CHANGES IN QUALITATIVE CHARACTERISTICS OF APPLES STORED IN MODIFIED ATMOSPHERE PACKAGING

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Abstract. The aim of the work was to compare the changes in the qualitative characteristics of "Szampion" apples during their storage in a cold room in Xtend® bags with a modified atmosphere and in a cold store with a normal atmosphere. The scope of research included the measurement of qualitative characteristics of apples (ethylene concentration, firmness, soluble solids content and acidity) from two harvest dates that were stored for 30 and 50 days in a cold store in a normal atmosphere in micro-perforated bags, for two cases of shelf-life. The research material was Szampion apples, which were divided into three batches. Two were packed into Xtend® bags and placed in a cold room at 1-2 ºC and 5-6 ºC for 2 days and the bags were stored in a cold room with a normal atmosphere. It was possible this way to assess the effect of fruit temperature on the atmosphere composition in the packaging as well as on the quality of apples. The third batch of unwrapped fruit was stored in a normal atmosphere. After the storage period, fruit quality was evaluated immediately after being removed from the cold room and after 7 days of shelf-life at 18 ºC. It was found that the use of Xtend® bags slows down the rate of apple ripening and has a positive effect on maintaining their firmness and acidity. Regardless of the length of the storage period, the fruits stored in Xtend® bags were characterized by a lower concentration of ethylene in the seed chambers in relation to fruits stored in a normal atmosphere. There was no significant impact of fruit storage in Xtend® bags on the soluble solid content.

Keywords: apple storage, micro-perforation bags, qualitative characteristics.

Introduction

After harvest, during storage in apples physiological processes continue. The firmness of the flesh and acidity of the fruit decrease. These processes cannot be stopped, they can only be slowed down limiting disadvantageous qualitative changes [1].

The firmness of apples during harvest is often associated with the stage of their physiological maturity and it is one of the most important parameters that define quality [2; 3]. According to Tu et al [4], the harvest time may effect on the rate of decrease in firmness during storage. Often, if the harvest time is delayed, the firmness of the apples decreases [5; 6], but for some varieties these changes are not significant [7]. Testoni and Zerbini [8] think that apples from the earlier harvest date become softer faster during storage in a normal and controlled atmosphere than apples from later harvest. Apples stored in a controlled atmosphere are characterized by higher firmness than those stored in a cold room with a normal atmosphere. The most important factor limiting the rate of respiratory processes in apples is low temperature [9].

Two important qualitative characteristics of apples directly affect the sensory evaluation of fruit: the soluble solid content and titrable acidity. The content of acids in fruits depends primarily on the variety and degree of maturity, also on fertilization. However, nitrogen fertilization may influence nitrogen acidity[10]. Lange and Ostrowski [5] state that during the initial storage period as a result of hydrolysis of starch and changes in other compounds, the level of simple sugars and disaccharides in fruit is increased. According to them, the rate of breakdown of starch is influenced by the presence of ethylene, the temperature and composition of the atmosphere during storage. When determining the storage period, a reduction in the soluble solid content should be taken into account, which causes deterioration in the quality of the fruit [11].

During storage, the content of organic acids gradually decreases [12], while in the first months of storage the speed of these changes is higher [13]. The decrease in acidity of apples can be reduced under conditions of controlled atmosphere [14; 15].

An important factor that limits the ripening of fruits during storage is the modification of the composition of the atmosphere. Considering the way of regulating the composition of the storage atmosphere, we can distinguish technologies of fruit storage in cold stores with a normal atmosphere (NA), with a modified atmosphere (MA) and a controlled atmosphere (KA). In addition to the storage technologies mentioned above, the limitation of metabolic processes during the storage and trading process can be achieved by using innovative fruit packaging. These include MAP (Modified

Atmosphere Packaging) packaging with a modified atmosphere, created as a result of fruit breathing processes and appropriate barrier of the foil. A very important characteristic of these packages is their micro-perforation, which allows to reduce the excessive increase in the concentration of water vapor inside the packaging, and at the same time reduces the permeability of carbon dioxide and oxygen. An example of foil with micro-perforation is Xtend® by Stepac packaging used in the distribution of fresh fruit and vegetables. The distinguishing feature of these packages is the fixed WVTR (Water Vapor Transmission Rate) to keep the right amount of water vapor in the package.

The aim of the work was to compare the changes in the qualitative characteristics of "Szampion" apples during their storage in a cold room in Xtend® bags with a modified atmosphere and in a cold store with a normal atmosphere.

Materials and methods

The subject of the research was apples of the "Szampion" variety. Fruits were collected in two dates in the apple orchard near Łowicz, and then stored in an experimental cold store. The fruits were divided into three batches immediately after harvesting. Two were packed 10 kg into Xtend® bags and placed in a cold store at 1-2 ºC (*T1*) and 5-6 ºC (*T2*) for 48 hours. After this time, the bags were tied and transferred to a cold room with a normal atmosphere (*NA*) at a temperature of 1-2 ºC. The third batch of fruit remained unpacked and stored in *NA* at 1-2 ºC. Under these conditions, the fruits were stored for 50 days. After 30 days of storage (1st analysis date) the fruit quality was evaluated immediately after removal from the cold store and after 7 days of shelf-life (*SCT*) at +18 ºC. The second analysis was carried out after 50 days of storage and after 7 days of *SCT*.

The apples were subdivided into 10 kg samples, which were packed in commercial micro-perforated bags (Xtend® Film, Patent No. 6190710, StePac, Israel). According to the producer the material having a thickness of up to about 500 microns and a permeability to water vapor exceeding about 1.5 g mm m^{-2} per day at 38 ºC and 85–90 % relative humidity.

The ethylene concentration in fruit seed chambers was measured in all analysis dates to assess the degree of apple maturity, and the weight of a single fruit, soluble solid content, titratable acidity and firmness of the flesh were measured for fruit quality assessment.

The weight of the fruit was determined by weighing each fruit on the WPS2100/C/2 laboratory scale (Radwag, Poland). The results of the measurements were given with an accuracy of 0.1 g.

The fruit firmness was determined using the EPT-1R firmness meter (Kelowna, BC Canada) using a standard Magness-Taylor pivot (diameter 11 mm). Measurements were made on both sides of each fruit after first skinning by plunging the stem into the flesh to a depth of 8.7 mm. The results of the measurements are expressed with an accuracy of 1 N.

In order to measure the concentration of ethylene in the seed chambers, 1 ml of the gas sample from the apple was taken. Ethylene concentration measurement was performed on a gas chromatograph (HP 5890 II – Hewlett Packard, USA) with a flame ionization detector. The chromatograph was equipped with a glass column with a diameter of 6 mm and a length of 1200 mm, filled with aluminum oxide (Alumina F-1, 60/80 mesh). The results are given in $\mu l \cdot l^{-1}$ (ppm).

The measurement of oxygen and carbon dioxide concentration in bags after storing apples was carried out using the CheckMate II PBI Dansensor analyzer. Gas samples were taken from each bag with a syringe.

The soluble solid content was determined using the Atago PR-101 digital refractometer (ATAGO, Japan). The measurement was made in freshly squeezed juice from each fruit, and the result was expressed in %. Titrable acidity was determined on a DL 50 Graphix titrator (Mettler Toledo, Switzerland). The measurement was made by the method of titration with a 0.1 N sodium hydroxide solution (NaOH) to a certain volume of juice, until the pH value was 8.1, the result is expressed in % calculated on malic acid.

The research results were developed using the analysis of variance using the Statistica v.12 statistical package.

Results and discussion

The results of the analyzes carried out right after the harvest indicate that according to the assumptions fruits of different maturity and quality were allocated to the study, Table 1.

Table 1

Characteristics of fruits during harvest

Feature	1st harvest term	2nd harvest term
Mass, g	205.5	208.5
Ethylene concentration in seed chambers, ppm	0.06	0.11
Firmness of flesh, N	62.2	61.3
Soluble solid content, %	12.0	12.4
Titrable acidity, %	0.40	0.36

During the storage of apples in Xtend® bags, due to the breathing of the fruits contained in them, the composition of the atmosphere inside the package is modified, Table 2.

Table 2

Concentration of oxygen and carbon dioxide inside the bags

Storage time, days	Fruit temperature during the closing of bags, °C	Concentration inside the bags, %			
		1st harvest term		2nd harvest term	
		O_2	CO_2	O_2	CO_2
30	1-2 (T1)	13.3* ± 2.1**	3.9 ± 0.5	12.1 ± 2.2	3.5 ± 0.1
	5-6 (T2)	12.4 ± 0.9	4.2 ± 0.2	11.5 ± 0.1	3.7 ± 0.1
50	1-2 (T1)	12.9 ± 0.4	3.5 ± 0.2	14.2 ± 1.8	3.1 ± 0.2
	5-6 (T2)	11.7 ± 0.1	3.6 ± 0.1	13.2 ± 1.3	3.3 ± 0.1

* – average value, ** – standard deviation

As it can be seen from the data in Table 2 Xtend® bags are made of a material that allows the formation of an atmosphere containing from 11.5 % to 14.2 % oxygen and from 3.1 % to 4.2 % carbon dioxide. The data indicate that the sum of concentrations of both gases is not equal to 21 %, so it can be concluded that the film selectively transmits atmospheric oxygen and carbon dioxide to the outside of the package. For fruits from both harvesting dates, there was a tendency of lower oxygen concentration in the packaging, in which the fruits with higher temperature were placed. This may be due to the higher breathing rate of warmer fruits. This is consistent with the data presented, inter alia, by Hardenburg et al [9].

The data presented in Figure 1 indicate a significant reduction in the concentration of ethylene in the seed chambers of apples from the first harvesting period and stored for 30 days in the Xtend® system. This applies to both the analysis after 1 day and after 7 days of shelf-life.

a) b)

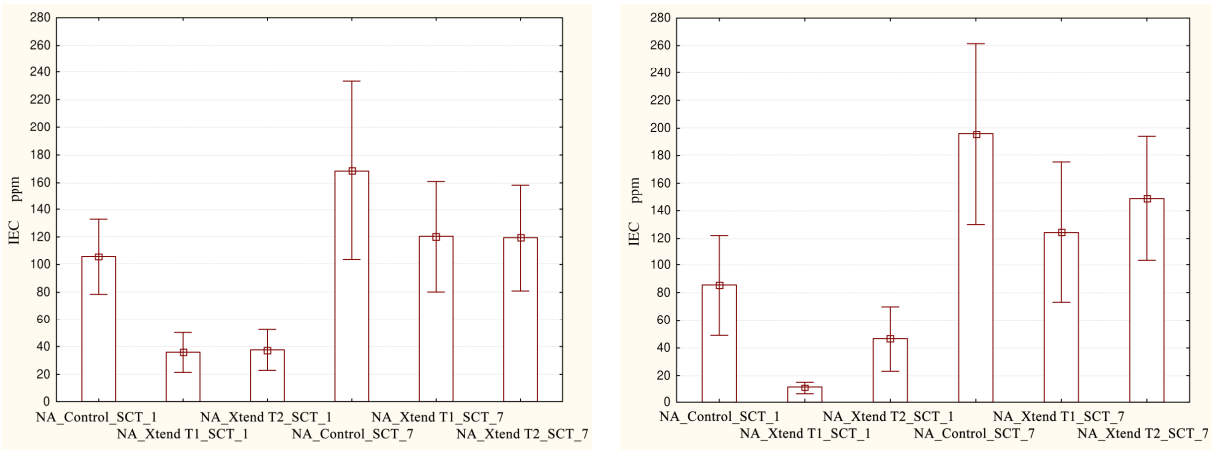

Fig. 1. **Concentration of ethylene in seed chambers of apples from 1st harvesting period:** a) after 30 days, b) after 50 days of storage – kept for 1 and 7 days in *SCT* conditions

No differences were found between the fruits having different temperature when closing the bags. For fruits stored for 50 days, a significantly higher concentration of ethylene was found in seed chambers stored in a normal atmosphere in relation to the fruits stored in Xtend® bags. In addition, in this case a tendency to increase the concentration of ethylene in the seed chambers of fruits closed at 5-6 ° C was observed. A similar relationship was observed for fruits from the second harvest period, Fig. 2. Regardless of the length of the storage period, the fruits stored in Xtend® bags were characterized by a lower concentration of ethylene in the seed boxes in relation to the fruits stored in a normal atmosphere. This regularity was valid both after 1 and after 7 days of shelf-life. The obtained results confirm earlier observations that the conditions of the modified or controlled atmosphere delay the maturation of stored apples.

a) b)

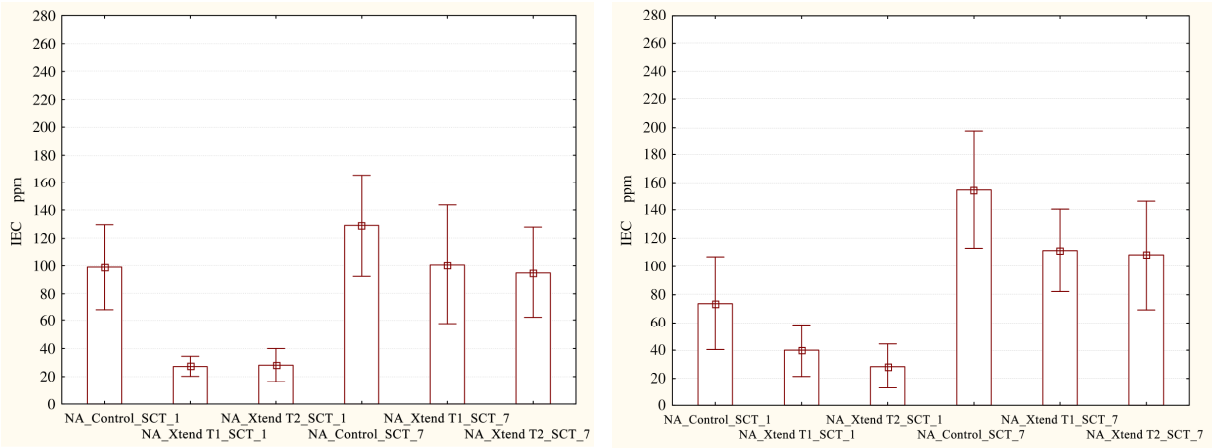

Fig. 2. **Concentration of ethylene in apple seed chambers from 2nd harvesting period:** a) after 30 days, b) after 50 days of storage – kept for 1 and 7 days in *SCT* conditions

The speed of firmness loss depends on the degree of fruit maturity during the harvest, storage temperature and the composition of the storage atmosphere [16].

The fruit's firmness during harvest was just over 60 N, Table 1. During storage, its decline is observed. The firmness of apples after 30 days of storage in the normal atmosphere and day 1 of simulated commodity turnover was about 40 N and 32 N, respectively for fruits from the first and second harvesting dates, Fig. 3 and Fig. 4. These results confirm earlier observations that delaying the harvest time negatively affects the firmness of apples [5]. According to Fallahi et al. [17], differences in apple firmness that occur during multiple harvesting may fade during storage. Further fruit storage at room temperature resulted in progressive softening. Extending the storage period to 50 days resulted in a further decrease in firmness to approx. 33 N and 30 N respectively for fruits from the first and second harvesting dates stored in a normal atmosphere. After 7 days of shelf-life, progressive softening was observed and firmness of 29 N and 26 N for apples from the first and second harvesting time were noted, respectively. Irrespective of the harvesting time and storage period (except 30 storage days and 7 days of shelf-life), the firmness of apples stored in the Xtend® system was significantly higher than those stored under normal atmosphere conditions. This can be explained by the composition of the atmosphere in the bags during storage. The beneficial influence of the controlled atmosphere on maintaining the firmness of apples was indicated by, among others, Skrzyński [18], Ben and Błaszczyk [8].

As indicated by the data presented in Figures 3 and 4, a beneficial effect of closure of the fruit at a higher temperature on maintaining the firmness during storage was observed. It was visible especially after the first day of shelf-life. It may be related to the composition of the atmosphere inside the bags. As can be seen from the data in Table 2, the oxygen concentration in bags closed at 5-6 ºC was lower by about 1 % in relation to that in the bags closed at 1-2 ºC. Although these differences disappeared after 7 days of shelf-life, an important role of oxygen concentration should be indicated to maintain the apple firmness. The beneficial influence of carbon dioxide in the atmosphere surrounding the fruit on their firmness is indicated, inter alia, by Viskelis et al. [19].

a) b)

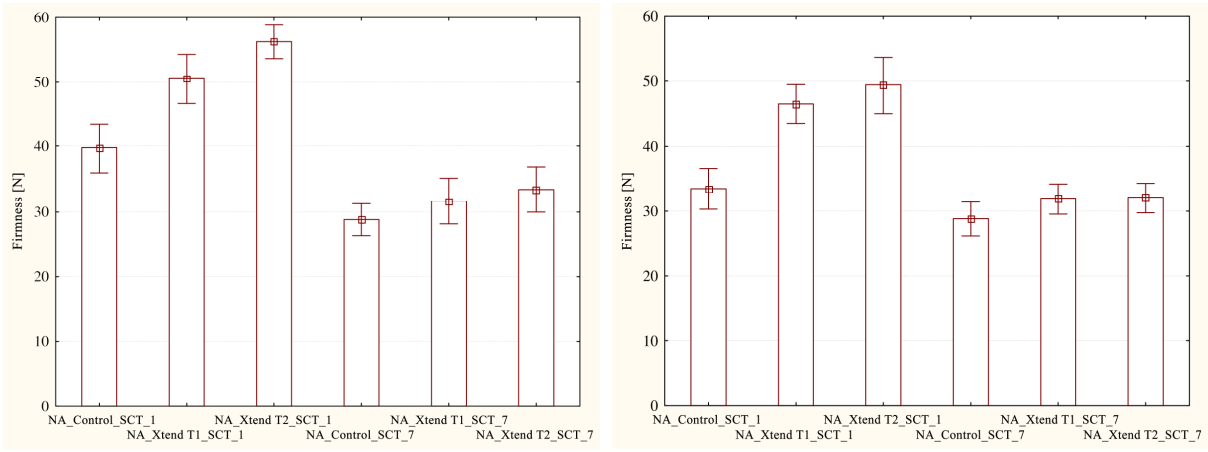

Fig. 3. **Firmness of "Szampion" apples from first harvest date:**
a) after 30 days, b) after 50 days of storage – kept for 1 and 7 days in *SCT* conditions

a) b)

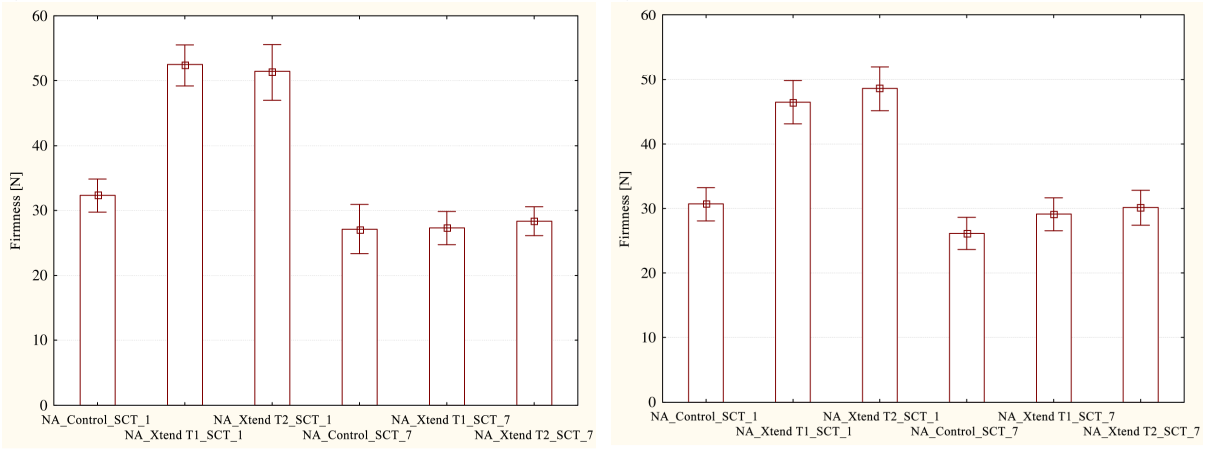

Fig. 4. **Firmness of "Szampion" apples from 2nd harvesting period:**
a) after 30 days, b) after 50 days of storage – kept for 1 and 7 days in *SCT* conditions

The soluble solid content immediately after harvest was 12 % and 12.4 % for fruits from the first and second harvesting dates respectively, Table 1. During storage, a slight increase in the soluble solid content was observed, Table 3, which confirms the previous observations of Lange and Ostrowski [5].

Table 3

Soluble solid content and titratable acidity in "Szampion" apples after 30 and 50 days of storage – kept for 1 and 7 days in *SCT* conditions

Date of harvest	Technology	Soluble solids content , %			
		30 days of storage		50 days of storage	
		1 day SCT	7 days SCT	1 day SCT	7 days SCT
I	NA control	12.8 a[x]	13.0 a	12.8 a	13.3 ab
	NA Xtend T1	12.6 a	13.2 a	12.8 a	13.4 b
	NA Xtend T2	12.8 a	13.1 a	12.6 a	13.0 a
II	NA control	12.6 a	12.7 a	13.5 b	13.3 a
	NA Xtend T1	12.9 a	12.4 a	13.0 a	12.9 a
	NA Xtend T2	12.8 a	12.7 a	12.8 a	12.8 a

Table 3 (continued)

Date of harvest	Technology	Soluble solids content , %			
		30 days of storage		50 days of storage	
		1 day SCT	7 days SCT	1 day SCT	7 days SCT
Titratable acidity, %					
I	NA control	0.35 a	0.34 a	0.35 a	0.31 a
	NA Xtend T1	0.37 b	0.37 b	0.34 a	0.33 b
	NA Xtend T2	0.35 a	0.36 b	0.37 b	0.35 c
II	NA control	0.33 a	0.30 b	0.31 a	0.29 a
	NA Xtend T1	0.33 a	0.32 c	0.31 a	0.29 a
	NA Xtend T2	0.33 a	0.29 a	0.32 ab	0.29 a

[x] means with the same letter do not differ significantly according to the Newman-Keulus test with the significance level $\alpha = 0.05$s

As indicated by the results, apart from two cases (I harvest time, 50 days storage and 7 days *SCT* and the second harvesting time, 50 days storage 1 day *SCT*) no significant effect of storage conditions on the content of extract in apples was observed.

The titratable acidity of the fruit immediately after harvest was 0.40 % and 0.36 % for fruits from the first and second harvesting dates respectively, Table 1. During storage, a slight decrease in acidity was observed, along with the extension of the storage period and the period of shelf-life, Table 3. This is in line with the previous observations, Olsen et al. [12], Nabiałek and Ben [15]. No significant influence of the change in the gas atmosphere composition on the maintenance of acidity was observed, as indicated by Skrzyński [14], Nabiałek and Ben [15]. This may be due to too high oxygen concentration in the Xtend® bags (above 11 %). and the standard controlled atmosphere conditions below 3 % oxygen.

Conclusions

1. The rate of change of the qualitative characteristics of "Szampion" apples varies according to the storage conditions.
2. For the apples stored in Xtend® bags, a lower concentration of ethylene in the seed chambers was observed, which indicates their slower ripening.
3. The use of Xtend® bags for 50 days of apple storage has a positive effect on maintaining their quality characteristics, especially firmness and titratable acidity.
4. There was no significant effect of the apple storage technology on the soluble solid content.
5. It is advisable to conduct further research on the storage of apples in bags with other selective gas permeability, which may result in even better maintenance of fruit quality characteristics.

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