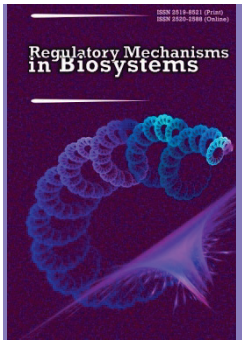

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The impact of 1-methylcyclopropene post-harvest treatment on the storability of the Ckifske zoloto and Dmiana apple varieties

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As a result of the conducted research, it was established that the post-harvest treatment of apple fruits with Oberigpro, the active substance of which is 1-methylcyclopropene, helps to extend the duration of their storage in the conditions of an ordinary cooled atmosphere. In addition, the processed fruits had a 14-day post-storage shelf life during which they did not lose their quality, which allows producers to extend the duration of the sales period. The fruits of the varieties treated with 1-methylcyclopropene were harder than the control ones when removed from storage. After 60 days of storage, control apples had 21.8 N less pulp hardness than treated apples. During the 14 days of the shelf life, during which the apples were at a temperature of + 19 ºC, the hardness of their pulp in the version with treatment did not significantly decrease, unlike the version where 1-methylcyclopropene treatment was not applied. During the first month of storage, an increase in the content of soluble solids (TSS) was observed in the fruits of the Dmiana variety from the variant where post-harvest processing was carried out. Control fruits on the 150th day of storage contained 0.20% titratable acids, which is 0.10% less than those treated with 1-methylcyclopropene. On the 7th day of the expiration date, the acidity of Dmiana was 0.17 in the control and 0.25% in the fruits from the experimental variant, which is 0.20 and 0.28% less than that during storage, respectively. During the shelf life, fruit weight loss in both versions of the research increased, and on the 14th day, in the version treated with 1-methylcyclopropene, the Skifske Zoloto variety was 0.76% less, and the Dmiana variety was 1.59% less than in options without processing. With the growth of mass loss, the damage of the fruit withering increased, which negatively affected their appearance. On the 14th day of the post-harvest shelf life, Dmiana apples from the variant where 1-methylcyclopropene was not used were covered with an oily coating, and Skifske Zoloto 100% were affected by tan.

Keywords: apples; growth regulator; storage duration; shelf life; physiological disorders.

Introduction

The apple tree (*Malus domestica* Borkh) belongs to the Rosaceae family and subfamily Pomoideae Spengler (2019) is mostly grown in regions with a temperate climate and is one of the most widespread fruit crops in the world and the main one in Ukraine (Shevchuk et al., 2022). In 2020, 94,900 hectares were planted with apple trees in Ukraine, which is 43% of all fruit and berry crops (Ukrstat, 2023). Since the beginning of the war, the area under apple trees has significantly decreased, because almost a third of apple orchards are concentrated in the zone of conflict such as Kherson region, Donetsk region, Zaporizzha region (especially nearby Melitopol) and Kharkiv region. But even under such conditions, priority in growing among fruit crops in Ukraine is given to the apple tree, because of its high adaptability to the growing conditions of Ukraine, excellent taste of its fruits, consumption and therapeutic and preventive qualities. Sensory characteristics of apples, in particular, taste, pulp structure, as well as susceptibility to damage by functional disorders are the main components of their internal quality (Qi et al., 2020). Apples belong to climacteric fruits that continue to ripen after harvesting and are characterized by an increase in the intensity of respiration and the release of the hormone ethylene, which leads to a rapid decrease in their shelf life, quality and marketable appearance. A number of important physiological changes during their ripening, such as a decrease of pulp hardness, an increase in the content of soluble solids and the formation of volatile aromatic compounds, are associated with this hormone (Bi et al., 2019; Giné-Bordonaba et al., 2019; Liu, 2019; Song et al., 2019). According to Ciesa et al. (2013), the shelf life of apple fruits can be increased by storing them in a controlled atmosphere; however, this ultra-low oxygen (ULO) technology can suppress their production of aroma compounds, which is a key indicator of the sensory quality of apples (Raffo et al., 2009; Ciesa et al., 2013). There is another, widely used way of storing climacteric fruits, namely, using pre-storage treatment with 1-methylcyclopropene Satekge and Magwaza (2022). This substance binds ethylene receptors, thereby suppressing ethylene production, which extends the shelf life of fruits (Whitaker et al., 2004; Win et al., 2021). At the same time, the probability of the development of functional disorders decreases, the loss of mass and the decrease in the hardness of pulp are significantly slowed down, which extends the shelf life. The mechanism of action of 1-methylcyclopropene is based on the blocking of ethylene receptors and thereby preventing its physiological action (Sisler & Serek, 1997). However, as noted by a number of authors, the effect of 1-methylcyclopropene differs depending on the genotype of the variety (De Ell et al., 2016; Yoo et al., 2021).

Besides, the group of late ripening varieties should be characterised with a good shelf life of fruits in order to extend the period of their consumption and provide the population with useful products.

Skifske Zoloto (direct translation Scythian gold) and Dmiana are varieties of the Ukrainian apple breeding programme with excellent sensory quality indicators. Besides, the value of Skifske Zoloto lies in its resistance to scab and powdery mildew, and Dmiana has a gene for resistance to powdery mildew as well. According to the high value of Skifske Zoloto

and Dmiana varieties, the aim of our research was to establish the effect of post-harvest treatment of fruits with the ethylene inhibitor Oberigpro, the active substance of which is 1-methylcyclopropene, on the preservation of the hardness of their pulp, the content of soluble solids, titrated acids, as well as damage by physiological disorders and establishing maximum shelf life.

Materials and methods

The study of the shelf life of apple fruits of the Skifske Zoloto and Dmiana varieties was carried out during two storage seasons: 2020–2021 and 2021–2022. Skifske Zoloto is mid-season variety, and Dmiana – late season one. Fruits for research were selected in the experimental plots of the Institute of Horticulture of the National Academy of Agrarian Sciences of Ukraine (IH). The location of the IH natural and climatic zone is the Forest Steppe of Ukraine, the height above sea level is 187 m, (50° 27`16`` N, 30° 131`25`` W), at a distance of 4 km from Kyiv. The soil of the plot is gray forest medium loam, the supply of nutrients is maintained at an optimal level, the content of humus is 2.5–3.0%, the reaction of the soil solution is slightly acidic (pH = 5.9...6.5), the plot is suitable for growing apple trees. The plants are grown on a medium-growing rootstock M.126, the care of the garden is carried out according to the generally accepted technology for the forest-steppe zone of Ukraine, the protection of the garden was carried out using the integrated protection system of the Syngenta company.

During the growing season, 4 foliar treatments of plantings were carried out with the drug Vrexil Ca, the consumption rate of the drug according to the manufacturer's recommendations. The first treatment was done after the June wave of precipitation (the third decade of June), followed by an interval of 3 weeks.

Apples for research were collected of the highest (extra) commercial grade in accordance with the requirements of UNECE Standard FFV-50 concerning the marketing and commercial quality control of apples.

The ripeness of the fruits was determined by the degree of starch degradation (9-point scale) and according to the content of soluble solids as well as the hardness of the pulp.

Before the fruits' trearment with an ethylene inhibitor and putting them into storage, the degree of starch degradation of Skifske Zoloto fruits was 5 points, the content of soluble solids was 13.2%, the hardness of the pulp was 84 N. The degree of starch degradation of Dmiana fruits was 4 points, the TSS content – 13.8%, pulp hardness – 96 N.

Fruits for storage were packed in plastic containers. The experiment includes two variants: control – fruits without pre-storage treatment with Oberigpro (active substance 1-methylcyclopropene (1-MCP) and fruits with pre-storage treatment. Every variant of the experiment had three repetitions of 50 fruits each. To determine the hardness of the pulp, the content of soluble solids and sugars, 50 fruits were additionally stored for each repetition.

On the day of harvesting, apple fruits were delivered to the fruit storage, where they were cooled for 24 hours to an endogenous temperature of +4 °C. Post-harvest treatment of apples with Oberigpro (active ingredient 1-methylcyclopropene, developed by the Scientific and Technical Complex "Institute of Single Crystals" of the National Academy of Sciences of Ukraine) was carried out in a separate hermetic chamber two days after harvesting. The substance was prepared immediately before the fruits treatment. The rate of consumption of the working solution per m^3 is 0.2–0.3 L, the drug is 0.025 g/m^3. Exposure continued for 24 hours (one day). At the end of the exposure, the hermetic box was ventilated for 25 minutes. Further, treated and untreated fruits were stored in separate chambers at a temperature of 0...+1 °C and a relative humidity of 90–93%.

Fruit quality was assessed every month. For this purpose, during monthly reviews, the presence of functional disorders and oiliness on the fruits was determined by inspection method. For the planned analytical studies, the fruits of each variety were selected from each variant of research and repetition.

The signal for removing apples from storage was: the loss of the hardness of their pulp by more than 20 N and the decrease in the content of titrated acids by more than 1/3 of what they had during the period of storage, as well as the beginning of manifestations of functional disorders.

To determine the hardness of the pulp, was used a stationary "Wagner Fruit Test" penetrometer (FT 30 FT716 nozzle with a diameter of 11 mm). The hardness of the pulp was measured on 6 apples from two opposite sides, for this apples were peeled at the puncture site.

Soluble dry matter was determined using a portable Atago Pal-1 refractometer. To prepare an analytical sample from fruits in the amount of 4 pcs., 4 segments were cut diametrically, which were crushed with the help of a homogenizer, then a drop of juice was squeezed through the tissue onto the glass of the refractometer.When recording the data, the temperature error was taken into account. Data were expressed as a percentage of raw weight. For acid extraction, 25 g of crushed mass from 4 apples was taken, washed with 150 mL of hot distilled water and transferred to a measuring glass flask with a capacity of 250 mL. Then the flask was placed for 30 minutes in a water bath and left for 30 minutes, after which it was cooled. The contents of the flask were brought up to the mark with distilled water and filtered through a filter into a 250 mL conical flask. Pipette 20 mL of the extract was poured into a 250 mL conical flask, 3–4 drops of phenolphthalein and titrate with 0.1 N sodium hydroxide were added until a pink color appeared, corresponding to pH 7.0. At least two parallel measurements were carried out and the average value of the indicator was found. The content of titrated acids in the sample was calculated according to the formula, using the titer index of 0.1 N sodium hydroxide and the conversion factor for malic acid (Kondratenko et al., 2008).

The shelf life of apple fruits was determined after the end of the optimal storage period. For this purpose, selected samples of apples (40 fruits) from each repetition according to the variants of the experiment were further transferred to conditions where the temperature was maintained at 19 ± 1 °C. The study of the quality of apples was carried out after 7 days and 14 days. For each analysis 10 fruits were taken from three repetitions of the variant. After the fruits were weighed, we determined weight loss, pulp hardness, content of soluble solids, titrated acids as well as the presence of physiological disorders (inspection method). Based on the results, conclusions were drawn on the duration of the shelf life of fruits of the Skifske Zoloto and Dmiana varieties.

To determine the natural weight loss of fruits before storage, 5 fruits were selected from each variant and repetition, they were marked and weighed at the end of storage and after 7 and 14 days of shelf life. The difference in the weight of the fruit between the initial weight and after storage weighing is expressed as a percentage, represented as a loss of weight.

As a result of the visual inspection, external symptoms of physiological disorders of the fruits were revealed, in particular, wilting, scald, bitter pitting, browning of the pulp and swelling. To determine the presence of internal functional disorders, such as browning of the pulp, browning of the core, diffuse darkening of the pulp and swelling, the apple was peeled and cut horizontally into two parts. The frequency of fruits affected by physiological disorders is presented as the percentage of affected fruits in the total number. In addition, the presence of an oily coating on the skin of the fruits was evaluated. The intensity of this manifestation was determined and demarcated according to the following principle: completely absent, barely perceptible, weakly felt, moderately felt, felt, very strongly felt, fruits stick strongly.

Statistical data processing was performed using the Statistica 13.1 program (StatSoft, Inc., USA). Results are presented as means with their standard errors as mean ± standard error (x ± SE). Differences between replicates, as well as relative to the intervarietal mean, were determined using ANOVA. Research results are presented at the level of significance at $P < 0.05$.

Results

The initial pulp hardness of Skifske Zoloto fruits was 84.0, and Dmiana was 95.7 N. After 30 days of storage, Skifske Zoloto control apples had a pulp hardness of 74.5, and Dmiany was 84.5 N. In fruits of both varieties treated with 1-methylcyclopropene, the flesh hardness during this period was higher than in the control ones, in particular, in Skifske Zoloto by 7, and Dmiana by 7.5 N. At 60 days of storage, the difference between the flesh hardness of treated and of unprocessed fruits of Scythian gold was more significant. Its decrease in relation to the one at the time of placing the apples in storage was 29.0 N in untreated and 7.2 N in treated

apples. Fruits of Skifske Zoloto treated with 1-methylcyclopropene for 120 days of storage had a pulp hardness of 67.5 N, which is 16.5 N less than the initial one. When removed from storage after 150 days, control apples of the Dmiana variety had a pulp hardness of 63.3, and those treated with 1-methylcyclopropene – 76.8 N (Table 1).

During the post-harvest shelf life, the intensity of the decrease in the hardness of the apple pulp was higher in the control. In particular, in Skifske Zoloto apples that were not treated with 1-methylcyclopropene after 60 days of storage and 7 days of staying at a temperature of +19 ºC, the pulp hardness was 49.0 N, while in those treated after 120 days of storage and also staying at the specified temperature, it was was at the level of 57.5 N. The tendency to decrease in the hardness of the pulp of Skifske Zoloto fruits was also observed on the 14th day of the shelf life, 42.3 in the control variant and 53.5 N in the variant with 1-methylcyclopropene treatment (Table 1). Fruits of the Dmiana variety, not treated with 1-methylcyclopropene, after 150 days of storage and 7 days of post-storage had a pulp hardness of 57.8 N, and at a two-week shelf life – 50.3 N, which is lower than in the version with treatment for 15, 7 and 18 N, respectively (Table 1).

The content of soluble solids in apple fruits of the Skifske Zoloto variety after 60 days of storage was 14.0% in the control version, against 13.7% in the version where 1-methylcyclopropene treatment was carried out. During the seven-day shelf-life period, their number in untreated apples decreased to 13.6%, and in the two-week shelf life to 13.2%, while in processed apples, the decrease in TSS was not significant (Table 2).

Fruits of variety Skifske Zoloto, treated with 1-methylcyclopropene were stored longer, 120 days, and when removed from storage, the amount of soluble solids was slightly lower (by 0.16%) compared with initial data. An increase in TSS in fruits treated with the ethylene inhibitor was observed throughout the shelf life, namely by 0.38% within seven days and by as much more during the following week relative to the content they had when they were removed from storage (Table 2).

Table 1

The effect of post-harvest treatment of apples with the ethylene inhibitor Oberigpro (active substance 1- methylcyclopropene) on the hardness of their pulp during storage (x ± SE, n = 18)

Storage duration, days	Skifske Zoloto		Storage duration, days	Dmiana	
	untreated with 1-MCP	treated with 1-MCP		untreated with 1-MCP	treated with 1-MCP
Start of storage	84.0 ± 0.2	84.0 ± 0.2	Start of storage	95.7 ± 1.4	95.7 ± 1.4
30	74.5 ± 1.8	81.5 ± 2.4**	30	84.5 ± 1.7	92.0 ± 2.3***
60	55.0 ± 1.9	76.8 ± 1.8***	60	77.5 ± 1.7	88.8 ± 1.9***
Expiration date, 7 days	49.0 ± 2.5	74.0 ± 1.5***	90	75.0 ± 2.0	84.5 ± 1.8***
Expiration date, 14 days	42.3 ± 1.9	68.5 ± 1.3***	120	67.8 ± 1.9	80.5 ± 2.5***
90	0.0 ± 0.0	76.0 ± 1.5***	150	63.3 ± 1.5	76.8 ± 1.7***
120	0.0 ± 0.0	67.5 ± 1.3***	Expiration date, 7 days	57.8 ± 2.6	73.5 ± 1.7***
Expiration date, 7 days	0.0 ± 0.0	57.5 ± 1.7***	Expiration date, 14 days	50.3 ± 2.5	68.3 ± 0.9***
Expiration date, 14 days	0.0 ± 0.0	53.5 ± 1.3***			

Note: P < 0.05 indicates a level of significant difference between the control and the experimental variant where 1-MCP treatment was applied; * < 0.05;** < 0.01, *** < 0.001 – according to ANOVA results; 0.0 ± 0.0 – fruits were not stored.

Table 2

The effect of post-harvest treatment of apples with the ethylene inhibitor Oberigpro (active substance 1-methylcyclopropene) on the content of soluble solids during storage (x ± SE, n = 6)

Duration of storage, days	Skifske Zoloto		Duration of storage, days	Dmiana	
	untreated with 1-MCP	treated with 1-MCP		untreated with 1-MCP	treated with 1-MCP
Untreated with 1-MSP	treated with 1-MSP	13.16 ± 0.12	Start of storage	13.80 ± 0.14	13.80 ± 0.14
30	13.86 ± 0.10	13.38 ± 0.11**	30	13.63 ± 0.13	14.28 ± 0.12**
60	14.02 ± 0.07	13.68 ± 0.08**	60	12.80 ± 0.14	13.76 ± 0.09***
Expiration date, 7 days	13.56 ± 0.11	12.94 ± 0.10***	90	12.54 ± 0.09	13.74 ± 0.09***
Expiration date, 14 days	13,16 ± 0.12	12,63 ± 0.15***	120	12.46 ± 0.12	13.96 ± 0.11***
90	0.0 ± 0.0	13.40 ± 0.10***	150	12.78 ± 0.11	13.12 ± 0.12**
120	0.0 ± 0.0	13.00 ± 0.16***	Expiration date, 7 days	12.26 ± 0.14	12.72 ± 0.09**
Expiration date, 7 days	0.0 ± 0.0	13.38 ± 0.20***	Expiration date, 14 days	12.00 ± 0.10	12.26 ± 0.14*

Note: see Table 1.

The number of soluble solids in apples of Dmiana variety during the period from storage to their removal from storage varied: in the control from 13.80 to 12.78%, and in the variant treated with an ethylene inhibitor from 13.80 to 13.12%. However, an increase in TSS by 0.48% was observed in apples treated with 1-methylcyclopropene during the first month of storage. In the control version, during the 150-day storage period and 7-day shelf life after removal from storage, a decrease in TSS was observed compared with the content at the beginning of storage. However, it is worth noting that on the 150th day of storage, the control fruits of Dmiana had more, by 0.32%, TSS than on the 120th. (Table 2).

The amount of titrated acids in fruits of Skifske Zoloto at the beginning of storage was 0.66, and Dmiana - 0.45%. During the first month of storage, untreated apples of both studied varieties lost 0.15% of titrated acids. The tendency to losses of titrated acids was observed during the storage process. On the 60th day of storage, control apples of Skifske Zoloto contained 0.45% of titrated acids, which is 0.21% less than the initial amount. During the seven-day shelf life, the acidity of the Scythian gold control apples decreased by 0.14%, and after the 14th day, by another 0.09% and amounted to 0.20%. The loss of acidity of processed apples of the Skifske Zoloto variety during the 7-day storage period after 120 days of storage was 0.21, and after 14 days - 0.28% compared to the content they had on the 150th day of storage (Table 3). Fruits of the Dmiana variety that were removed from storage had a content of titrated acids of 0.20 (control) and 0.30% in the variant of post-harvest treatment with 1-MCP. On the 7th day of the expiration date, the acidity of Dmiana was 0.17 in the control and 0.26% in the fruits from the experimental variant. On the 14th day of the shelf life, the tendency to decrease the content of titrated acids remained (Table 3).

Fruits of the Skifske Zoloto variety removed from storage, both from the control and the experimental variant, had an excellent appearance, were without obvious signs of damage, disorders, rot and spots. However, on the 7th day of the shelf life, fruits that were not treated with Oberigpro lost moisture as a result of increased metabolic processes and transpiration intensity, which was the reason for their wilting, 1/3 of the control fruits were affected by scald. The intensity of this disorder increased during the next 7 days of the expiration date. On the 14th day of the post-storage period, fruits from the control variant 100% were affected by scald, and the total weight loss was 3.73% (Table 4).

Table 3
The effect of post-harvest treatment of apples with the ethylene inhibitor Oberigpro (active substance 1-MCP) on the content of titric acids during storage (x ± SE, n = 6)

Duration of storage, days	Skifske Zoloto		Duration of storage, days	Dmiana	
	untreated with 1-MCP	treated with 1-MCP		untreated with 1-MCP	treated with 1-MCP
Start of storage	0.66 ± 0.02	0.66 ± 0,02	Start of storage	0.45 ± 0.02	0.45 ± 0.02
30	0.51 ± 0.01	0.61 ± 0.02*	30	0.40 ± 0.01	0.43 ± 0.02*
60	0.45 ± 0.01	0.56 ± 0.02*	60	0.38 ± 0.01	0.42 ± 0.01*
Expiration date, 7 days	0.31 ± 0.02	0.50 ± 0.02**	90	0.34 ± 0.01	0.38 ± 0.02*
Expiration date, 14 days	0.20 ± 0.01	0.46 ± 0.02**	120	0.26 ± 0.01	0.34 ± 0.02**
90	0.0 ± 0.0	0.56 ± 0.02***	15	0.20 ± 0.01	0.30 ± 0.01***
120	0.0 ± 0.0	0.51 ± 0.02***	Expiration date, 7 days	0.17 ± 0.01	0.26 ± 0.01***
Expiration date, 7 days	0.0 ± 0.0	0.45 ± 0.02***	Expiration date, 14 days	0.11 ± 0.01	0.20 ± 0.04***
Expiration date, 14 days	0.0 ± 0.0	0.38 ± 0.02***			

Note: see Table 1.

Table 4
Natural weight loss of apple fruits of the Dmiana and Skifske Zoloto varieties during storage and the post-storage shelf life period (x ± SE, n = 20)

Determination time	Research variants	
	without treatment 1-MCP	with 1-MCP treatment
Skifske Zoloto		
For the entire storage period	1.17 ± 0.05	0.67 ± 0.06***
For the period of validity, 7 days	1.23 ± 0.08	1.11 ± 0,16**
For the period of validity,14 days	1.33 ± 0.08	1.19 ± 0.05**
Total mass losses during the storage period and shelf life	3.73 ± 0.18	2.97 ± 0.15***
Dmiana		
For the entire storage period	1.03 ± 0.18	0.67 ± 0.07***
For the period of validity, 7 days	1.23 ± 0.12	0.64 ± 0.07***
For the period of validity,14 days	1.40 ± 0.12	0.77 ± 0.09***
Total mass losses during the storage period and shelf life	3.67 ± 0.38	2.08 ± 0.13***

Note: see Table 1.

Fruits of Skifske Zoloto that were treated with 1-methylcyclopropene during the entire storage period had less significant weight loss (0.67%) than the control ones. During the post-harvest shelf life, the weight loss of apples increased and at its end amounted to 2.97%, which is less than in the control by 0.76% with a longer storage period of 60 days (Table 4). As weight loss increased, fruit wilting increased, which negatively affected their appearance. However, on the 14th day of the shelf life, apples treated 1-methylcyclopropene did not have an oily coating. The fruits treated with Oberigpro were completely free of scald. This is due to the fact that the active ingredient of 1-methylcyclopropene reduces the accumulation of α-farnesene and conjugated trienols during storage and the frequency of tanning in treated apples is lower.

Apples of the Dmiana variety, both from the control and from the variant treated with 1-methylcyclopropene, had an excellent appearance when removed from storage. The presence of a weak oily skin was observed only on control apples. Mass losses during removal of fruits from storage between untreated and treated 1-methylcyclopropene differed significantly, and amounted to 1.03 and 0.67%, respectively, the tendency to their increase in both variants was observed throughout the shelf life (Table 4). Fruits from the control variant lost more moisture, which negatively affected their appearance and caused severe wilting. In addition, all apples from the control variant had a very noticeable oily coating and were sticky.

During the shelf-life, on fruits of Dmiana variety, both from the control variant and the investigated one, signs of physiological disorders appeared. On the 7th day of shelf life, 30% of apples from the control variant and 21% – treated with 1-methylcyclopropene were affected by browning of the pulp. After the 14-day shelf life of Dmiana apples from both variants, almost 100% were affected by browning of the pulp and aging disorder, the development of fungal rot was visualized on individual fruits.

Discussion

The obtained research data confirm the version of American researchers regarding the effectiveness of post-harvest treatment of apple fruits with substances based on 1-methylcyclopropene on the duration of hardness of their pulp, and, as the scientists noted, the effectiveness of treatment does not depend on the storage technology (Watkins et al., 2000; Bai et al., 2005; Peng & Lu, 2007; Lee et al., 2019). Polish and Canadian colleagues obtained similar data on slowing down the loss of pulp hardness of apples treated with substances with the active ingredient 1-methylcyclopropene. Studies were conducted with the variety 'Red Jonaprince' (Tomala et al., 2020) and 'Gala' (De Ell et al., 2022). Other researchers emphasized that the pre-storage treatment of fruits with 1-methylcyclopropene contributes not only to the preservation of the firmness of the apple pulp, but also to the reduction of acidity losses (DeEll et al., 2002, 2007, 2022; Watkins, 2007). These scientists established that, the preservation of the firmness of fruits treated with 1-methylcyclopropene may be due to the reduced availability of ethylene, which affects the modification of the cell wall and the degradation of genes and enzymes that are regulated by ethylene (Bennett & Labavitch, 2008; Gwanpua et al., 2016; Win et al., 2021). Li et al. (2022) showed that 1-MSP delays cell wall pectin modification and softening of apple flesh during cold storage.

The obtained data on the dynamics of changes in the content of soluble solids in the fruits of Skifske Zoloto and Dmiana are comparable to those obtained in different years by a number of scientists. They noted that pre-storage treatments with 1-MSP have no significant effect on the content of soluble solids and the dynamics of their changes in apple fruits (Fan et al., 1999; Rupasinghe et al., 2000; Zennela, 2003; DeLong et al., 2004, 2006). Similar data were obtained by Watkins et al. (2000), who reported that 1-MSP reduced TSS levels in some cultivars, both when stored in a conventional refrigerated environment and in a controlled atmosphere, but had no effect on other biochemical components (Watkins et al., 2005), which was confirmed by other scientists from the USA in their researches (Bai et al., 2005). Similar data were obtained by other scientists who noted that during cold storage, TSS can increase in fruits treated with 1-MSP (Watkins et al., 2000; DeEll et al., 2008).

The results of our research, dedicated to intensity of changes in titrated acids during storage, are comparable to those obtained by a number of researchers from different countries of the world. American scientists (Win et al., 2019) noted that the acidity of fruits treated with substances of 1-methylcyclopropene during storage slowed down; their results were confirmed by researchers from Korea (Gago et al., 2015; Lee et al., 2017; Yoo et al., 2021), as well as Turkey (Özkaya & Dündar 2009) and Poland (Tomala et al., 2023).

According to Gong et al. (2021), scald is one of the most common storage disorders of apple fruits. The development of this physiological disorder of apples is usually correlated with α-farnesene to conjugated triene hydroperoxides (Huelin & Coggiola, 1970; Filmer & Meigh, 1971; Rowan et al., 2001; Watkins et al., 2007). Avoiding the development of scald can be prevented by postharvest fruit treatment with diphenylamine (DPA) (Golding et al., 2001; Ju & Curry, 2002) or 1-methylcyclopropene (Shaham et al., 2003; Zanella, 2003), which took place in our research. In our research it became possible completely avoid the development of scald on both varieties by treating the fruits with Oberigpro (the active substance is 1-methylcyclopropene).

In the studies conducted by Watkins (1995) and Lurie & Watkins (2012) it was shown that scald symptoms mainly appeared during the storage period at room temperature (20 °C) after refrigerated storage at tem-

peratures from –1 to 4 °C, which was also found in our research with fruits of the Skifske Zoloto variety in the control version.

As noted by a number of scientists, post-harvest treatment of fruits with 1-MSP helps to reduce the oiliness of the skin of apples (Fan et al., 1999; Nock & Watkins, 2013; Lee et al., 2019; Shoffe et al., 2021), which was confirmed by the results of our research. Fruits of the Skifske Zoloto and Dmina varieties did not have an oily coating only in the variant treated with Oberigpro, and it also was absent during the entire period of application (14 days).

In the variant with the Dmiana variety, unlike the Skifske Zoloto, we cannot claim a positive effect of 1-methylcyclopropene treatment on the post-harvest quality of the fruits. The ambiguous effect of 1-methylcyclopropene on the course of physiological and biochemical processes in fruits of different varieties was emphasized by Yoo et al. (2021). De Ell (2022), conducting a study with the Gala variety, claimed that the treatment of apples with 1-methylcyclopropene did not help to avoid the development of internal browning of pulp. Similar data were obtained by Lee et al. (2017), they noted that both post-harvest treatment of 1-methylcyclopropene and air temperature during storage could cause browning of the pulp of 'Royal Gala' apples (Lee et al., 2017). Researchers Saba & Watkins (2020) from Cornell University (USA) after conducting research with the "Empire" variety also emphasized that the development of pulp browning can be provoked by both low storage temperature and fruit treatment with 1-methylcyclopropene.

Conclusions

As a result of the conducted research, it was established that post-harvest treatment of apples of the Skifske Zoloto variety with Oberigpro, the active substance of which is 1-methylcyclopropene, contributes to the extension of their shelf life, by 60 days more compared to the control. Moreover, treated fruits of Skifske Zoloto have a two-week shelf life during which they retain their sensory quality indicators and are not affected by tanning.

Research has not established a significant difference in the storage terms of control and treated 1-MSP fruits of the Dmiana variety. Moving the fruits to a temperature of 19 ± 1 °C caused an intensive development of the physiological disorder such as browning of the pulp, and later swelling, which was present in both versions of the studies. In order to establish the reasons that caused the development of these disorders and to determine the storage conditions under which Dmiana apples will retain their commercial, consumer and sensory quality indicators, as well as have an extended post-storage shelf life, there is a need to conduct new research with this variety.

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