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BIOSTIMULANTS' EFFECT ON WEIGHT LOSS AND BIOCHEMICAL COMPOSITION OF APPLE (*MALUS DOMESTICA* L.) FRUITS DURING LONG-TERM STORAGE

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SUMMARY

This study presents results from determining the effects of biostimulants on the natural weight loss and biochemical composition of apples (*Malus domestica* L.) during long-term storage. Foliar application with 1% WPU Antifreeze + 1% WP Drip Ca+Mg contributed to a significant decrease in average weight loss in apple cultivar Sinap Orlovsky fruits during long-term storage compared with the control treatment and other options. In apple fruits, the TSS content enhanced in all variants after storage, i.e., control (8.6%), 1% WPU Antifreeze + 1% WP Drip Ca+Mg (12.5%), and 3% WPU Antifreeze + 3% WP Drip Ca+Mg (7.9%). At the end of storage, a significant decrease resulted in the titrated acids in apple, viz., 53.1% in control and 52.1% and 57.5% in variants with foliar treatments (with 1% and 3% solutions, respectively). Largely, the sugar content increased by 16.7% at the end of apple storage with 1% WPU Antifreeze + 1% WP Drip Ca+Mg. The studies revealed a notable influence of meteorological conditions on the accumulation of TSS, organic acids, sugar content, and ascorbic acid in the apple cultivar Sinap Orlovsky.

Keywords: Apple (*M. domestica* L.), cultivar Sinap Orlovsky, weight loss, biochemical composition, long storage

Key findings: The biostimulant showed the highest efficiency by using 1% WPU Antifreeze + 1% WP Drip Ca+Mg in apple (*M. domestica* L.) cultivation technologies to improve and preserve the quality of apples during long-time storage.

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INTRODUCTION

Apples (*Malus domestica* L.) are one of the most popular fruits, being a source of nutrients and bioactive compounds. Apples contain organic acids, pectin, fiber, phenolic compounds, B vitamins, biotin, and ascorbic, pantothenic, and folic acids necessary for the human body. The macro- and micronutrients found in apple fruits also promote the digestibility of proteins and mineral salts (Andreeva and Bobrovich, 2020).

Despite the highest growth rate of production, the volume of apple imports in Russia accounts for about 50% of the total market volume, and the wholesale apple prices increased by an average of 10%–12% in 2019 (Kulistikova and Maksimova, 2019). This could refer to a high proportion of seasonal apples unintended for long-term storage and sold at a low price, as well as a lack of proper storage conditions for late-ripening apples sold throughout the year (Mahunu *et al*., 2016). Thus, about one-third of the production of the harvested apples is lost during long-term storage. Other fruit losses occur after removing apples from long-term storage and putting them into short-term storage in retail conditions (Mikani *et al*., 2008).

In fresh apple fruits, the biological processes also continue during storage (Jan and Rab, 2012). The replacement of complex metabolic processes of nutrient accumulation during the formation and maturation of apple fruits results from the various processes of their decomposition and consumption for respiration during storage. Fruits undergo both qualitative variations and alterations in the biochemical composition of apples due to various environmental factors (Lisina *et al*., 2010). Environmental conditions significantly influence the yield and quality of fruits by affecting their size, weight, biochemical composition, and potential shelf life (Hodges, 2023).

Storage problems become much more complicated given that various apple cultivars may considerably vary in their storage performance (Golias *et al*., 2008). Therefore, the postharvest losses may depend on external and internal environmental conditions, which affect fruit firmness, juice content, weight loss, pH, soluble solids content, and other quality parameters (Tu *et al*., 2000). Grafir *et al*. (2009) reported that fruits of the apple cultivars Golden Delicious, Starking Delicious, Star Crimson, and Gala exhibited significant differences in physiological and anatomical parameters. These include ethylene production, responsible for the variations in texture and fruit softening (Nilsson and Gustavsson, 2007), and water loss (Khan and Ahmad, 2005). The promising research aimed to study the effect of organo-mineral fertilizers on the natural weight loss and biochemical composition of apple fruits during long-term storage under normal atmospheric conditions.

MATERIALS AND METHODS

The presented study determined the effects of biostimulants on the natural weight loss and biochemical composition of apples (*M. domestica* L.) during long-term storage carried out in 2021–2023. The calculation of the hydrothermal coefficient (HTC), an indicator of territorial drought proposed by climatologist G.T. Selyaninov, assessed moisture (Selyaninov, 1928). The HTC value ranging from 1.0 to 1.4 shows the optimal moisture, with a value more than 1.4 indicating excessive moisture and a value less than 1.0 pointing to drought. The HTC calculation used the formula below:

$$\text{HTC} = \frac{\text{Precipitation Amount}}{\text{The sum of the average daily temperature x 0,1}}$$

Over the study years, the assessment of the hydrothermal coefficient showed an uneven distribution of temperature and precipitation. Thus, in 2023, 30 days before the apple (*M. domestica* L.) harvest, the sum of the average daily temperatures (≥10 °C) was higher by 48.1 °C and 33.5 °C than in 2021 and 2022, respectively. It is important to note that during the study period in 2022, the lowest plant moisture conditions prevailed. Hence, in 2022, 30 days before the apple cultivar Sinap Orlovsky fruit harvest, less precipitation by 14 and 8.8 mm occurred

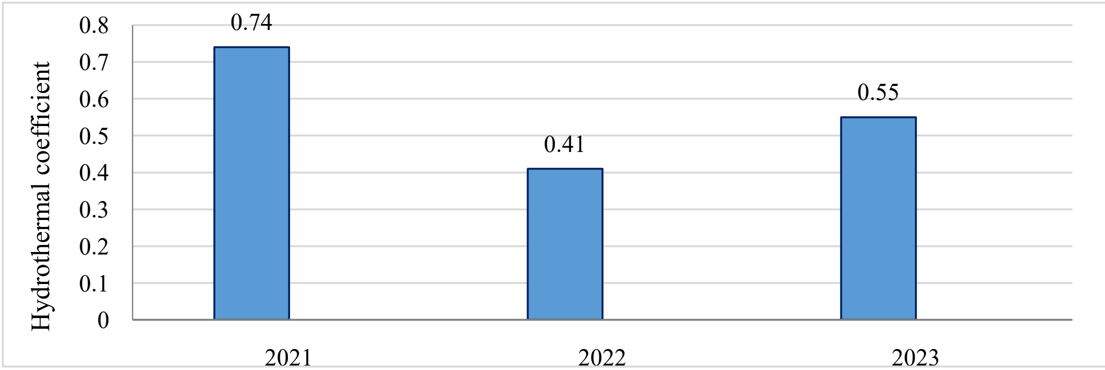

Figure 1. HTC 30 days before the apple cultivar Sinap Orlovsky fruit harvest.

versus in 2021 and 2023, respectively (Figure 1). In 2021–2023, organomineral-based biological products underwent testing, i.e., Natural Plant Complex (NPC) White Pearl (Krasnodar, Russia). The fertilizer has no hazard class.

NPC White Pearl Universal (WPU) Antifreeze is a suspension of a group of minerals of natural origin, containing a concentrate of extracts of spruce, pine, and Siberian fir needles. The fertilizer composition comprised SiO_2 (5.6%), N (total) (6%), CaO (5,000 ppm), MgO (7,000 ppm), K_2O (0.2%), B (130 ppm), Zn (150 ppm), Mo (200 ppm), and Al_2O_3 (1,600 ppm). The NPC White Pearl (WP) Drip Ca+Mg is an extract of vegetative mass of oceanic bioflora on an organomineral basis. The composition includes bio-elements, i.e., Ca (3,490 ppm), Mg (2,829 ppm), P (42.9 ppm), K (38.8 ppm), S (0.3 ppm), Fe (68.7 ppm), Mn (3.65 ppm), B (3.37 ppm), Cu (0.85 ppm), Zn (0.05 ppm), Si (0.1 ppm), Se (0.003 ppm), J (2.1 ppm), Mo (0.01 ppm), SiO_2 (5.6%), CaO (0.4%), MgO (0.4%), K_2O (0.2%), Fe_2O_3 (0.4%), and Al_2O_3 (0.16%). The organomineral fertilizers also include vitamins A, D, E, K, B1, B2, and B6, PP, H, chlorophyll, flavonoids, sugars, proteins, and amino, sulfonic, and humic acids. The testing of the organomineral fertilizer NPC White Pearl continued on the apple cultivar Sinap Orlovsky, a triploid cultivar of late winter maturation.

The grafting of apple cultivar Sinap Orlovsky transpired on a medium-sized rootstock (54–118). The trees' planting in 2013 was on a site with agro-gray forest soils. In the garden, the layout of the trees was 6 m × 3 m. Generally accepted agronomical practices took place for apple trees in the central part of Russia. The three factors used in the study were as follows: Factor A—years, Factor B—experiment options, and Factor C—analysis timings. Each variant had three repetitions, with five accounting trees in each repetition. In summer, foliar spraying of the apple cultivar Sinap Orlovsky trees ensued with biostimulants of different concentrations to protect the fruits from shedding and improve the fruit quality: 14 days after flowering, the fruit-hazel phenophase, the fruit-walnut phenophase, and 25 days before harvest. The experiment treatments had three versions, i.e., a) control (without treatment), b) foliar sprays with a 1% WPU Antifreeze + 1% WP Drip Ca+Mg, and c) foliar sprays with a 3% WPU Antifreeze + 3% WP Drip Ca+Mg.

The biochemical composition of apple fruits at the harvest and consumer stages of maturity bore scrutiny in accordance with the methodology of Sedov and Ogoltsova (1999). The content of soluble solids, as determined, used a PAL-3 refractometer (Atago, Japan). Determining the amount of sugars employed the Bertrand method. The titrated acidity detection engaged titration with a decinormal NaOH solution. The content of ascorbic acid determination was by titration of oxalic acid extracts with 2,6-dichlorophenolindophenol. For experimental storage, using the fruits of cultivar Sinap Orlovsky proceeded on the day of removal from the trees. The fruits remained stored traditionally in a CV114-S (Polair, Russia) refrigerator at a temperature of +2 °C and a relative humidity of 85%–90%. For each option, three standard boxes remained for long-term storage. One box was a repetition, and each repetition had 40 fruits. Fifteen fruits selected from each variant incurred testing for weight loss. Weight loss (%) calculation used the following formula:

$$\text{Fruit weight loss (\%)} = \frac{\text{Initial weight} - \text{final weight}}{\text{Initial weight}} \times 100\%$$

Statistical analysis

All the recorded data's analysis and evaluation used a two- and three-factor analysis of variance (ANOVA) (Version 22, SPSS). The significance level for all the analyses remained at the $P < 0.05$.

RESULTS AND DISCUSSION

Biostimulants' effect on weight loss

At the first revision after three months of storage, the natural weight loss of apple fruits averaged from 2.7% in 2022 to 3.1% in 2023. The lowest values of this parameter were evident in all the variants studied in 2022. However, during 2023, the maximum weight loss for this period was visible in the control and in the variant treated with organomineral fertilizers of 3% WPU Antifreeze + 3% WP Drip Ca+Mg. In the variant treated with 1% WPU Antifreeze + 1% WP Drip Ca+Mg, the average weight loss was significantly lower than the control and other variants. The apple (*M. domestica* L.) cultivars considerably vary for weight loss in cold storage (Golias *et al*., 2008), which may, in turn, influence the texture and storage performance of the apple cultivars (Hoehn *et al*., 2003). The weight loss in apple fruits depends upon the structure of the skin and nature of waxes on the surface of the fruits (Jan and Rab, 2012).

After seven months of storage, a significant (2.1-to-2.7-fold) increase in the natural weight loss of the apple fruits resulted in all the variants compared with the results obtained from three months of storage. Foliar treatment with biostimulants (with 1% solutions) contributed a substantial decrease in the average weight loss of the experimental apples versus the control and other variants. In 2023, the largest decrease in the average weight of apples appeared in the control and in the variant treated with biostimulants (with 3% solutions). In the variant treated with a 1% solution of organomineral fertilizers, in 2023, the natural loss did not significantly differ from the value of fruit weight loss in 2022 (Table 1). From past studies, the percent weight loss in apples had considerable enhancement with incremental increases in storage duration to 4.05% and 4.53% with 120 and 150 days, respectively (Jan and Rab, 2012). Thus, the biostimulants (with a 1% concentration solution) contributed a noteworthy reduction in the natural weight loss of the apple during long-term storage. During storage, apples undergo numerous changes, including a natural decrease in weight caused by the evaporation of moisture and the consumption of organic substances during respiration (Gunina and Trosko, 2024).

Biostimulants' effect on total soluble solids (TSS)

According to the biochemical analysis conducted before putting the apples into long-term storage, a significant influence of weather conditions appeared on the TSS content in apple cultivar Sinap Orlovsky. Thus, in 2021, in apple fruits, the accumulated TSS was 6.2% and 4.1% more than in the dry and warmer years of 2022 and 2023, respectively. However, in 2022, the TSS content in apple fruits after storage was significantly less than in 2021. In general, the mass fraction of TSS increased in apples after storage in all the experimental variants. Therefore, at the end of storage, the TSS content in fruits increased by 8.6% in the control, in the variant with 1% WPU Antifreeze + 1% WPU Drip Ca+Mg (12.5%), and in the other variant (7.9%). An increase in the TSS concentration in ripened apples by the end of storage displayed an

Table 1. Variations in the average weight and natural weight loss of apple cultivar Sinap Orlovsky.

Factor A, Year	Factor B, Experiment Options	Average weight of the fruit before storage (g)	Loss of mass (%)		Average weight of the fruit after storage (g)
			3 months	7 months	
2022	Control (Without Treatment)	202.9	2.6	6.0	190.7
		193.7	3.3	7.4	180.4
2023	1% WPU Antifreeze+1% WP Drip Ca+Mg	208.3	2.7	5.8	196.2
		230.4	2.7	7.2	213.6
2022	3% WPU Antifreeze+3% WP Drip Ca+Mg	206.7	2.7	6.1	194.0
		195.5	3.3	7.2	183.4
Average by Factor A	2022	206.0	2.7	6.0	193.6
	2023	206.5	3.1	7.2	192.6
Average by Factor B	Control (Without Treatment)	198.3	3.0	6.7	185.5
	1% WPU Antifreeze+1% WP Drip Ca+Mg	219.3	2.8	6.5	205.0
	3% WPU Antifreeze+3% WP Drip Ca+Mg	201.1	3.0	6.7	188.7
LSD_{05}	A	$F_f< F_t$	0.2	0.4	$F_f< F_t$
	B	16.1	0.2	$F_f< F_t$	15.3
	AB	$F_f< F_t$	0.3	$F_f< F_t$	$F_f< F_t$

association with an increase in their sugar content, since most of the solids in the fruits were carbohydrates and mainly sugars (Ozherelieva *et al*., 2024). Throughout the study years, apples treated with biostimulants (3% solutions) had the highest level of TSS at the end of storage. For apple cultivars grown in Central Russia, the high level of TSS in apple fruits seemed to be more than 13% (Sedov *et al*., 2007). The rise in TSS could be due to the breakdown of starch (Beaudry *et al*., 1989) into sugars (Crouch, 2003) and the hydrolysis of cell wall polysaccharides (Ben and Gaweda, 1985).

The highest content of TSS in apple fruits was also remarkable during 2021 and 2023 at the end of storage in the variant of biostimulants with 1% solutions (Table 2). The TSS content of apple fruits increased gradually when extending the storage duration. Jan and Rab (2012) reported the maximum TSS (13.08%) in fruits stored for 150 days as compared to 9.93% observed in fresh-harvested apple fruits. The presented study revealed a significant influence of weather conditions on the accumulation of TSS in apple fruits. During the long-term storage, the TSS content increased greatly in apples in the variant with 1% WPU Antifreeze + 1% WP Drip Ca+Mg. TSS content in apple fruit is the chief quality parameter having correlations with the texture and biochemical composition (Kamiloglu, 2011). Ali *et al*. (2004) declared relevant variations in TSS, acidity, and other physicochemical characteristics of apples harvested from different varieties; however, the different cultivars exhibited nonsignificant variations in TSS. The TSS rose during storage (Riveria, 2005).

Biostimulants' effect on the titrated acids

Before long-term storage in 2021, the titrated acidity in apple fruits in the control and in the variant with organic fertilizers (1% solutions) was at the highest level (> 0.86%). In the variant treated with 3% WPU Antifreeze + 3% WP Drip Ca+Mg, the average level of titrated acidity emerged in apple fruits. In subsequent years, the cultivar Sinap Orlovsky fruits showed characteristics of an average content of titrated acids after harvesting in all the variants. The organic acid content was 17% and 29% lower, respectively, in the apples at harvesting with dry and warmer seasons during 2022 and 2023 than in 2021. The

Table 2. Soluble solids content (%) in apple cultivar Sinap Orlovsky.

Factor A, Year	Factor B, Experiment Options	Analysis time C		Average	
		Before storage	After storage	A	AB
2021	Control (WithoutTreatment)	12.07	12.87		12.47
	1% WPU Antifreeze+1% WP Drip Ca+Mg	11.77	13.43		12.60
	3% WPU Antifreeze+3% WP Drip Ca+Mg	12.73	13.87		13.30
	Average AC	12.19	13.39	12.79	
2022	Control (WithoutTreatment)	11.07	12.33		11.70
	1% WPU Antifreeze+1% WP Drip Ca+Mg	11.20	12.40		11.80
	3% WPU Antifreeze+3% WP Drip Ca+Mg	12.17	13.00		12.59
	Average AC	11.48	12.58	12.03	
2023	Control (WithoutTreatment)	11.67	12.90		12.29
	1% WPU Antifreeze+1% WP Drip Ca+Mg	11.07	13.10		12.09
	3% WPU Antifreeze+3% WP Drip Ca+Mg	12.40	13.63		13.02
	Average AC	11.71	13.21	12.46	
	$LSDA_{05}$ = 0.55 $BF_f<F_t$ $LSDC_{05}$ = 0.45 $LSDAB_{05}$ = 0.95 $LSDBC_{05}$ = 0.78 $ACF_f<F_t$ $ABCF_f<F_t$				

variations in titratable acidity exhibited significant influences from the rate of metabolism (Clarke *et al*., 2003), especially respiration, which consumed organic acid and thus, a decline in acidity during storage (Sedov *et al*., 2007; Ghafir *et al*., 2009).

The maximum decrease in the titrated acids (by 2.7 times) was prominent in apples in the control during storage. In the variants treated with 1% and 3% solutions of organomineral fertilizers, the decrease was 2.4 and 2.8 times, respectively, from the initial level noted in 2021. In 2022, after storage, the level of organic acids in the control apples decreased by 1.7 times, while in the treated variants, it lowered by 1.9 times. For 2023, a 2.2-fold decrease existed in the titrated acids in the control. In the variant treated with 1% WPU Antifreeze + 1% WP Drip Ca+Mg, the level of titrated acidity in apple fruits declined by 2.0 times, while in the variant with 3% solution biostimulants, it decreased by 2.2 times. After prolonged storage, the titrated acidity index was at a low level (< 0.61%) in apple fruits (Table 3). Thus, the lower content of organic acids at the time of harvesting apples appeared in dry and warmer years. At the end of storage, a nonsignificant effect of foliar treatments with NPC White Pearl fertilizers occurred on the titrated acids in apples. Makarkina and Nikitin (2011) also noted a sizable decrease in the content of organic acids in apples at the end of storage.

Biostimulants' effect on the total sugars

In the concerned experiment, over the years of studies, an average (< 12%) of the sum of sugars resulted in apple cultivar Sinap Orlovsky fruits before storage for a longer time. Apples showed an increase in the total sugars at the end of storage in each variant of the experiment. Hence, in 2021, sugars in apples of the control treatment increased by 32.6%, while in the variants with organic fertilizers, these rose by 16.6% and 15.6%, respectively. In 2022, the increase in the sugar content was 27.4% and 24.9%, respectively, in treated fruits of variants with 1% and 3% solution biostimulants. For apples of the control, it rose by 17.0%. In 2023, after long-term storage, the increase in sugar content was 16.8% and 12.2%, respectively, while in the variants with foliar treatments of 1% and 3% solution biostimulants, the boost was 11.2% as compared with the control (Table 4). The starch-to-sugars conversion continues during storage (Beaudry *et al*., 1989), resulting in an increased total sugar with storage duration (Crouch, 2003).

In apples, the sugar content increased toward the end of storage and when maturing. During this period, the biochemical composition and properties of apple fruits vary. Thus, at the ripening stage, the total sugars' increase was due to starch biosynthesis. A slight rise in the sugar concentration may also occur because of

Table 3. Titrated acid content (%) in apple cultivar Sinap Orlovsky.

Factor A, Year	Factor B, Experiment Options	Analysis time C		Average	
		Before storage	After storage	A	AB
2021	Control (Without Treatment)	0.96	0.35		0.66
	1% WPU Antifreeze+1% WP Drip Ca+Mg	0.95	0.39		0.67
	3% WPU Antifreeze+3% WP Drip Ca+Mg	0.83	0.30		0.57
	Average AC	0.91	0.35	0.63	
2022	Control (Without Treatment)	0.72	0.43		0.58
	1% WPU Antifreeze+1% WP Drip Ca+Mg	0.71	0.38		0.55
	3% WPU Antifreeze+3% WP Drip Ca+Mg	0.66	0.34		0.50
	Average AC	0.70	0.38	0.54	
2023	Control (Without Treatment)	0.72	0.33		0.53
	1% WPU Antifreeze+1% WP Drip Ca+Mg	0.67	0.33		0.50
	3% WPU Antifreeze+3% WP Drip Ca+Mg	0.64	0.27		0.46
	Average AC	0.68	0.31	0.49	
	$LSDA_{05}$ = 0.05 $BF_f<F_t$ $LSDC_{05}$ = 0.04 $LSDAB_{05}$ = 0.08 $LSDBC_{05}$ = 0.07 LSDAC = 0.07 $ABCF_f<F_t$				

Table 4. The total sugars (%) in apple cultivar Sinap Orlovsky.

FactorA, Year	Factor B, Experiment Options	Analysis time C		Average	
		Before storage	After storage	A	AB
2021	Control (Without Treatment)	9.52	12.62		11.07
	1% WPU Antifreeze+1% WP Drip Ca+Mg	10.58	12.34		11.07
	3% WPU Antifreeze+3% WP Drip Ca+Mg	10.73	12.40		11.57
	Average AC	10.28	12.45	11.37	
2022	Control (Without Treatment)	8.94	10.46		9.70
	1% WPU Antifreeze+1% WP Drip Ca+Mg	8.75	11.15		9.95
	3% WPU Antifreeze+3% WP Drip Ca+Mg	9.23	11.53		10.38
	Average AC	8.97	11.05	10.01	
2023	Control (Without Treatment)	9.90	11.01		10.46
	1% WPU Antifreeze+1% WP Drip Ca+Mg	9.91	11.57		10.74
	3% WPU Antifreeze+3% WP Drip Ca+Mg	10.29	11.55		10.92
	Average AC	10.03	11.37	10.70	
	$LSDA_{05}$ = 0.47 $BF_f<F_t$ $CF_f<F_t$ $LSDAB_{05}$ = 0.82 $LSDBC_{05}$ = 0.67 $LSDAC_{05}$ = 0.67 $ABCF_f<F_t$				

moisture evaporation from apples, since during this period, the evaporation is more intense than the consumption of acids and other substances for respiration. The apple fruits accumulate starch at the early stages of maturation and, later on, hydrolyze to sugars at maturity (Magein and Leurquin, 2000).

Biostimulants' effect on the sugar-acid index (SAI)

The optimal SAI value, which serves to determine the harmonious (sweet and sour) taste of fruits, was 15–20 (Table 5). In the presented experiment, after apple harvesting, the SAI ranged from 9.9 to 13.8 (control), while it ranged from 11.1 to 14.8 in the variant treated with 1% solution biostimulants in apple fruits. However, a more optimal value of the SAI (from 12.9 to 16.3) emerged in apple fruits after the foliar application of a 3% solution of organomineral fertilizers.

At the stage of consumer maturity, apple fruits formed a good sweet-and-sour taste in all variants, as evidenced by the values of the SAI. After long-term storage, the SAI increased in apples, both in the control and in the experimental variants. For the variant with

Table 5. Sugar/acid ratio in apple cultivar Sinap Orlovsky.

Factor A, Year	Factor B, Experiment Options	Analysis time C		Average	
		Before storage	After storage	A	AB
2021	Control (Without Treatment)	9.9	36.1		23.0
	1% WPU Antifreeze+1% WP Drip Ca+Mg	11.1	31.6		21.4
	3% WPU Antifreeze+3% WP Drip Ca+Mg	12.9	41.3		27.1
	Average AC	11.3	36.3	23.8	
2022	Control (Without Treatment)	12.4	24.3		18.4
	1% WPU Antifreeze+1% WP Drip Ca+Mg	12.3	29.3		20.8
	3% WPU Antifreeze+3% WP Drip Ca+Mg	14.0	33.9		24.0
	Average AC	12.9	29.2	21.0	
2023	Control (Without Treatment)	13.8	33.4		23.6
	1% WPU Antifreeze+1% WP Drip Ca+Mg	14.8	35.1		25.0
	3% WPU Antifreeze+3% WP Drip Ca+Mg	16.1	42.8		29.5
	Average AC	14.9	37.1	26.0	
	$AF_f<F_t$ $BF_f<F_t$ $LSDC_{05}$ = 3.6 $LSDAB_{05}$ = 7.6 $LSDBC_{05}$ = 6.2 $ACF_f<F_t$ $ABCF_f<F_t$				

1% solution organomineral fertilizers, the SAI increased by 2.4 to 2.8 times in apples. In apples of another variant (with 3% solution biostimulants), an elevation by 2.4 to 3.2 times was prominent in the SAI. In the control, an increase in the SAI value was by 2.4 to 2.7 times (Table 5).

Thus, due to a decrease in the content of titrated acids during storage and an increase in the total sugars in apples, the SAI value increased and had a positive effect on the fruit's taste. The tasting score was higher for the fruits in the variants with foliar treatments, i.e., 4.6–4.7 points (appearance) and 4.8–4.9 points (taste), while the control fruits had a score of 4.5 and 4.6 points, respectively.

Biostimulants' effect on ascorbic acid (AA)

The prevailing weather conditions during the study years influenced the accumulation of ascorbic acid (AA) in apple fruits. Thus, in 2021, the AA content in cultivar Sinap Orlovsky was by 13.61 mg/100 g and 16.3 mg/100 g higher than in 2022 and 2023, respectively. The apples of the variant treated with 1% solution biostimulants contained the higher AA by 4.4 and 10.3 mg/100 g in 2021, by 3.67 and 2.97 mg/100 g in 2022, and by 2.3 mg/100 g in 2023 than the control and other variants, respectively. Ascorbic acid (AA) usually served as an index of nutrient quality in apple fruits. The AA is a bioactive compound having antioxidant properties (Lata, 2007). The apple cultivars significantly differed in their AA content (Nour *et al*., 2010). Apple cultivar Red Delicious had the highest AA, followed by Royal Gala and Mondial Gala, while it was lowest in the cultivar Golden Delicious. The AA decreased gradually and significantly with incremental increases in storage duration (Hayat *et al*., 2003).

At the time of the fruits' removal from storage, on average, the AA content in the apple cultivar Sinap Orlovsky decreased significantly by 13.45 mg/100 g (2021) and by 1.49 mg/100 g (2022) for all variants. Foliar treatment with the NPC White Pearl did not have a significant effect on the accumulation of AA in apples (Table 6). The AA in apple fruits proved sensitive to storage temperature and duration, with its degradation enhanced by adverse handling and storage conditions, such as higher temperature, low relative humidity, physical damage, and chilling injury (Adisa, 1986). Besides abiotic factors, the ascorbic acid can be irreversibly oxidized (Pardio-Sedas *et al*., 1994), which diminishes the edible quality and boosts susceptibility to different physiological disorders during storage (Jung and Watkins, 2008). The apple cultivars may vary in their initial AA content, as well as in the rate of decline during storage (Nour *et al*., 2010). Thus, in apple fruits, the AA content exhibited crucial effects from the weather conditions of the growing season.

Table 6. Ascorbic acid content (mg/100 g) in apple cultivar Sinap Orlovsky.

Factor A, Year	Factor B, Experiment Options	Analysis time C		Average	
		Before storage	After storage	A	AB
2021	Control (Without Treatment)	19.37	7.03		13.20
	1% WPU Antifreeze+1% WP Drip Ca+Mg	23.77	2.33		13.05
	3% WPU Antifreeze+3% WP Drip Ca+Mg	13.47	6.90		10.19
	Average AC	18.87	5.42	12.15	
2022	Control (Without Treatent)	3.80	2.37		3.09
	1% WPU Antifreeze +1% WP Drip Ca+Mg	7.47	4.40		5.94
	3% WPU Antifreeze+3% WP Drip Ca+Mg	4.50	4.53		4.52
	Average AC	5.26	3.77	4.51	
2023	Control (Without Treatment)	1.80	5.00		3.40
	1% WPU Antifreeze+1% WP Drip Ca+Mg	4.10	6.77		5.44
	3% WPU Antifreeze+3% WP Drip Ca+Mg	1.80	7.03		4.42
	Average AC	2.57	6.27	4.42	
	$LSDA_{05}$ = 2.58 $BF_f<F_t$ $LSDC_{05}$ = 2.1, $ABCF_f<F_t$	$LSDAB_{05}$ = 4.46,	$LSDBC_{05}$ = 3.64,	$LSDAC_{05}$ = 3.64	

CONCLUSIONS

The results enunciated foliar treatments with 1% solution biostimulants contributed a significant decrease in the weight loss in apple (*M. domestica* L.) fruits compared with the control and other variants during long-term storage. In the apple cultivar Sinap Orlovsky, a notable decrease in the titrated acids was evident at the end of storage. Largely, the sugar content in apple fruits increased at the end of storage in the variant treated with 1% WPU Antifreeze + 1% WP Drip Ca + Mg. After long-term storage, apples in all variants formed a better sweet-and-sour taste as per the sugar acid index.

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