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EFFECT OF 1-METHYLCYCLOPROPENE AND ULO CONDITIONS ON BIOACTIVE COMPOSITION AND ORGANOLEPTIC PROPERTIES OF APPLES DURING STORAGE

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ABSTRACT

The aim of this study was to analyze the effect of the use of an agent inhibiting ethylene release - 1-Methylcyclopropene in the storage of selected apple varieties 'Szampion', 'Gloster', 'Elstar', 'Ligol', 'Idared', 'Jonagold', and 'Honeygold' originating from orchards of the Fruit Plant in Wtelno and stored in chambers with a controlled atmosphere. Laboratory analyzes were performed immediately after harvest and after 6 months of storage in chambers under ULO conditions (<2% O_2, <2% CO_2) at a temperature of 1.5–2.0°C and relative air humidity of 95–96%. Fruits treated with 1-MCP were characterized by significantly lower losses of bioactive compounds, especially vitamin C, compared to untreated apples. The contents of total polyphenols and chlorogenic acid remained at a similar level as after harvest in untreated apple samples. After the storage period, the 'Szampion' variety contained significantly the most polyphenolic compounds, and the least - the 'Honeygold' variety, where the highest decrease was also recorded during storage (26.7%) in fruits not treated with 1-MCP. After storage, the 'Ligol' and 'Elstar' cultivars had the significantly highest content of chlorogenic acid. The highest losses of chlorogenic acid during apple storage (32.4%) were observed in the 'Honeygold' variety. The lowest loss of ascorbic acid during apple storage

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(34.9%) was observed in the 'Idared' variety, and the highest loss in the 'Honeygold' variety (66.8%).

Keywords: Vitamin C, chlorogenic acid, total polyphenols, FRAP oxidative capacity, storage

INTRODUCTION

Apples are one of the most popular fruits consumed in the world. Poland is the largest apple producer in Europe and the fourth largest in the world, after China, Turkey and the United States. Thanks to modern storage technologies, apples are available all year round, despite seasonal harvests. During storage, efforts are made to reduce losses, both quantitative and qualitative. These losses result, among others, from the release of ethylene, which stimulates the ripening and aging of climacteric fruits (e.g. apples, pears, plums), which results in the development of their typical taste and color and a change in texture. Apples, as a raw material valued by foreign customers, should also survive transport conditions as unchanged as possible, even to Asian or African countries. Therefore, the conditions in the storage room should ensure that they are stored unchanged for as long as possible. Controlled atmosphere (CA) with the possibility of using the ULO version (reduced oxygen content) is considered the best technology for storing fruit. This technology slows down the pace of physiological and biochemical processes that lead to fruit ripening and overriping, and also reduces sensitivity to some physiological diseases and reduces the sensitivity of fruit to ethylene. This results in a potential extension of fruit storage time while maintaining high commercial quality. Another beneficial effect is the reduction of pathogen activity and the ability to control the presence of rodents and insects in cold rooms. This technology also has disadvantages. Sometimes it is possible that the fruit may not develop the correct color and typical aroma after a long time of storage, especially in ULO chambers.

The technology of fogging fruit with a compound that blocks the release of ethylene is a method that complements the most frequently used methods of fruit storage. The SmartFresh 0.3 VP preparation is used, the active substance of which is 1-methylcyclopropene (1-MCP). Therefore, apples retain high firmness, juiciness, tenderness and taste typical of freshly picked fruit for a long period of time - both in the case of regular cold stores and KA/ULO cold storage facilities. This effect is visible both after removing the apples from cold storage and during trade, when the fruit remains under the influence of higher temperatures for a longer time. This is of great importance in the case of export or deliveries to retail chains. The use of SmartFresh allows you to reduce storage losses - also those caused by burns (Podymniak, 2012; Werner, 2011; Paradowski and Badowski, 2009). The period after opening the chamber is extended during which the fruit can be prepared and sold without loss of quality. In supermarket tests, consumers chose apples from chambers treated with 1-MCP because of their juiciness, firmness and fresh taste. Traders emphasized the lower level of losses and higher fruit sales (Hallman et al., 2023). Application (dosing) is made in the chamber immediately after fruit harvest. The conditions for effective treatment are the appropriate stage of fruit ripeness, a short time from harvest to full filling of the chamber and the gas-tightness of the cold store (but only for the time of application). One 24-hour treatment is performed in a chamber filled with apples. After this time, you can start storing in the storage regime of your choice (standard cold store, KA or ULO). It is possible to use 1-MCP in chambers with more than one variety (mixed chambers), but the optimal loading date must be maintained. Moreover, storage conditions should be adapted to a variety that is more sensitive, e.g. to lower CO_2 concentrations. The use of 1-methylcyclopropene has the most beneficial effect in cold stores, where it is possible to extend the storage time of fruit by up to several weeks, and as a complement to KA technology. At the same time, SmartFresh is completely safe for producers, consumers and the environment (Vijay and Rakesh, 2010).

Apples are a valuable addition to the daily diet, because to the bioactive compounds they contain, such as polyphenols, which are very strong antioxidants. In addition, apples are rich in acids that lower urine pH, may reduce the formation of kidney stones and increase the excretion of oxalates. These fruits are also rich in pectin substances, which support the removal of toxic substances from the body, such as heavy metals (Pyryt and Wrześniak, 2011).

The aim of the study was to analyze the impact of the storage technology ULO used (with used or without 1- Methylcyclopropene on the organoleptic and the bioactive composition and antioxidant capacity in selected apple varieties.

MATERIAL AND METHODS

The material for the research consisted of apple fruits from orchards with the Integrated Horticultural Production of the Fruit Plant in Wtelno from three years of harvest (2013-2015). The tests were conducted immediately after harvest and after 6 months of storage in storage chambers with a controlled atmosphere (ULO), i.e. 2% O_2, 2% CO_2, 1.5–2.0°C and 95–96% relative humidity with or without 1-Methylcyclopropene on selected apple varieties: Ligol, Idared, Szampion, Elstar, Gloster, Rubin, Honeygold. The application of 1-methylcyclopropene at a concentration of 1 $\mu L \cdot L^{-1}$ was performed for 24 hours in tightly closed chambers on fruit harvested at the technological ripeness recommended by the manufacturer. The control sample consisted of trials without the use of 1-MCP.

The scope of laboratory analyzes included determining the dry matter content using the gravimetric method according to PN-A-75101/03, Vitamin C content - using the Tillmans method according to PN-A-04019, total polyphenols - for analysis, the tested material was freeze-dried using an Alpha freeze dryer - 2-4 LSC for 72 hours. The content of total polyphenols after extraction was determined by the spectrophotometric method in the presence of the Folin-Ciocalteu reagent in relation to gallic acid, using a UV-Vis Meterech SP-8001 spectrophotometer at a wavelength of 735 nm (Fang et al., 2006). The content of chlorogenic acid was determined in the previously lyophilized material using the colorimetric method using the Meterech SP-8001 UV-Vis Spectrophotometer at a wavelength of 510 nm - according to Wynne et al. (1992). The determination of the FRAP antioxidant capacity in the analyzed apple varieties involved measuring the reducing capacity of the 2,3,6-tripyridyl-s-triazine ferric ion, called TPTZ. The iron (III) compound reacts with the antioxidant and the sample changes color (Bezie and Strain, 1996). The measurement method was used using the Meterech SP-8001 UV-Vis Spectrophotometer at a wavelength of 593 nm. The FRAP unit determines the ability of iron (III) to be reduced to iron (II). The antioxidant capacity of the tested sample is determined by comparing changes in the absorbance of the tested sample with the change in the extinction of the standard solution, i.e. Fe (II). The tested change in sample extinction is directly proportional to the antioxidant content in the tested material. An organoleptic analysis was also performed according to established own criteria by a trained team of people, tested for sensory predispositions in accordance with PN-ISO 6658:98. The organoleptic analysis in terms of taste, smell and palatability of apples included: taste - it was described as sweet, sour, winey, or with the flavors of other fruits with various combinations; smell - defined as: natural, slightly perceptible, clear or strong; palatability, i.e. the impression common to taste and smell, was determined on a scale of 1-9, where 1 was the worst and 9 was the best; Enzymatic darkening was assessed using a 9-point scale according to Danish color tables after 10 minutes and after 1 hour, where: 9 - flesh not darkening, 1 - almost black (5-1 disqualification).

The research results were analyzed statistically using analysis of variance for two-factor experiments, where the first factor was the apple variety, the second factor was the use of 1-methylcyclopropene. The Tukey test was used to assess the differences in object means of individual factors, determining the significance of differences at the significance level of $\alpha = 0.05$.

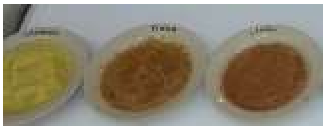
RESULTS AND DISCUSSION

In apple storage, the effect of ethylene is undesirable because it initiates increased production of ethylene in the fruit, thus accelerating their ripening. Under the influence of ethylene, the intensity of fruit respiration increases and their susceptibility to rot and some physiological diseases increases. In the study by Vilaplana et al. (2006), the use of 1-MCP significantly reduced the release of ethylene by apples, which consequently slowed down their ripening. The research results indicate a positive effect of 1-MCP against the applied storage conditions - ULO, i.e. 2% O_2, 2% CO_2, 1.5–2.0°C and 95–96% relative humidity on the organoleptic and physicochemical characteristics of apples. The varieties selected for testing were healthy, firm, juicy, fresh, clean, of good quality, with typical color, uniform in variety and calibrated according to size groups qualifying them to class I and Extra. The sum of permissible defects was not more than 5% (Extra class). In the study by Rupasinghe et al. (2000), apples treated with 1-MCP were significantly harder than untreated apples after storage and processing after storage for 7 to 14 days at 20°C. Additionally, 1-MCP treatment reduced the incidence of superficial scald on 'McIntosh' and 'Delicious' apples by 30% and 90%, respectively. Similar results with regard to those studied by Rupasinghe et al. (2000) of apple characteristics were obtained by Skrzyński (2007) and Sikora (2008). Under the influence of this compound, apples retained higher firmness and overall acidity. 1-MCP limited ethylene release and also helped maintain the green color of the peel. Moreover, treating the fruits with this compound and storing them under CA conditions turned out to be an effective method of reducing apple losses related to the occurrence of surface burns.

Table 1. Organoleptic evaluation of apples after harvest (synthesis from 2013-2015)

Apple features	Cultivar						
	Idared	Szampion	Honegold	Ligol	Gloster	Elstar	Jonagold
Color pulp/coloration	Light yellow Red on ¾ of the surface	Light yellow Red on ½ of the surface	Yellow Green	Light yellow Red on ½ of the surface	Light green Red on ¾ of the surface	Light cream striped light red blush above ½ of the surface	Light green, red blush above ¾ of the surface
Shape	Even shape	Even shape	Even shape	Even shape	Even shape	Even shape, spherical, flattened shape	Even shape spherical,
The consistency of the pulp	firm, fine-grained, juicy flesh	the flesh is crisp, medium-grained, juicy	delicate, juicy flesh	tender, juicy flesh	tight, juicy flesh	firm, juicy flesh	tender, juicy flesh
Size (diameter on cross-section)	7.20 ± 0.12	7.00 ± 0.16	7.50 ± 0.02	6.70 ± 0.0	7.30 ± 0.06	6.80 ± 0.04	7.50 ± 0.02
Smell	Natural	Natural	Slightly noticeable	Natural	Slightly noticeable	Natural	Natural
Taste	Sweet	Sweet	Faintly sweet Sweet - guilty	Very sweet	Faintly sweet Sweet - guilty	Sweet	Sweet
Deliciousness*	9.00 ± 0.15	9.00 ± 0.18	7.20 ± 0.20	8.10 ± 0.06	7.30 ± 0.05	9.00 ± 0.08	8.30 ± 0.02
Damage/rot	Few /lack	Lack	Lack	Lack	Lack	Lack	Lack
Enzymatic darkening*1: -after 10 minutes -after 1 hour	7.00 ±0.01 6.00 ±0.05	9.00 ±0.00 9.00 ±0.00	7.50 ±0.02 6.00 ±0.06	8.00 ±0.05 7.50 ±0.05	8.00 ±0.04 6.50 ±0.04	8.00 ±0.01 7.50 ± 0.02	8.00 ±0.03 7.00 ±0.06

*9-point scale, where 9 means extremely good, 1 means extremely bad
*1 9-point scale, where 9 means unchanged color, 1 – brown



Szampion Elstar Ligol

Jonagold Gloster Honeygold Idared

Figure 1. Enzymatic darkening of raw apple samples exposed to oxygen for 1 hour after harvest

Table 2. Organoleptic evaluation of apples after 6 months of storage in chambers without the use of 1-MCP (average from the storage seasons 2014-2016)

Apple features	Cultivar						
	Idared	Szampion	Honegold	Ligol	Gloster	Elstar	Jonagold
Color pulp/ Coloration	Light yellow/ Red on 80% of the surface	Light yellow/ Red on 70% of the surface	Yellow/ Green with a yellow blush on 30% of the surface	Light yellow/ Red on 60% of the surface	Light green/ Red on 90% of the surface	Light cream striped/red blush over 60% of the surface	Light green/ red blush over 70% of the surface
The consistency of the pulp	The flesh is crisp, fine-grained, juicy	The flesh is crisp, medium-grained, juicy	Delicate, juicy flesh	Tender, juicy flesh	Firm, juicy flesh	Firm, juicy flesh	Tender, juicy flesh
Smell	Slightly noticeable	Natural	Slightly noticeable	Slightly noticeable	Slightly noticeable	Slightly noticeable	Slightly noticeable
Taste	Sweet	Very sweet	Faintly sweet Sweet - guilty	Very sweet	Faintly sweet Sweet - guilty	Sweet	Sweet
Deliciousness*	8.50 ± 0.02	8.50 ± 0.03	6.10 ± 0.05	7.50 ± 0.05	7.10 ± 0.06	7.20 ± 0.10	7.10 ± 0.12
Enzymatic darkening*1: -after 10 minutes -after 1 hour	6.00 ± 0.05 5.10 ± 0.05	8.70 ± 0.03 8.40 ± 0.01	6.10 ± 0.02 5.10 ± 0.04	7.90 ± 0.02 7.00 ± 0.03	7.5 ± 0.01 6.2 ± 0.05	7.70 ± 1.00 7.00 ± 0.06	7.50 ± 0.02 6.50 ± 0.03

Table 3. Organoleptic evaluation of apples after 6 months of storage in chambers using 1-MCP (average from the 2014-2016 storage seasons)

Apple features	Cultivar						
	Idared	Szampion	Honegold	Ligol	Gloster	Elstar	Jonagold
Color pulp/ Coloration	Light yellow Red on ¾ of the surface	Light yellow Red on 60% of the surface	Yellow Green on 10% of the surface	Light yellow Red on ½ of the surface	Light green Red on ¾ of the surface	Light cream striped light red blush above ½ of the surface	Light green, red blush above ¾ of the surface
The consistency of the pulp	Firm, fine-grained, juicy flesh	The flesh is crisp, medium-grained, juicy	Delicate, juicy flesh	Tender, juicy flesh	Firm, juicy flesh	Firm, juicy flesh	Tender, juicy flesh
Smell	Slightly noticeable	Natural	Slightly noticeable	Natural	Slightly noticeable	Slightly noticeable	Natural
Taste	Sweet	Sweet	Faintly sweet, Sweet and guilty	Very sweet	Faintly sweet Sweet - guilty	Sweet	Sweet
Deliciousness*	8.50 ± 0.02	9.00 ± 0.03	7.00 ± 0.05	8.00 ± 0.06	7.00 ± 0.04	8.50 ± 0.02	8.10 ± 0.01
Enzymatic darkening*1: -after 10 minutes -after 1 hour	6.50 ± 0.02 5.90 ± 0.01	9.00 ± 0.0 9.00 ± 0.0	7.50 ± 0.02 6.00 ± 0.03	7.90 ± 0.01 7.50 ± 0.05	7.90 ± 0.04 6.50 ± 0.06	7.90 ± 0.01 7.50 ± 0.02	7.70 ± 0.02 7.00 ± 0.06

The most important features of apples are their appearance (color), taste and smell. Research by Adamczyk et al. (2006) conducted on apples stored in ordinary cold stores showed a deterioration of the sensory quality of the analyzed fruits, including a decrease in the intensity of flavor and aroma characteristics. Marks (2011) also showed a decrease in the palatability of tested apples stored in various types of storage, paying attention to the smallest losses obtained from apples stored in ULO chambers. Paradowski and Badowski (2009) claim that storing fruit with SmartFresh technology allows them to remain firm, juicy and tasty for longer. The use of SmartFresh™ maintains the firmness and acidity of the fruit at the appropriate level. Tests carried out to assess consumer preferences on fruit showed that hard and juicy apples are preferred (Tomala et al., 2013). Moreover, the agent limits and delays the occurrence of surface burns (Tomala et al., 2013). The technology of using 1-MCP can apply to any type of tight chambers, but a stronger effect is demonstrated in CA conditions. The effectiveness of using the product on apples depends, among others, on: on the variety and storage conditions, including temperature and storage duration (Watkins et al., 2000; DeEll et al., 2010, 2016). The results presented by Błaszczyk and Gasparski (2019) confirmed that different storage conditions have a significant impact on the quality of stored apples. Fruits of the 'Red Jonaprince' variety in condition CA cold storage, even in combination with treatment with 1-MCP, lost their firmness the fastest, while fruits stored in ULO conditions with the use of 1-MCP retained their firmness the best. However, post-harvest application of 1-MCP had a positive effect on the final firmness of apples of all tested varieties. According to Tomala et al. (2014), lowering the temperature and oxygen level while increasing the carbon dioxide level in storage facilities extends the possibility of long-term storage of apples, but for varieties characterized by low firmness, such as 'Szampion', this may be insufficient. In turn, accelerating the harvest in order to maintain higher firmness of the fruit of this variety usually results in insufficient color of the apples that does not meet high consumer requirements. Therefore, the 'Szampion' variety should be harvested at the right time, but the fruit should be protected as best as possible, protecting them against further loss of firmness. The use of 1-MCP (SmartFresh™) in such situations resulted in maintaining the required firmness, while in apples stored without 1-MCP, especially those harvested later, more intense ethylene release was observed (Tomala et al., 2014). The fruits also retained their fresh appearance and firmness for longer after being removed from storage chambers. Our own research on apples stored in SmartFresh chambers confirmed the high sensory quality of the fruit. Tested apple varieties in accordance with Commission Regulation (EC) No. 85/2004 of January 15, 2004. establishing marketing standards for apples have been classified as first quality class. The fruits showed no contamination or damage, were ripe, uniform in shape and appropriate in color. The palatability of apples is determined primarily by the ratio of organic acids to sugars. Malic acid is the dominant acid in apple, it affects not only the taste, but also has a significant impact on the quality of the fruit (Guan et al., 2015). During fruit ripening and aging, the acid content decreases may result from acid oxidation to meet energy needs (Butkeviciute et al., 2021). The most desirable palatability after harvest (combined impression of taste and smell) (Table 1) on a 9-point scale was characterized by the cultivars 'Idared', 'Szampion' and 'Elstar', receiving the highest score of 9, and the worst - 'Honeygold' and 'Gloster' '. Appropriate taste and smell influence the palatability of the fruit, therefore, of the tested apple varieties, the most desirable were the 'Idared', 'Szampion', 'Ligol', 'Elstar', 'Jonagold' varieties, while the 'Honeygold' variety was characterized by an indistinct taste and a slightly noticeable foreign odor. As for the tendency to enzymatic darkening tested after 1 hour of exposure to oxygen on the pulp, the 'Szampion' variety darkened the least among the examined varieties, followed by 'Elstar', 'Ligol', 'Jonagold', 'Gloster', 'Honychold', and the darkest variety 'Idaret' (Fig. 1).The use of 1-MCP resulted in minor changes in all tested varieties in their organoleptic characteristics after 6 months of storage (Table 3). In turn, in samples not treated with 1-MCP, changes in the color and consistency of the flesh, smell, flavor, palatability and darkening were observed, especially in the 'Honeygold' variety (Table 2). However, in the case of the 'Elstar' variety stored in chambers without the use of 1-MCP, a change in the apple aroma occurred (Table 2). In turn, in the Lithuanian experiment, apples stored under ULO conditions were rated much higher in terms of palatability and color compared to apples treated with 1-MCP. However, it was noted positive effect of 1-MCP on maintaining the quality of apples stored for 6 months under NA conditions. The quality of these apples was comparable to fruit stored in the same period under ULO conditions (Juhnevica-Radenkova and Radenkovs, 2016). The results of the research by Błaszczyk and Gasparski (2019) confirmed that different storage conditions have a significant impact on the quality of stored apples. The fruits of the 'Red Jonaprince' variety in NA cold storage conditions, even in combination with treatment with 1-MCP, lost their firmness the fastest, while the fruits stored in ULO conditions with 1-MCP retained their firmness the best. In turn, Sganzerla et al. (2018) examined the effect of 1-MCP on the quality parameters of fruits of three mutations of the 'Gala' variety stored at 0°C for 90 days. It turned out that 'Mondial Gala', 'Imperial Gala' and 'Galaxy' differ significantly in the date of reaching harvest maturity. However, post-harvest application of 1-MCP had a positive effect on the final firmness of apples of all tested varieties. However, the use of 1-MCP did not have a significant impact on the basic color of the peel.

In our own post-harvest research, among the varieties assessed visually, after 10 minutes and 1 hour of exposure to oxygen, the flesh of the 'Idared' variety darkened the most, and the ‘Szampion’ variety was the least susceptible to enzymatic darkening, both after harvest and after storage. regardless of the storage technology used. According to Biegańska-Marecik and Czapski (2003), the slowest darkening varieties include 'Szampion', 'Ozark Gold', 'Elstar', 'Fantazja', while the rapidly darkening varieties include 'Spartan', 'Lobo', 'Liberty' and 'Idared' '. Visually assessing the cut apples directly and 4 hours after cutting, they found that the 'Cortland' and 'Szampion' varieties showed no discoloration of the flesh, slight discoloration at the core was observed in the 'Elstar' and 'Gala' varieties, while the darkest color was observed in the 'Elstar' and 'Gala' apples. Idared' (Bieganska-Marecik and Czapski 2003; Oszmiański et al., 2018).

Table 4. Dry matter content in apples (% dry matter) depending on the variety and the storage technology used (synthesis from 2013-2015)

Cultivar (I)	After storage	After 6 months of storage		
		Used technology (II)		Mean
		Control	1-MCP	
Ligol	12.41 ± 0.05	12.71 ± 0.04	12.33 ± 0.03	12.52
Honegold	12.10 ± 0.04	12.32 ± 0.01	12.22 ± 0.01	12.27
Elstar	13.22 ± 0.06	13.52 ± 0.03	13.11 ± 0.06	13.32
Idared	12.44 ± 0.05	12.61 ± 0.06	12.54 ± 0.04	12.58
Szampion	13.62 ± 0.04	13.91 ± 0.09	13.71 ± 0.06	13.81
Gloster	14.11 ± 0.07	14.52 ± 0.10	14.31 ± 0.07	14.42
Jonagold	14.02 ± 0.02	14.42 ± 0.01	14.31 ± 0.07	14.37
Mean	13.13	13.43	13.21	13.32
LSD $_{p=0.05}$ cultivar (I)	0.070	0.070		
LSD $_{p=0.05}$ technology used (II)	-	0.021		
LSD $_{p=0,05}$ interaction I/II	-	0.036		

The term dry matter means all the ingredients that remain after the water evaporates from the product and the volatile substances are separated from it (Jarczyk, 2006). In the conducted research (Table 4), the cultivars 'Gloster' (14.01%) and 'Jonagold' (13.98) had the highest dry matter content, and the lowest content was 'Honeygold' (12.10%). According to Jarczyk (2006), apple fruit has a dry matter content of approximately 15%. Differences in content result from the varietal characteristics of the fruit. The technology used also had a significant impact on the tested parameter, where a higher dry matter content was obtained in apples without the use of 1-MCP. The greatest amount of dry matter after storage was found in the 'Gloster' variety stored in chambers without the use of 1-MCP.

Table 5. Vitamin C content in apples (mg kg⁻¹ FM) depending on the variety and storage technology used (synthesis from 2013-2015)

Cultivar (I)	After storage	After 6 months of storage		
		Used technology (II)		Mean
		Control	1-MCP	
Ligol	57.71 ± 0.08	37.26 ± 0.21	41.26 ± 0.11	39.26
Honegold	41.11 ± 0.06	11.52 ± 0.06	15.68 ± 0.01	13.60
Elstar	68.61 ± 0.01	38.56 ± 0.04	42.59 ± 0.10	40.58
Idared	48.12 ± 0.05	27.31 ± 0.06	35.35 ± 0.10	31.33
Szampion	79.02 ± 0.05	51.48 ± 0.08	55.42 ± 0.01	53.45
Gloster	28.25 ± 0.05	17.89 ± 0.12	19.65 ± 0.03	18.77
Jonagold	46.23 ± 0.05	28.95 ± 0.03	30.25 ± 0.11	29.60
Mean	52.72	30.42	34.31	32.37
LSD $_{p=0.05}$ cultivar (I)	2.227	0.499		
LSD $_{p=0.05}$ technology used (II)	-	0.137		
LSD $_{p=0.05}$ interaction I/II	-	0.392		

Table 6. Content of chlorogenic acid in apples (mg·kg⁻¹ dry weight) depending on the variety and storage technology used (synthesis from 2013-2015)

Cultivar (I)	After storage	After 6 months of storage		
		Used technology (II)		Mean
		Control	1-MCP	
Ligol	271.42 ± 0.21	268.54 ± 0.05	263.51 ± 0.05	266.03
Honegold	275.21 ± 0.14	189.13 ± 0.05	186.52 ± 0.03	187.83
Elstar	278.12 ± 0.11	268.61 ± 0.02	265.23 ± 0.10	266.92
Idared	249.23 ± 0.11	237.21 ± 0.01	230.11 ± 0.09	233.66
Szampion	209.41 ± 0.02	202.11 ± 0.04	204.51 ± 0.05	203.31
Gloster	223.60 ± 0.05	215.52 ± 0.05	221.62 ± 0.05	218.57
Jonagold	238.20 ± 0.06	231.21 ± 0.09	236.31 ± 0.02	233.76
Mean	249.3	230.3	229.7	230.01
LSD $_{p=0.05}$ cultivar (I)	0.300	0.272		
LSD $_{p=0.05}$ technology used (II)	-	0.122		
LSD $_{p=0.05}$ interaction I/II	-	0.206		

Table 7. Content of total polyphenols in apples (mg·kg⁻¹ dry matter) depending on the variety and storage technology used (synthesis from 2013-2015)

Cultivar (I)	After storage	After 6 months of storage		
		Used technology (II)		Mean
		Control	1-MCP	
Ligol	1258.31 ± 0.23	1254.30 ± 0.03	1225.21 ± 0.55	1239.76
Honegold	1130.50 ± 0.56	836.57 ± 0.21	836.89 ± 0.17	836.73
Elstar	1296.92 ± 0.21	1276.20 ± 0.14	1128.87 ± 0.14	1202.54
Idared	993.41 ± 0.22	969.22 ± 0.15	934.31 ± 0.15	951.77
Szampion	1198.20 ± 0.15	1178.21 ± 0.15	1138.63 ± 0.11	1158.42
Gloster	988.50 ± 0.23	964.21 ± 0.08	935.61 ± 0.11	949.91
Jonagold	1242.41 ±0.15	1195.60 ± 0.09	1145.60 ± 0.12	1170.60
Mean	1158.32	1096.33	1049.30	1072.82
LSD $_{p=0.05}$ cultivar (I)	0.231	0.027		
LSD $_{p=0.05}$ technology used (II)	-	0.014		
LSD $_{p=0.05}$ interaction I/II	-	0.020		

Table 8. Antioxidant capacity of FRAP in the tested apple varieties (μmol Fe2+/kg-3 dw) after harvest and after storage (synthesis from 2013-2015)

Cultivar (I)	After storage	After 6 months of storage		
		Used technology (II)		Mean
		Control	1-MCP	
Ligol	2786.51 ± 0.23	2451.31 ± 0.20	2658.91 ± 0.25	2555.11
Honegold	3128.20 ± 0.29	2759.59 ± 0.15	3005.59 ± 0.28	2882.59
Elstar	2899.61 ± 0.31	2351.61 ± 0.12	2789.57 ± 0.41	2570.59
Idared	2849.22 ± 0.11	2298.62 ± 0.11	2689.31 ± 0.31	2493.97
Szampion	3146.51 ± 0.12	2987.87 ± 0.18	3012.21 ± 0.29	3000.04
Gloster	2568.22 ± 0.52	2456.32 ± 0.21	2489.64 ± 0.25	2472.98
Jonagold	2854.21 ± 0.58	2754.31 ± 0.23	2756.43 ± 0.24	2755.37
Mean	2890.35	2579.95	2771.67	2675.81
LSD $_{p=0.05}$ cultivar (I)	0.231	0.182		
LSD $_{p=0.05}$ technology used (II)	-	0.094		
LSD $_{p=0.05}$ interaction I/II	-	0.139		

Apples are fruits available all year round, so consumers eat them very often and for this reason, like potatoes, they are a very good source of Vitamin C (Świetlikowska, 2008; Ivanov 2014). This vitamin is an important antioxidant that strengthens immunity, the functioning of the circulatory system and lowers blood pressure. In the conducted research (Table 5), the Szampion variety had the highest vitamin C content, containing 79.02 mg· kg^{-1} fresh matter, and the lowest was the Gloster variety, which contained 28.25 mg· kg^{-1} fresh matter. According to Świetlikowska (2008) and Jarczyk (2006), the vitamin C content in apple fruit after harvest was 92 mg·kg-1. The average value is related to a given variety and storage conditions (during storage, the vitamin C content is subject to significant losses, even over 60%). The aging process is associated with the accumulation of active oxygen species and, consequently, a reduction in the content of antioxidants, especially ascorbic acid (Ivanov, 2014). In storage studies using SmartFresh technology conducted by Wichrowska et al. (2021) in broccoli samples, vitamin C losses were halved compared to untreated samples.

Polyphenols are secondary plant metabolites involved in the defense of plants against mechanical, thermal and water stress (Wojcieszyńska and Wilczek, 2006). They naturally occur in fruits, vegetables, seeds, nuts, cereals and drinks such as coffee, tea and juices (Zujko et al., 2018). Polyphenols, also called phenolic compounds, play an important role in the enzymatic browning process. Thanks to the antioxidant properties of many polyphenols, it is possible to directly neutralize chemical oxidants, free radicals and environmental carcinogens, thus preventing damage to the genetic material (Gawlik-Dziki, 2004). 1-MCP is widely used in apples to maintain phenolic content during storage (Rudell and Mattheis, 2008). Further research showed that the effect of 1-MCP on total phenolic content varies depending on the apple variety. In the 'Cripps Pink' apple, 1-MCP reduced the total phenolic content in the pulp, and the levels of chlorogenic acid and caffeic acid also decreased. In our own research, the level of total polyphenols decreased during storage, to a greater extent in untreated fruit (Table 7). Similar relationships were obtained by MacLean et al. (2006). Chlorogenic acid is the most frequently studied polyphenol in apples, highly soluble and found in high concentrations in apple pulp, and is the main substrate of polyphenol oxidase. Its impact on the quality of fruit products is also significant, as it gives them a tart taste, and when oxidized with PPO, it supports the oxidation of less easily oxidized polyphenols and accelerates browning. During ripening in the orchard, its concentration may increase and decrease, while during longer storage, the total content of phenolic acids in the pulp decreases and the anthocyanin content in the peel layer increases. The phenolic compounds in apples include procyanidin oligomers, epicatechin, catechin, quercetin glycosides and chlorogenic acid. The content of the latter in apples reaches up to 200 mg·kg-1 in fresh weight (Budryn and Nebesny, 2006).

The relationship between the behavior of chlorogenic acid during storage was studied by Mikulič Petkovšek et al. (2009). They showed that the content of the analyzed acid in the fruit pulp remains at a similar level during storage, while in the peel it increases slightly. Among the varieties analyzed in our own research, the Honeygold apple variety contained the most chlorogenic acid (Table 6) - they were also characterized by dark pulp after 1 hour of exposure to oxygen (Fig. 1). PPO inhibitors may include pasteurization used in the technological process, as well as the addition of antioxidants, including ascorbic acid, the content of which in the juice production process may be reduced by up to 70%. The varieties with the best technological parameters affecting the degree of enzymatic darkening are ‘Szampion’ and ‘Elstar’. According to MacLean et al., (2006), the level of chlorogenic acid was lower in fruits treated with 1-MCP than in untreated fruits.

The antioxidant capacity was higher in all tested apple varieties treated with 1-MCP (Table 8). Similar relationships were obtained by Vilaplana et al. (2006). Ethylene released during storage accelerates the aging processes, which reduce the antioxidant content, and the use of an ethylene release blocker significantly slows down this process, increasing the antioxidant capacity. 1-MCP may increase the content of organic acids, amino acids and fatty acids in fruits during storage, depending on the fruit species, variety and storage conditions. It may also help maintain higher antioxidant content in many fruits after cold storage (Wojdyło at al. 2010; Guan et al. 2013). Roth et al. (2007) indicated that the antioxidant activity increased during apple storage. The reason for the increase in antioxidant capacity was the higher content of total polyphenols.

CONCLUSIONS

The use of an ethylene blocker - 1-methylcyclopropene allows you to delay or reduce the rate of ethylene-induced changes, such as: softening of the flesh, loss of the basic green color of the peel, the formation of cold damage, and the occurrence of pulp disintegration. The use of 1-MCP resulted in minor changes in all tested varieties in their organoleptic characteristics after 6 months of storage. In turn, in samples not treated with 1-MCP, changes in the color and consistency of the flesh, smell, flavor, palatability and darkening were observed, especially in the 'Honeygold' variety. However, in the case of the 'Elstar' variety stored in chambers without the use of 1-MCP, a change in the aroma of apples occurred. 1-MCP also had a significant impact on the content of bioactive compounds - the decrease in vitamin C content and antioxidant capacity after storage was lower in the treated samples, while in relation to the content of polyphenols and chlorogenic acid - the untreated samples contained more of these compounds, which also significantly depended on the variety. . In order to avoid the negative effects of ethylene and at the same time maintain the high quality of the fruit, it is recommended to maintain a very low concentration of this phytohormone in the storage place by using 1-methylcyclopropene and ULO conditions.

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