCP_N apples were evaluated as those with a pronounced aroma, sweetness, and color. Apple samples that had been stored under CA conditions (ULO2), after 20 and 25 days of shelf-life, were characterized as having a distinctive juiciness and acidity (A1_ULO2 and A2_ULO2).

Post-harvest apple softening is a serious problem for many growers. Within the time, knowledge on biological causes of softening was obtained, so that this process can be managed or regulated more effectively. Softening is generally considered an undesirable ripening process in apple fruit, as firmer apples tend to be juicier, crisper, crunchier, and less mealy than softer fruits (Conforti & Totty 2007). Weight losses of apples that were stored for 14 days at 16 °C accounted 3.5% (Synowiec et al. 2014) and 4.13% (Kraśniewska et al. 2014). Similar findings were observed in this study (Table 2). The apples harvested in A1 and stored for 6 months under NA lost more fresh weight during shelf-life, than those harvested in A2. The A1 apples treated with 1-MCP before storage lost more fresh weight during 15 days of shelf-life than A2 harvested apples. Total loss of weight of apples that had been stored under ULO1 conditions was 2.81% for A1 and 3.01% whereas those stored under ULO2 was 3.15% (A1) and 3.51% (A2).

Most fruits and vegetables become unmarketable when they lose 5–10% of their fresh weight (Burton 1982). One of the main reasons for the loss of fresh weight during storage is water transpiration and the second reason are the metabolic processes that take place during storage and are associated mainly with respiratory metabolism. According to Juhņevica-Radenkova et al. (2014), storage under ULO conditions as well as treatment with 1-MCP can significantly reduce the loss of fresh weight during shelf-life of apples.

In addition, it has been already proved (Drudze 2003; 2005) that harvesting time considerably influences the shelf-life and quality of fruits. If the apples

at the moment of harvesting are unripe, during storage, their respiration processes are more intensive, which leads to substantial loss of moisture, whereas overripe fruits will be poor in quality, with low nutritional value; also, they are sensitive to low temperature (+2 °C) in short time of storage. The results presented here authorize to conclusion that apples stored under controlled environment conditions (A1_ULO2 and A2_ULO2) and those treated with 1-MCP (A1_MCP_N) can be stored at 18 °C for 25 days without any appreciable deterioration in quality and acceptability.

Fruit flesh firmness is one of the most important characteristics of apple quality. It is influ-

enced greatly by many pre-harvest and post-harvest factors. Maintaining of apple fruit firmness within period from the orchard through to the consumer tends to be one of the major issues facing apple production.

Data that are depicted in Table 3 disclose that at the beginning of shelf-life, flesh firmness of ‘Auksis’ apples kept under cold storage was 32.02 N (A1) and 32.46 N (A2). During 15 days of shelf-life, it decreased considerably to 24.6 N. Flesh firmness of apples treated with 1-MCP at the beginning of shelf-life was 33.95 N (A1) and 32.12 N (A2) and it was decreased during 15 days of shelf-life to about 25 N for both terms of harvesting.

Table 2. Changes in fresh weight of apples (in %) during shelf-life for ‘Auksis’

| First harvesting | Days of shelf-life | | | | | Total |
|----------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------|
| | 5 | 10 | 15 | 20 | 25 | |
| Cold storage | 0.96 ^{bd} | 1.01 ^{ac} | 1.14 ^{ab} | 1.32 ^{aA} | – | 4.43 |
| Cold storage + 1-MCP | 0.90 ^{cC} | 0.58 ^{cd} | 0.47 ^{dE} | 1.01 ^{bB} | 1.05 ^{aA} | 4.01 |
| ULO1 | 0.88 ^{dC} | 0.98 ^{bA} | 0.95 ^{bB} | – | – | 2.81 |
| ULO2 | 1.04 ^{aA} | 0.31 ^{dE} | 0.82 ^{cB} | 0.53 ^{cC} | 0.45 ^{bd} | 3.15 |
| Second harvesting | | | | | | |
| Cold storage | 0.76 ^{dC} | 0.89 ^{cB} | 1.37 ^{aA} | – | – | 3.02 |
| Cold storage + 1-MCP | 0.98 ^{aB} | 1.24 ^{aA} | 0.82 ^{cC} | 0.71 ^{bd} | – | 3.75 |
| ULO1 | 0.95 ^{bC} | 1.05 ^{bA} | 1.01 ^{bB} | – | – | 3.01 |
| ULO2 | 0.80 ^{cC} | 0.36 ^{dE} | 0.42 ^{dD} | 0.94 ^{aB} | 0.99 ^A | 3.51 |

Mean value with standard deviation (\pm) within the same storage period and the same harvesting at 18 °C followed by different small letters are significantly different at $p \leq 0.05$ (LSD test). Means within the same storage conditions followed by different capital letters are significantly different at $p \leq 0.05$ (LSD test). No data indicates the absence of apple sample.

Table 3. Changes in flesh firmness (in N) of ‘Auksis’ apples during shelf-life at 18 °C

| First harvesting | Days of shelf-life | | | | | |
|----------------------|---------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|--------------------------------|
| | 0 | 5 | 10 | 15 | 20 | 25 |
| Cold storage | 32.02 \pm 3.00 ^{dA} | 29.15 \pm 2.11 ^{dB} | 27.44 \pm 1.86 ^{dC} | 24.66 \pm 1.83 ^{dD} | – | – |
| Cold storage + 1-MCP | 33.95 \pm 2.98 ^{cA} | 31.19 \pm 2.24 ^{cB} | 28.83 \pm 2.01 ^{cC} | 25.09 \pm 2.12 ^{cD} | 20.77 \pm 2.43 ^{bE} | 17.33 \pm 1.18 ^{bF} |
| ULO1 | 96.2 \pm 2.87 ^{bA} | 74.91 \pm 2.54 ^{bB} | 65.12 \pm 1.99 ^{aC} | 61.7 \pm 2.21 ^{aD} | – | – |
| ULO2 | 96.52 \pm 2.80 ^{aA} | 78.17 \pm 2.21 ^{aB} | 64.77 \pm 2.03 ^{bC} | 60.17 \pm 1.94 ^{bD} | 59.52 \pm 2.32 ^{aE} | 42.58 \pm 1.87 ^{aF} |
| Second harvesting | | | | | | |
| Cold storage | 32.46 \pm 2.14 ^{cA} | 27.93 \pm 2.22 ^{dB} | 26.42 \pm 2.20 ^{dC} | 23.02 \pm 1.74 ^{dD} | 18.79 \pm 2.47 ^{cE} | – |
| Cold storage + 1-MCP | 32.12 \pm 2.13 ^{cA} | 31.91 \pm 2.24 ^{cB} | 29.23 \pm 1.99 ^{cC} | 24.95 \pm 2.14 ^{cD} | 21.08 \pm 1.97 ^{bE} | – |
| ULO1 | 102.53 \pm 4.11 ^{bA} | 76.8 \pm 2.28 ^{bB} | 66.32 \pm 2.32 ^{bC} | 62.04 \pm 1.62 ^{bD} | – | – |
| ULO2 | 125.72 \pm 4.78 ^{aA} | 82.51 \pm 2.65 ^{aB} | 75.74 \pm 2.21 ^{aC} | 70.01 \pm 2.12 ^{aD} | 65.23 \pm 2.54 ^{aE} | 44.91 \pm 1.64 ^F |

Note: see Table 2.

Flesh firmness of apples kept under ULO1 condition within 15 days of storage decreased from 96.2 to 61.7 N. In turn, in apples stored in ULO2, the initial firmness was 96.5 (A1) and 125.72 N (A2) and decreased to 42.58 (A1) and 44.91 (A2) during 25 days of storage. According to Prange et al. (1993), apples of firmness less than 44.12 N are usually rejected by consumers and, therefore, this is the minimum acceptable for many soft cultivars. Results revealed that CA conditions also reduced the loss of fruit flesh firmness at least by 30% but compared with apples stored under NA conditions the value was much higher because after the storage the value was much higher and therefore they have more acceptable firmness.

Data that are depicted in Table 4 disclose that at the beginning of shelf-life, titratable acidity of apples 'Auksis' fluctuated in a range from 0.58% to 0.72% (A1) and from 0.47% to 0.58% (A2), depending on storage condition. During 15 days at

18 °C, titratable acidity was significantly ($p < 0.05$) depleted. However, it was higher in apples stored under CA conditions in ULO1 and ULO2 (A1) and in ULO1 (A2). In turn, after 15 days of shelf-life maintenance, the lower titratable acidity was recorded in apples kept in cold storage + 1-MCP and in cold storage (A1) and in cold storage and ULO2 (A2). Similar results were reported by Brackmann et al. (2000), who showed that 'Gala' apples kept during long-term storage under air conditions underwent rapid quality loss, whereas low oxygen and other complementary storage procedures could increase the storability and retain fruits' quality. Our results are in coincidence with the findings provided by Fan et al. (1999) and Fan and Mattheis (1999), who noted a positive effect of 1-MCP treatment that allows to maintain content of total acids during shelf-life of such cultivar of apples as 'Red Delicious', 'Granny Smith', 'Fuji, Jonagold', 'Ginger Gold', and 'Gala'.

Table 4. Changes in titratable acidity (in %) in 'Auksis' apple during shelf-life at 18 °C

| First harvesting | Days of shelf-life | | | | | |
|----------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|---------------------------|
| | 0 | 5 | 10 | 15 | 20 | 25 |
| Cold storage | 0.58 ± 0.05 ^{ca} | 0.40 ± 0.05 ^{dc} | 0.29 ± 0.05 ^{cd} | 0.43 ± 0.05 ^{cb} | – | – |
| Cold storage + 1-MCP | 0.58 ± 0.05 ^{cb} | 0.65 ± 0.05 ^{ba} | 0.43 ± 0.05 ^{bc} | 0.36 ± 0.05 ^{bd} | 0.47 ± 0.05 ^{cc} | 0.43 ± 0.05 ^{cc} |
| ULO1 | 0.65 ± 0.05 ^{ba} | 0.62 ± 0.05 ^{cb} | 0.54 ± 0.05 ^{ac} | 0.47 ± 0.05 ^{bd} | – | – |
| ULO2 | 0.72 ± 0.05 ^{aa} | 0.72 ± 0.05 ^{aa} | 0.43 ± 0.05 ^{bc} | 0.58 ± 0.05 ^{ab} | 0.43 ± 0.05 ^{bc} | 0.40 ± 0.05 ^{bc} |
| Second harvesting | | | | | | |
| Cold storage | 0.47 ± 0.05 ^{db} | 0.51 ± 0.05 ^{ca} | 0.33 ± 0.05 ^{dc} | 0.29 ± 0.05 ^{cd} | 0.33 ± 0.05 ^{bc} | – |
| Cold storage + 1-MCP | 0.54 ± 0.05 ^{bc} | 0.58 ± 0.05 ^{bb} | 0.72 ± 0.05 ^{aa} | 0.43 ± 0.05 ^{bd} | 0.43 ± 0.05 ^{ad} | – |
| ULO1 | 0.58 ± 0.05 ^{aa} | 0.58 ± 0.05 ^{ba} | 0.58 ± 0.05 ^{ba} | 0.51 ± 0.05 ^{ab} | – | – |
| ULO2 | 0.51 ± 0.05 ^{cb} | 0.62 ± 0.05 ^{aa} | 0.36 ± 0.05 ^{cd} | 0.29 ± 0.05 ^{de} | 0.43 ± 0.05 ^{cc} | 0.47 ± 0.05 ^c |

Note: see Table 2.

Table 5. Changes in soluble solids content (in °Brix) in 'Auksis' apples during shelf-life at 18 °C

| First harvesting | Days of shelf-life | | | | | |
|----------------------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|
| | 0 | 5 | 10 | 15 | 20 | 25 |
| Cold storage | 13.32 ± 0.21 ^{ba} | 12.68 ± 0.14 ^{dc} | 11.74 ± 0.12 ^{dd} | 12.71 ± 0.19 ^{bb} | – | – |
| Cold storage + 1-MCP | 13.35 ± 0.20 ^{ab} | 14.90 ± 0.14 ^{aa} | 11.80 ± 0.11 ^{cf} | 12.87 ± 0.21 ^{ac} | 12.20 ± 0.13 ^{bd} | 12.05 ± 0.18 ^{ae} |
| ULO1 | 12.90 ± 0.19 ^{cb} | 13.61 ± 0.12 ^{ca} | 12.45 ± 0.13 ^{bc} | 10.22 ± 0.18 ^{dd} | – | – |
| ULO2 | 12.83 ± 0.18 ^{dd} | 13.79 ± 0.18 ^{ba} | 13.70 ± 0.12 ^{ab} | 10.33 ± 0.17 ^{de} | 13.62 ± 0.13 ^{ac} | 10.11 ± 0.21 ^{bf} |
| Second harvesting | | | | | | |
| Cold storage | 13.44 ± 0.18 ^{aa} | 12.90 ± 0.17 ^{bd} | 12.69 ± 0.11 ^{ae} | 13.32 ± 0.11 ^{bb} | 13.20 ± 0.23 ^{bc} | – |
| Cold storage + 1-MCP | 12.75 ± 0.14 ^{cb} | 12.22 ± 0.15 ^{cc} | 11.04 ± 0.09 ^{de} | 11.82 ± 0.12 ^{cd} | 12.92 ± 0.11 ^{ca} | – |
| ULO1 | 12.70 ± 0.17 ^{dc} | 13.71 ± 0.17 ^{aa} | 12.65 ± 0.15 ^{bd} | 13.31 ± 0.11 ^{bb} | – | – |
| ULO2 | 13.18 ± 0.15 ^{bd} | 13.70 ± 0.18 ^{ac} | 12.47 ± 0.14 ^{ce} | 14.38 ± 0.11 ^{aa} | 13.85 ± 0.14 ^{ab} | 11.46 ± 0.21 ^f |

Note: see Table 2.

Total soluble solids content is an indicator of maturity and internal quality of apples that influences consumers' acceptance (Lu 2004).

At the beginning of shelf-life, total soluble solids content in apples 'Auksis' was similar for A1 and A2 (Table 5). A higher soluble solids content was recorded in those samples that had been treated with 1-MCP before storage (first harvest), as well in those that were kept under ULO2 conditions (second harvest).

When fruits were kept for 15 days at 18 °C, significant ($p < 0.05$) reduction of total soluble solids content was recorded in all apple samples (A1) and in cold storage and cold storage +1-MCP apples (A2). In turn, in apples that had been stored under CA conditions, an increase in soluble solids was observed (A1). Reduction of soluble solids content of apples stored under ULO can be explained that after sample removal from conditions with reduced oxygen, apples have experienced stress that triggered intensive respiration resulting in fluctuation of results.

CONCLUSIONS

On the basis of results from sensory evaluation, maximum shelf-life of 'Auksis' apples that were kept in cold storage and ULO1 was 15 days, whereas for apples that were treated with 1-MCP and those that were stored in ULO2 was 25 days. PCA of results from sensory evaluation showed that storage technology has impact on sensory quality of apples (aroma, taste, acidity, sweetness, juiciness, and color). In turn, results from physiochemical evaluation confirmed that type of storage and duration of shelf-life significantly affect the chemical composition of fruit. The treatment with 1-MCP in general did not result in significant differences among the results from sensory evaluation (0 days of shelf-life) of 'Auksis' apples. After 20 days of shelf-life, apples were described as fruits with a pronounced aroma, sweetness, and color (A1_MCP_N and A2_MCP_N). Even after 25 days of shelf-life, apples had retained their best characteristics (A1_MCP_N). After 20 days of shelf-life, apple samples that had been stored under CA conditions (ULO2) were characterized as fruit with distinctive juiciness and acidity (A1_ULO2 and A2_ULO2);

besides, after 25 days of shelf-life, the similar fruit characteristics were observed (A1_ULO2 and A2_ULO2).

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