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DETERMINING BIOCHEMICAL QUALITATIVE INDICATORS OF GRAPES DURING LONG-TERM STORAGE

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This paper reports a study aimed at determining the biochemical quality indicators of grapes during long-term storage. The object of research was nine table varieties of ripened grapes. These include white varieties – Tabrizi, Karaburnu, White Shasla, Agadai; pink varieties – Nimrang, Marandi Shamakhi, Taifi pink; red varieties – Kyzyl raisins and Hamburg Muscat.

The grapes were stored in refrigerators for 5–6 months, at a temperature of 0–1 °C and air humidity of 87–95 %. The grapes were studied before planting and 30–40 days before the end of storage.

Long-term refrigerated storage of grapes using weekly fumigation with sulfur dioxide is accompanied by a decrease in the activity of oxyreductases and a gradual increase in the activity of pectinesterase. This causes changes in the quantity and proportions of nutrients and other chemical components that determine the nutritional and biological value of the final product.

It was revealed that during the sale of ripened grapes stored using weekly fumigation with sulfur dioxide, the activity of the studied oxyreductases is slightly restored in pink varieties – Nimrang, Taifi pink, and in white varieties – in Karaburnu and Tabrizi. In the Marandi Shamakhi variety, the activity of enzymes does not change, therefore, for a long time in these grape varieties, especially in the Marandi Shamakhi variety, darkening and softening of the berries are not observed during their sale.

Among the studied table grape varieties, Tabrizi, Karaburnu, Nimrang, and Marandi Shamakhi, with long-term refrigerated storage using weekly fumigation with sulfur dioxide, have the longest shelf life; under a controlled gas environment, the results reported here could prove useful in practice

Keywords: Ganja table, Marandi Shamakhi, Karaburnu, Kyzyl raisins, ascorbate oxidase, o-diphenol oxidase, peroxidase, catalase, long-term storage

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1. Introduction

Fresh grapes are a high-calorie food product with valuable nutritional, taste, dietary and medicinal properties. However, they could only be used for fresh consumption during 2.5–3 months. Long-term storage of grapes makes it possible to significantly increase the period of their consumption [1].

The issues of ensuring the safety of fruits and vegetables, including table grapes, improving their storage conditions, and reducing losses are currently becoming of great importance. In this regard, the study of the theoretical foundations and practical issues of storing grapes is an urgent problem in solving the tasks of providing the population with fresh grapes throughout the year [2].

Viticulture is developing rapidly. The winegrowers are tasked with increasing the supply of fresh grapes to the population not only in the fall but also in the winter and spring. The development of this industry is moving along the path of further expansion of areas and an increase in gross receipts. At the same time, winegrowers are fighting against losses and damage to grapes [3].

Grapes (*Vitis vinifera L.*) are one of the most important horticultural crops in the world. Grapes are a valuable crop compared to various products in terms of production, so they play an important role in the economies of countries [4].

The problem of extending the consumption period, ensuring high-quality preservation, and reducing losses is given a lot of attention. Several years ago, specialists tried to grow grapes in greenhouses. However, due to the high cost of construction, low yields, and therefore the high cost of final products, this method turned out to be ineffective [5].

Using long-known techniques of storing fresh grapes (on dry and green ridges, in boxes without artificial refrigeration, using antiseptics, etc.), it is possible to provide them to the population in November and the first ten days of December. But due to significant damage to products during storage, these methods have not found industrial application.

The issue of extending the shelf life of grapes is mainly when using special storage facilities with artificial cooling. The most effective industrial technique is to store fresh grapes in refrigerated storage facilities with a predefined optimal regime [6].

At industrial centers and specialized farms in the republic there are refrigerators for storing fresh grapes. The current level of development of science and technology makes it possible, when storing grapes in special storage facilities, to significantly extend their shelf life and reduce the large losses that occur. At the same time, modern technologies for storing grapes remain poorly understood. In this regard, there is a need for extensive research in order to preserve large quantities and select special varieties. The main attention should be paid to studying the influence of the degree of ripeness on the keeping quality of grapes and its resistance to phytopathogenic microorganisms [7].

It is quite clear that when studying modern technologies for storing grapes, it is necessary to be guided by modern ideas about the biochemical nature of the keeping quality of grapes. Therefore, the development of theoretically based, more effective methods for long-term storage of grapes is of great interest. Along with the preservation, without significant changes, of the more important biochemical components: carbohydrates, vitamins, organic acids, phenolic substances, and other components that determine the nutritional and biological value of the product [8].

Therefore, it is a relevant task to carry out studies on determining the biochemical quality indicators of grapes during long-term storage. Taking into account the fact that maintaining the quality of grapes during long-term storage is an important problem for producers and consumers, research into defining the quality indicators of grapes and factors affecting their preservation remains extremely relevant. This is important for the development of effective storage, processing, and transportation methods that will preserve the quality and nutritional properties of grapes throughout the entire period of storage and delivery to the consumer. Such research helps improve product quality, reduce losses, and increase customer satisfaction.

2. Literature review and problem statement

One of the effective ways to store table grapes is to store them in a controlled gas environment. In the course of research, it was established [9] that the storage conditions for grapes include low temperature, high relative air humidity, and a changed composition of the controlled gas environment. These conditions were observed in the refrigeration chamber but the temperature inside the grapes was not studied.

Grapes, as one of the important horticultural crops, play a significant role in maintaining health. Study [10] examined the effect of nitric oxide (NO) on some physical-biochemical properties and the activity of antioxidant enzymes in grape fruits damaged by hypothermia.

Paper [11] reports the results of research related to the study of resistance to low negative temperatures of grape varieties of various ecological and geographical groups according to the activity of the peroxidase enzyme and its isoforms. But the activity of other enzymes (oxidoreductase, o-diphenoloxidase, catalase) was not studied. To do this, the authors studied the dynamics of changes in the activity of enzymes belonging to the class of oxidoreductases, analyzing all three varieties once a month from the beginning to the end of storage of grape varieties.

Storing grapes in refrigerated chambers with a controlled gas environment (CGE) is a rather rare method. Storage under normal conditions [11] assumes a normal air environment with a normal content of oxygen (21 %), carbon dioxide, and other gases in the atmosphere. Storage in a controlled gas environment is the storage of fruits in an environment with a certain concentration of CO_2 and oxygen at a certain temperature. In this case, one or another gas regime is selected in such a way as to maintain normal respiratory gas exchange, as well as the proper relationship between temperature and the condition of the fruit. But too low oxygen content in the environment and high CO_2 content (more than 10 %) can cause physiological disorders.

Paper [12] indicates that in a controlled gas environment, compared to storage in a normal air environment, the quality of the fruit is better preserved. In addition, the green color lasts longer, the hydrolytic processes of protopectin decomposition slow down (the fruits remain hard longer). CO_2 and oxygen also affect the biosynthesis of ethylene in fruits and its biological effect on ripening processes. The problem identified in the work is that controlled gas storage may be more effective than conventional air storage in maintaining fruit quality, but this method does not solve all problems. For example, although it may slow down the hydrolytic breakdown of protopectin and preserve the green color of the fruit, it does not exclude the possibility of other decomposition processes or loss of quality. Objective reasons why this problem remains unresolved may include the difficulty of creating and maintaining an optimal gas environment at storage facilities, as well as insufficient understanding of all aspects of the impact of gases on the processes of fruit ripening and storage. For example, it can be difficult to precisely control CO_2 and oxygen concentrations to ensure optimal conditions for each grape variety. Subjective reasons may include the priorities and interests of researchers who may choose other areas of research or focus on other aspects of fruit storage and processing.

As a result of research [13], it was found that table grape varieties are rich in nutrients necessary for the human body, mainly simple sugars, organic acids, phenolic compounds, minerals, and iodine. Before storing fully ripened grape varieties, it was established that the enzymes ascorbate oxidase, o-diphenol oxidase, peroxidase, and catalase in their composition are constantly active and change differently. The problem, in the work, is that the enzymes contained in fully ripened grapes remain active before storage and change differently. This can cause problems when storing grapes as the activity of these enzymes can contribute to various biochemical processes, including nutrient loss, oxidative reactions, and changes in product quality.

At room temperature, an increase in enzyme activity [14] leads to the breakdown of nutrients in grapes and their use in the respiration process. From the specific features of enzymes, it is known that they weaken their activity at low temperatures (0 °C to +5 °C). Reduced enzyme activity prevents the decomposition of organic and inorganic substances in grapes. The problem here is that at room temperature the enzymes continue to work actively, which can lead to rapid degradation of the grapes and loss of their nutritional properties. Under cold conditions (0 °C to +5 °C), the activity of the enzymes responsible for the breakdown of nutrients in grapes is significantly reduced. This can lead to undesirable results; while such conditions may slow down the decomposition of nutrients and increase the shelf life of the grapes, they can also cause changes in their structure and quality, such as loss of taste, texture, or nutritional value. Thus, a balance is required between preserving nutrients and preserving product quality under cold storage conditions.

This is the approach used in [15]. This approach reflects an attempt to balance between maintaining the quality of the product and increasing its shelf life. By studying the dynamics of changes in the activity of enzymes, such as oxidoreductases, during the entire storage period of grapes, researchers can determine optimal storage conditions that slow down the processes of nutrient decomposition as much as possible, while maintaining product quality.

Study [16] quantified the content and composition of sugars and organic acids in 17 grape varieties over two consecutive years using high-performance liquid chromatography. However, changes in the activity of oxidoreductases of grape varieties during storage using weekly fumigation with sulfur dioxide have not been studied. This means that there is information about the chemical composition of grapes but there is no data on how the activity of oxidoreductases changes under the influence of fumigation. This can be important information for understanding how storage and processing methods affect the physiological processes of grapes and their quality. Studying the effect of fumigation on the activity of oxidoreductases could complement previous data by providing a more complete understanding of the processes occurring during grape storage that affect its quality and nutritional properties.

Given these limitations and the potential negative effects on the quality of grapes during long-term storage, it is advisable to conduct a study that would determine the biochemical quality parameters of grapes under various storage conditions, including the use of weekly fumigation with sulfur dioxide. Such a study will allow us to more fully understand the effect of fumigation on the biochemical processes of grapes and their quality, as well as determine optimal storage conditions to preserve its nutritional and organoleptic properties. Taking this into account, it is necessary to conduct a study that would determine the optimal storage conditions for grapes in terms of preserving their biochemical qualities. This is important in order to compile storage recommendations that will meet product quality and safety requirements while satisfying the needs of producers and consumers.

3. The aim and objectives of the study

The purpose of our work is to identify the effect of long-term storage of grapes on their biochemical quality indicators. This will make it possible to study changes in enzyme activity during storage using weekly fumigation with sulfur dioxide.

To achieve the goal, the following tasks were set:

– to study changes in the activity of oxidoreductases in grape varieties during storage using weekly fumigation with sulfur dioxide;

– to study changes in the biochemical parameters of white, pink, and red grape varieties during storage using weekly fumigation with sulfur dioxide;

– to study changes in pectinesterase activity in grape varieties during storage using weekly fumigation with sulfur dioxide;

– to study changes in the content of pectin substances in grape varieties during storage using weekly fumigation with sulfur dioxide;

– to study changes in the activity of oxidoreductases in grape varieties after long-term storage using weekly fumigation with sulfur dioxide before sale.

4. The study materials and methods

4. 1. The object and hypothesis of the study

The object of research was nine table varieties of ripened grapes. These include white varieties – Tabrizi, Karaburnu, White Shasla, Agadai; pink varieties – Nimrang, Marandi Shamakhi, Taifi pink; red varieties – Kyzyl raisins and Hamburg Muscat.

The study was carried out at the Gok-Gol agro-industrial complex in the Republic of Azerbaijan. The grapes for storage were collected at the specified farm, as well as at the subsidiary-experimental farm of the experimental station for viticulture and winemaking in the city of Ganja.

The research hypothesis assumed that a slight change in pectin substances in the above-mentioned grape varieties contributes to the fact that their berries do not lose their original freshness and are slightly susceptible to microbiological spoilage. During the storage of all grape varieties, using weekly fumigation with sulfur dioxide, it is accompanied by a decrease in the activity of oxidoreductases and a gradual increase in the activity of pectinesterase. There is a quantitative change in the content of glucose, fructose, vitamin C, phenolic and pectin substances, organic acids, and the pH value of other ingredients.

It was assumed that when storing grapes, if weekly fumigation with sulfur dioxide is used, the catalytic activity of enzymes would contribute to a more intense reduction in metabolic processes.

4. 2. Research methods

The studies were conducted in 2018–2020.

Before storing, the grapes were sorted, packed in standard boxes, and placed in refrigerator compartments on the same day. The degree of ripeness of the grapes, the condition of the bunches, the outside temperature, the time of harvesting, and other factors were taken into account. The grapes were harvested in the afternoon. The refrigerator chamber was thoroughly disinfected with sulfur dioxide before adding grapes. In the refrigerator chamber, only fumigation was carried out weekly with sulfur dioxide at a rate of 1–1.5 g per 1 m^3 of the refrigerator chamber [17]. The grapes were stored in refrigerators for 5–6 months, at a temperature of 0–1 °C and air humidity of 87–95 %. The grapes were studied before planting and 30–40 days before the end of storage. The selection of an average sample of grape berries was carried out according to generally accepted methods. The total volume of the average sample in each variant was 1–1.5 kg.

In ripened grapes, the activity of oxidative enzymes of the class of oxidoreductases was determined: ascorbate oxidase, o-diphenoloxidase, peroxidase and catalase, and the activity of pectinesterase was studied among pectolytic enzymes [18].

The content of glucose was determined by iodometric method; fructose – calorimetric; titratable acidity – by direct titration method [19]; vitamin C – by dichlorophenolindophenol methods; and phenolic compounds [17] and non-volatile organic acids were determined by chromotomasspectometry.

In addition, active acidity was determined by the potentiometric method using a Polish pH meter No. 5123 [17]. Free and total sulfite acids were determined by iodometric methods, and pectic substances were determined by carbosol methods [17].

5. Results of investigating the biochemical quality indicators of grapes during long-term storage

5. 1. Change in the activity of oxidoreductases of grape varieties during storage using weekly fumigation with sulfur dioxide

Changes in the activity of oxidoreductases of white grape varieties during storage using weekly fumigation with sulfur dioxide are given in Table 1.

Table 1 demonstrates that when analyzing the activity of grape enzymes during long-term storage using weekly fumigation with sulfur dioxide, the fact that different enzymes have unequal activity deserves attention.

5. 2. Changes in the biochemical parameters of grape varieties during storage with weekly fumigation with sulfur dioxide

Changes in the biochemical parameters of white grape varieties during storage using weekly fumigation with sulfur dioxide are given in Table 2.

Changes in the biochemical parameters of pink grape varieties during storage using weekly fumigation with sulfur dioxide are given in Table 3.

During the storage period of pink grape varieties, a noticeable decrease in the catalytic activity of oxidoreductases is also observed (Table 3).

The change in the activity of oxidoreductases of white grape varieties during long-term storage with weekly fumigation with sulfur dioxide is shown in Fig. 1, 2.

Change in the activity of oxidoreductases of pink grape varieties during long-term storage with weekly fumigation with sulfur dioxide is shown in Fig. 3.

Table 1

Changes in the activity of oxidoreductases of grape varieties during storage using weekly fumigation with sulfur dioxide (mg of oxidized substrate decomposed in 30 minutes by enzymes 1 g of tissue)

Grape variety	Ascorbate oxidase				O-diphenol oxidase				Peroxidase				Catalase			
	Before storage	After storage	difference		Before storage	After storage	difference		Before storage	After storage	difference		Before storage	After storage	difference	
			unit	%			unit	%			unit	%			unit	%
Tabrizi	0.64	0.17	–0.47	73.6	0.70	0.33	–0.37	57.1	2.20	0.80	–1.40	63.6	0.33	0.10	–0.23	70.0
Karaburnu	0.55	0.20	–0.35	63.6	0.72	0.30	–0.42	58.3	1.98	0.87	–1.11	55.8	0.39	0.10	–0.29	74.0
White Chasselas	0.58	0.26	–0.32	55.2	0.68	0.34	–0.34	50.0	2.42	1.21	–1.21	50.0	0.34	0.14	–0.20	58.8
Agadai	0.55	0.22	–0.33	60.0	0.70	0.32	–0.38	54.3	2.32	1.01	–1.31	56.5	0.36	0.12	–0.24	56.7
Nimrang	0.64	0.10	–0.54	84.4	0.72	0.16	–0.56	77.8	1.88	0.66	–1.22	64.9	0.34	0.08	–0.26	76.5
Marandi Shamakhi	0.60	0.05	–0.55	91.7	0.70	0.10	–0.60	85.7	1.86	0.34	–1.52	81.7	0.33	0.05	–0.28	84.8
Taifi pink	0.58	0.16	–0.42	72.4	0.66	0.20	–0.46	70.0	1.92	0.78	–1.14	59.4	0.38	0.10	–0.28	73.7
Kyzyl raisins	0.55	0.34	–0.21	38.2	0.74	0.56	–0.18	32.1	2.32	1.32	–1.00	43.1	0.36	0.20	–0.16	44.4
Muscat of Hamburg	0.68	0.50	–0.18	26.5	0.76	0.58	–0.18	31.0	2.42	1.54	–0.88	57.1	0.40	0.30	–0.10	25.0

Table 2

Changes in the biochemical parameters of white grape varieties during storage using weekly fumigation with sulfur dioxide

Biochemical parameters	Tabrizi				Karaburnu				Shasla white				Agadai			
	Before storage	After storage	difference		Before storage	After storage	difference		Before storage	After storage	difference		Before storage	After storage	difference	
			unit	%			unit	%			unit	%			unit	%
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Glucose, g/100 cm^3	9.5	8.8	–0.7	7.4	9.1	8.6	–0.7	7.7	9.4	8.5	–0.9	9.6	9.5	8.4	–1.1	11.6
Fructose, g/100 cm^3	9.8	9.0	–0.8	8.2	9.4	8.8	–0.6	6.4	8.5	7.1	–1.4	16.5	8.8	7.9	–0.9	10.2
Glucose:Fructose	0.97	0.98	+0.01	0.97	0.97	0.98	+0.01	1.0	1.1	1.2	+0.1	9.1	1.08	1.1	+0.02	1.8
Invert sugar, g/100 cm^3	19.3	17.8	–1.5	18.5	18.5	17.4	–1.1	5.9	17.9	15.6	–2.3	12.8	18.3	16.3	–2.0	10.9
Vitamin C, mg/100 cm^3	7.2	1.8	–5.4	7.8	7.8	1.9	–5.9	75.7	6.4	1.1	–5.3	82.8	6.8	1.3	–5.5	80.9
Phenolic substances, mg/100 cm^3	0.08	0.058	–0.22	0.082	0.082	0.058	–0.024	29.2	0.075	0.045	0.030	40.0	0.078	0.052	–0.026	33.3
Active acidity, (pH)	4.1	3.9	–0.2	4.2	4.2	4.0	–0.2	4.7	4.2	3.9	–0.3	7.1	4.2	4.0	–0.2	4.7
Titratable acidity, g/100 cm^3	0.72	0.63	–0.09	0.74	0.74	0.64	–0.10	13.5	0.67	0.54	–0.13	19.4	0.65	0.54	–0.11	16.9

Continuation of Table 2

1	2	3	4	5	6	7	8	9	0	11	12	13	14	15	16	17
Organic acids:																
Tartaric acid	0.48	0.45	–0.03	6.2	0.48	0.43	–0.05	10.4	0.43	0.38	–0.05	11.6	0.42	0.37	–0.05	11.9
Malic acid	0.19	0.16	–0.03	15.8	0.21	0.18	–0.03	14.3	0.18	0.12	–0.06	33.3	0.17	0.13	0.04	23.5
Succinic acid	0.028	0.021	–0.007	25.0	0.024	0.017	0.007	29.3	0.025	0.013	–0.012	48.0	0.028	0.016	0.012	42.9
Citric acid	0.007	0.0035	–0.0035	50.0	0.0095	0.0055	–0.004	42.1	0.008	0.004	–0.004	50.0	0.009	0.007	0.002	22.2
Oxalic acid	0.065	0.0025	–0.004	51.5	0.008	0.004	–0.004	50.0	0.007	0.0045	–0.0025	35.7	0.0075	0.005	–0.0025	33.3
Sulphatic acid, *mg*/100 cm^3:																
Free	0.36	0.74	+0.38	105.6	0.38	0.68	+0.30	78.9	0.36	0.84	+0.48	133.3	0.36	0.78	+0.42	116.7
Total	0.78	1.72	+0.94	120.5	0.74	1.52	+0.78	105.4	0.78	1.80	+1.02	130.8	0.78	1.70	+0.92	117.9

Table 3

Changes in the biochemical parameters of pink grape varieties during storage using weekly fumigation with sulfur dioxide

Biochemical parameters	Nimrang				Marandi Shamakhi				Taifi pink			
	Before storage	After storage	difference		Before storage	After storage	difference		Before storage	After storage	difference	
			unit	%			unit	%			unit	%
Glucose, g/100 cm^3	8.8	8.3	–0.5	5.7	8.6	8.2	– 0.4	4.6	9.2	9.2	8.5	–0.7
Fructose, g/100 cm^3	9.8	9.2	–0.6	6.1	10.8	10.5	0.3	2.8	9.6	9.6	8.8	–0.8
Glucose: Fructose	0.89	0.90	+0.01	1.1	0.80	0.80	–	–	0.96	0.97	+0.01	1.1
Invert sugar, g/100 cm^3	18.6	17.5	–1.1	5.9	19.4	18.7	–0.7	3.6	18.8	17.3	–1.5	8.0
Vitamin C, mg/100 cm^3	8.7	5.4	–3.3	37.9	10.2	7.5	–2.7	26.5	8.5	4.8	–3.7	43.5
Phenolic substances, mg/100 cm^3	0.18	0.16	–0.02	11.1	0.16	0.15	–0.01	6.2	0.20	0.17	–0.03	15.0
Active acidity, (pH)	3.7	3.6	–0.1	2.7	3.7	3.6	–0.1	2.7	3.7	3.5	–0.2	5.4
Titratable acidity, g/100 cm^3	0.68	0.61	–0.01	8.8	0.65	0.61	–0.04	6.1	0.65	0.58	–0.08	12.1
Organic acids:												
Tartaric acid	0.46	0.42	–0.04	8.7	0.44	0.42	–0.02	4.5	0.42	0.35	–0.07	16.7
Malic acid	0.19	0.17	–0.02	10.5	0.17	0.16	–0.01	5.9	0.20	0.16	–0.04	20.0
Succinic acid	0.022	0.018	–0.04	18.2	0.018	0.015	–0.003	16.7	0.024	0.024	0.004	16.7
Citric acid	0.0052	0.0038	–0.0014	26.9	0.006	0.05	–0.01	16.7	0.0064	0.0064	–0.0016	25.0
Oxalic acid	0.0045	0.0034	–0.0011	24.4	0.005	0.004	–0.01	20.0	0.0055	0.0055	–0.0011	20.0
Sulphatic acid, *mg*/100 cm^3:												
Free	0.34	0.52	+0.18	52.9	0.28	0.38	+0.10	35.7	0.36	0.60	+0.24	66.7
Total	0.62	1.04	+0.42	57.7	0.54	0.84	+0.30	55.5	0.68	0.24	+0.56	82.3

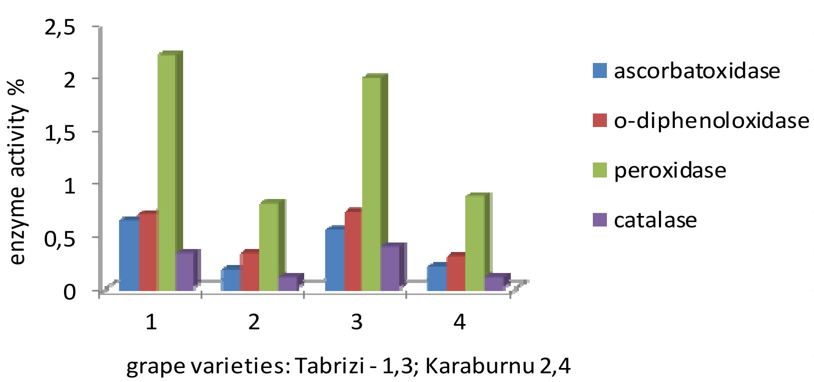

Fig. 1. Changes in the activity of oxidoreductases of white grape varieties Tabrizi and Karaburnu during long-term storage with weekly fumigation with sulfur dioxide (1, 3 — before storage, 2, 4 — after storage)

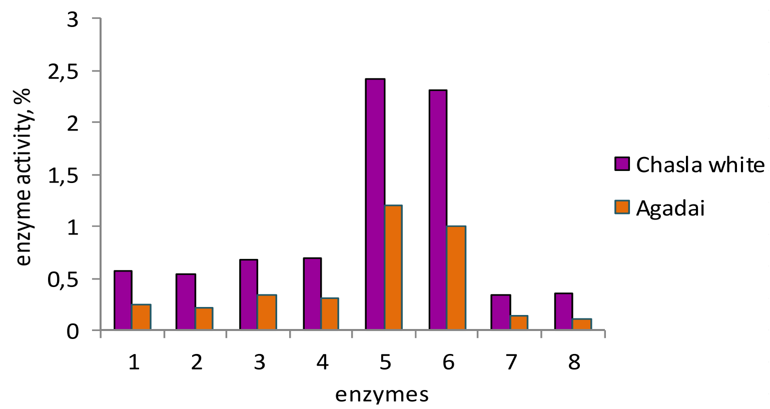

Fig. 2. Changes in the activity of oxidoreductases in white grape varieties during long-term storage with weekly fumigation with sulfur dioxide (1, 2 — ascorbate oxidase, 3, 4 — o-diphenol oxidase, 5, 6 — peroxidase, 7, 8 — catalase)

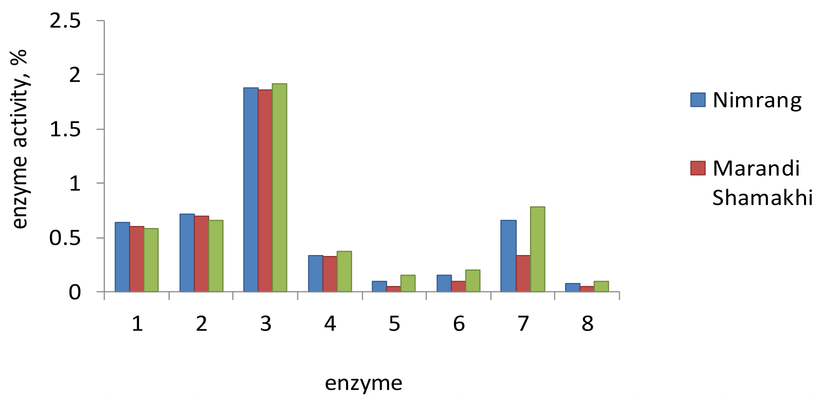

Fig. 3. Changes in the activity of oxidoreductases of pink grape varieties during long-term storage with weekly fumigation with sulfur dioxide (1, 2 — ascorbate oxidase, 3, 4 — o-diphenol oxidase, 5, 6 — peroxidase, 7, 8 — catalase)

Change in the activity of oxidoreductases of red grape varieties during long-term storage with weekly fumigation with sulfur dioxide is shown in Fig. 4.

In red grape varieties, as studies have shown, there is a more moderate and gradual decrease in the catalytic activity of the studied oxidoreductases (Fig. 4).

Changes in the biochemical parameters of red grape varieties during storage using weekly fumigation with sulfur dioxide are given in Table 4.

The greatest reduction in the amounts of glucose and fructose during the period of storing grapes in the refrigerator with the treatment of weekly fumigation with sulfur dioxide is observed in red grape varieties (Table 4).

Changes in the activity of oxidoreductase enzymes in grape varieties are shown in Fig. 5.

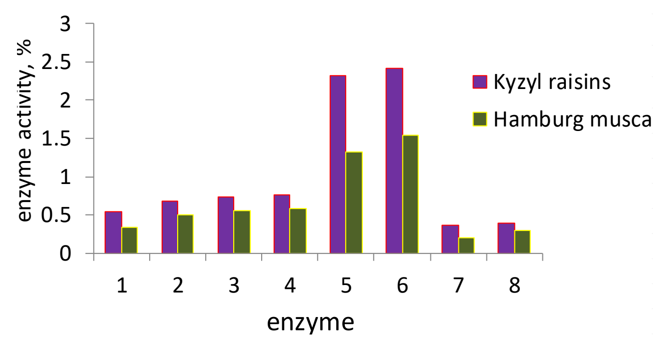

Fig. 4. Changes in the activity of oxidoreductases of red grape varieties during long-term storage with weekly fumigation with sulfur dioxide (1, 2 — ascorbate oxidase, 3, 4 — o-diphenol oxidase, 5, 6 — peroxidase, 7, 8 — catalase)

Table 4

Changes in the biochemical parameters of red grape varieties during storage using weekly fumigation with sulfur dioxide

Biochemical parameters	Kyzyl raisins Hamburg muscat				Kyzyl raisins Hamburg muscat			
	Before storage	After storage	difference		Before storage	After storage	difference	
			unit	%			unit	%
1	2	3	4	5	6	7	8	9
Glucose, g/100 cm^3	8.9	7.3	–1.6	18.0	9.1	7.1	–2.0	22.0
Fructose, g/100 cm^3	9.3	7.3	–2.0	21.5	9.5	7.3	–2.2	23.2
Glucose: Fructose	0.96	1.0	+0.04	4.2	0.96	0.97	+0.01	1.0
Invert sugar, g/100 cm^3	18.2	14.6	–3.6	19.8	18.6	14.4	–4.2	22.6
Vitamin C, mg/100 cm^3	7.8	1.4	–6.4	82.0	7.4	1.2	–6.2	83.8

Continuation of Table 4

1	2	3	4	5	6	7	8	9
Phenolic substances, mg/100 cm^3	0.48	0.34	–0.14	29.2	0.42	0.30	–0.12	28.6
Active acidity, (pH)	3.7	3.4	–0.3	8.1	3.7	3.4	–0.3	8.1
Titratable acidity, g/100 cm^3	0.65	0.50	–0.15	23.1	0.53	0.47	–0.16	25.4
Organic acids:								
Tartaric acid	0.44	0.36	–0.08	18.2	0.42	0.33	0.09	21.4
Malic acid	0.18	0.13	–0.05	27.8	0.19	0.13	0.06	31.6
Succinic acid	0.024	0.016	–0.008	33.3	0.026	0.016	–0.01	38.5
Citric acid	0.006	0.003	–0.003	50.0	0.0065	0.0035	–0.003	46.1
Oxalic acid	0.0055	0.0035	–0.002	36.4	0.005	0.003	–0.002	40.0
Sulphatic acid, *mg*/100 *cm*^{3}:								
Free	0.36	0.60	+0.24	66.7	0.38	0.64	+0.26	68.4
Total	0.70	1.28	+0.58	82.9	0.74	1.36	+0.62	83.8

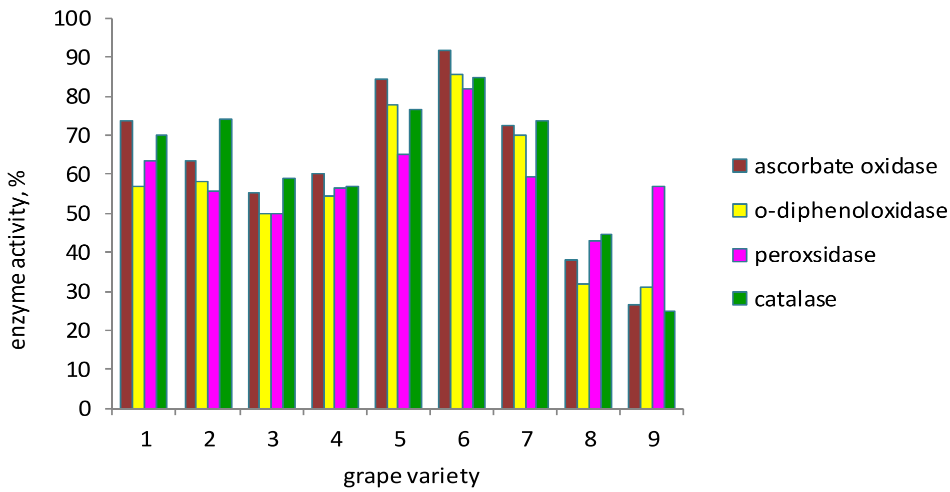

Fig. 5. Changes in the activity of oxidoreductase enzymes in the studied grape varieties (1 – Tabrizi, 2 – Karaburnu, 3 – Chaslas White, 4 – Agadai, 5 – Nimrang, 6 – Marandi Shamakhi, 7 – Taify Pink, 8 – Kyzyl raisin, 9 – Hamburg Muscat

Fig. 5 shows that the greatest decrease in the activity of the studied oxidoreductases of ripened table grape varieties, at the end of long-term refrigerated storage, is shown by Marandi Shamakhi, then Nimrang, Taifi pink, Tabrizi, and Karaburnu. The smallest decrease was found in the varieties Agadai, Chasla white, Kyzyl raisin, and Hamburg Muscat.

5. 3. Change in pectinesterase activity of grape varieties during storage using weekly fumigation with sulfur dioxide

Changes in pectinesterase activity of grape varieties during storage using weekly fumigation with sulfur dioxide are given in Table 5.

The results of analysis of changes in pectinesterase activity revealed that among the studied grape varieties, Hamburg Muscat, Kyzyl raisin, White Chasselas, and Agadai have the highest PE activity (Table 5 and Fig. 6).

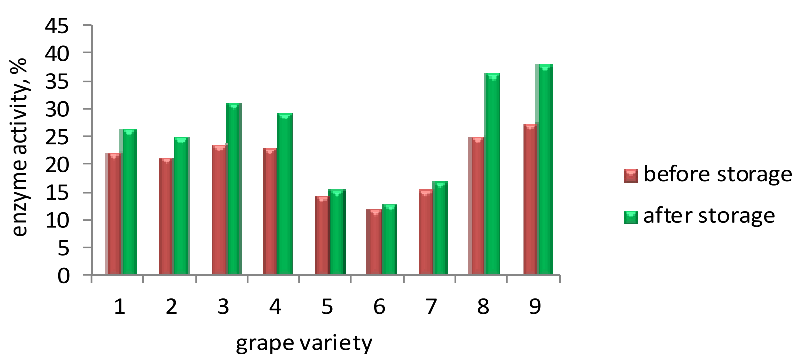

Fig. 6. Changes in pectinesterase during long-term storage of the studied grape varieties

Table 5

Change in pectinesterase activity of grape varieties during storage using weekly fumigation with sulfur dioxide (in relative units per mg of acetone preparation)

Grape variety	Incubation time of mixture reaction, 30 min			
	Before storage	After storage	difference	
			unit	%
1	2	3	4	5
Tabrizi	22.4	26.7	+4.3	19.2

Continuation of Table 5

Karaburnu	21.6	25.4	+3.8	17.6
Chasselas white	23.8	31.4	+7.6	31.9
Agadai	23.2	29.6	+5.4	27.8
Nimrang	14.6	15.8	+1.2	9.8
Marandi Shamakhi	12.3	13.1	+0.8	6.5
Taifi pink	15.6	17.2	+1.6	10.2
Kyzyl raisins	25.4	36.6	+10.2	38.6
Muscat of Hamburg	27.6	38.4	+10.8	40.0

The results of the analysis showed (Table 5, Fig. 6) that among the studied grape varieties, Hamburg Muscat, Kyzyl raisin, White Chasselas, and Agadai have the highest PE activity.

During long-term refrigerated storage of grapes, a change in pectin substances also occurs. It has been established that among the studied varieties, pectin substances are largely characteristic of red grape varieties.

5. 4. Change in the content of pectin substances in grape varieties during storage with weekly fumigation with sulfur dioxide

The change in the content of pectin substances in grape varieties during storage using weekly fumigation with sulfur dioxide is shown in Table 6.

5. 5. Changes in the activity of oxidoreductases of grape varieties after long-term storage during their sale

Changes in the activity of oxidoreductases of grape varieties after long-term storage using weekly fumigation with sulfur dioxide during their sale are given in Table 7.

Table 6

Change in the content of pectin substances in grape varieties during storage using weekly fumigation with sulfur dioxide (% of wet weight)

Biochemical indicators	Water-soluble pectin				Protopectin				Total pectin			
	Before storage	After storage	difference		Before storage	After storage	difference		Before storage	After storage	difference	
			unit	%			unit	%			unit	%
Tabrizi	0.12	0.07	–0.05	41.7	0.13	0.06	–0.07	53.8	0.25	0.13	–0.12	48.0
Karaburnu	0.11	0.06	–0.05	45.5	0.15	0.08	–0.07	46.7	0.25	0.14	–0.12	46.1
Chasselas white	0.13	0.07	–0.05	46.1	0.14	0.05	–0.08	57.1	0.27	0.13	–0.14	51.8
Agadai	0.12	0.07	–0.05	41.7	0.15	0.06	–0.09	60.0	0.27	0.13	–0.14	51.8
Nimrang	0.13	0.10	–0.13	23.1	0.17	0.06	–0.02	11.8	0.30	0.25	–0.05	16.7
Marandi Shamakhi	0.10	0.09	– 0.01	10.0	0.18	0.15	–0.01	5.5	0.28	0.25	–0.02	7.1
Taifi pink	0.13	0.09	–0.04	30.8	0.19	0.17	–0.08	42.1	0.32	0.20	–0.12	37.5
Kyzyl raisins	0.15	0.09	–0.06	40.0	0.20	0.06	–0.14	70.0	0.35	0.15	–0.20	57.1
Muscat of Hamburg	0.16	0.09	–0.07	43.7	0.20	0.05	–0.15	75.0	0.36	0.14	–0.22	61.1

Table 7

Changes in the activity of oxidoreductases of grape varieties after long-term storage using weekly fumigation with sulfur dioxide during their sale

Grape sort	Ascorbate oxidase				O-diphenol oxidase				Peroxidase				Catalase			
	Before storage	After storage	difference		Before storage	After storage	difference		Before storage	After storage	difference		Before storage	After storage	difference	
			unit	%			unit	%			unit	unit			unit	%
Tabrizi	0.17	0.21	+0.03	17.6	0.33	0.39	+0.06	18.2	0.80	0.96	+0.16	20.0	0.10	0.12	+0.02	20.0
Karaburnu	0.20	0.23	+0.03	15.0	0.30	0.35	+0.05	16.7	0.87	1.01	+0.14	16.1	0.10	0.12	+0.02	2 0.0
Chasselas white	0.25	0.31	+0.05	19.2	0.34	0.41	+0.07	20.6	1.1	1.47	+0.26	21.5	0.14	0.17	+0.03	21.4
Agadai	0.22	0.25	+0.04	18.2	0.32	0.39	+0.07	21.9	1.01	1.25	+0.24	23.8	0.12	0.15	+0.03	25.0
Nimrang	0.10	0.11	+0.01	10.0	0.16	0.18	+0.02	12.5	0.66	0.72	+0.06	9.1	0.08	0.09	+0.01	12.5
Marandi Shama-Kha	0.05	0.5	0	0	0.10	0.10	0	0	0.34	0.35	+0.01	2.9	0.05	0.05	0	0
Taifi pink	0.16	0.18	+0.02	12.5	0.20	0.23	+0.03	15.0	0.78	0.86	+0.08	10.3	0.10	0.11	+0.01	12.5
Kyzyl raisins	0.34	0.44	+0.10	29.4	0.56	0.72	+0.16	28.6	1.32	1.65	+0.33	25.2	0.20	0.25	+0.05	25.0
Muscat of Hamburg	0.50	0.64	+0.14	28.0	0.58	0.75	+0.17	29.3	1.54	1.92	+0.38	24.7	0.30	0.37	+0.07	23.3

An increase in the activity of these enzymes is significantly observed in white (15–25.0 **%**) and red (23.3–29.4 **%**) grape varieties.

6. Discussion of results from determining the biochemical quality indicators of grapes during long-term storage

The results of studies on changes in the biochemical parameters of ripened table grape varieties during long-term refrigerated storage using weekly fumigation with sulfur dioxide are displayed in Tables 1–7 and Fig. 1–5. From the data in Table 1, in the studied white, pink, and red grape varieties, the catalytic activity of ascorbate oxidase, o-diphenoloxidase, peroxidase and catalase decreases markedly during the storage period. Peroxidase is the most active in all grape varieties. The second place is occupied by o-diphenol oxidase, followed by ascorbate oxidase. Catalase has the least activity. This pattern in the activity of these oxidoreductases persists throughout the entire storage period of grapes.

Analysis of the research results (Table 1, Fig. 1, 2) reveals that in white grape varieties, the catalytic activity of oxidoreductases is significantly reduced in the Tabrizi variety (by 57.1÷73.6 %) and Karaburnu (by 58.3÷74.0 %). To a lesser extent, this decrease is noticeable in the Chasselas white variety (by 50.0÷58.8 %) and Agadai (by 54.3÷60.0 %).

During the storage period of pink grape varieties, a noticeable decrease in the catalytic activity of oxidoreductases was also observed. To the greatest extent, this decrease occurs in the Marandi Shamakhi variety (by 85.7–91.7 %) and in Nimrang (from 64.9 to 84.4 %). In the Taifi pink variety, the decrease in activity does not exceed 73.7 % (Table 1, Fig. 3).

In red grape varieties, as studies have shown, there is a more moderate and gradual decrease in the catalytic activity of the studied oxidoreductases. Their change ranges from 25.0 to 44.4 % (Table 1, Fig. 4).

Fig. 5 shows that the greatest decrease in the activity of the studied oxidoreductases of ripened table grape varieties, at the end of long-term refrigerated storage, is demonstrated by Marandi Shamakhi, then Nimrang, Taifi pink, Tabrizi, and Karaburnu. The smallest decrease was found in the varieties Agadai, Chasla white, Kyzyl raisin, and Hamburg Muscat.

Among the studied grape varieties, during storage in the refrigerator with weekly fumigation with sulfur dioxide, the greatest decrease in the catalytic activity of these oxidoreductases is demonstrated by Tabrizi, Karaburnu, Nimrang, Taifi pink, especially Marandi Shamakhi (Fig. 1, 2).

Data on the content and changes during storage of basic monosaccharides, phenolic substances, organic acids, ascorbic acid, total and active acidity, free and total sulfite acid are given in Tables 2–4. It has been established that long-term storage of grapes using weekly fumigation with sulfur dioxide (Table 2) leads to a decrease in the content of glucose and fructose. Thus, in the Tabrizi variety, by the end of storage the amount of glucose decreases by 7.4 %, and fructose by 8.2 %. In Karaburnu, this figure is 7.7 % and 6.4 %, in Chaslet white – 9.6 % and 16.5 %, and in Agadai – 11.6 % and 10.2 %, respectively. It was revealed that the content of glucose and fructose changes to a lesser extent in the Tabrizi and Karaburnu varieties.

As studies have shown, pink grape varieties are the least susceptible to changes in glucose and fructose content (Table 3). Data in the Table shows that when storing grapes in the refrigerator, in the Marandi Shamakhi variety the decrease in glucose is 4.6 % and fructose is 2.8 %. In the Nimrang variety, the glucose content decreases by 5.7 % and fructose by 6.1 %. In the Taifi variety, pink – by 7.6 % and 8.3 %, respectively.

The greatest reduction in the amounts of glucose and fructose during the period of storing grapes in the refrigerator with the treatment of weekly fumigation with sulfur dioxide is observed in red grape varieties (Table 4). Thus, the amount of glucose and fructose decreases in the Kyzyl raisin variety by 18.0 % and 21.5 %, and in the Hamburg Muscat variety by 22.0 % and 23.2 %, respectively.

The ratio of the amount of glucose and fructose during storage changes and ranges from 0.80–1.20. The maximum increase in this indicator relative to the initial level at the end of storage is observed in the Shasla white and Kyzyl raisin varieties. In the varieties Marandi Shamakhi, Nimrang, Tabrizi, and Karaburnu, this change is insignificant.

Despite the reduction in invert sugar, these grape varieties still taste sweet at the end of storage. This fact is explained by the fact that in these varieties glucose is reduced to a greater extent and fructose is reduced to a lesser extent, and as is known, fructose is almost 2 times sweeter than glucose.

Research suggests that for storage it is desirable to use grape varieties in which at the stage of technical maturity the ratio of glucose to fructose would be less than one. These data confirm that this technique of storing grapes does not cause changes in the taste of sweetness in the Tabrizi, Karaburnu, Nimrang, and Marandi Shamakhi varieties.

Analysis of the data allows us to conclude that during the storage of all grape varieties, there is a continuous decrease in the content of sugars and organic acids. It was found that of the studied varieties, the greatest loss of sugars and acids after storage was observed in red varieties. The Muskat of Hamburg has 19.8 % sugar and 23.1 % acid while Kyzyl raisins have 22.6 % and 25.4 %, respectively. This is also observed in white varieties: Chasselas white (12.8 % and 19.4 %) and Agadai (10.9 % and 16.9 %), respectively. To a lesser extent, these indicators decrease in other grape varieties (Tabrizi – 7.8 % and 12.5 %; Karaburnu – 5.9 % and 13.5 %; Marandi Shamakhi – 3.6 % and 6.1 %; Nimrang – 5.9 % and 8.8 %; Taifi pink – 8.6 % and 12.1 %), respectively.

It is also important to note the limitations of our study. The analysis revealed that the studied varieties consume organic acids more rapidly during storage. This is explained by the fact that organic acids are more oxidizable compounds than sugars. Therefore, at low temperatures and fumigation with sulfur dioxide, which hinders the involvement of oxygen in respiratory gas exchange, they are more easily oxidized. In addition, as research has established, grapes consume less molecular oxygen, and therefore most of the organic acids are used for their respiration.

The above is in good agreement with the data on changes in the content of all organic acids studied. The most noticeable decrease in the amounts of citric, succinic, and oxalic acids in all grape varieties is at the end of storage. The oxidation of tartaric and malic acids ceases both during respiration and as a result of decarboxylation, during which decomposition occurs with the release of carbon dioxide.

The role of these compounds as energy material for the respiratory process in the di- and tricarboxylic acid cycle is extremely important. When storing grapes, the content of titratable acids in all grape varieties decreases mainly due to their consumption for respiration. A decrease in the pH value indicates an increase in active acidity, i.e., a slight increase in the concentration of hydrogen ions. This phenomenon is apparently due to the unequal oxidation of different grape acids during respiration. In this case, in all likelihood, stronger acids are formed, which, through greater dissociation, contribute to an increase in the concentration of hydrogen ions.

Research data allows us to conclude that during the storage of grapes using weekly fumigation with sulfur dioxide, phenolic substances and ascorbic acid are oxidized at the highest rate. The reaction of phenol oxidase oxidation of polyphenols to quinones and the conversion of ascorbic acid to dehydroascorbic acid by ascorbate oxidase occupies an intermediate position. The content of phenolic substances in white grape varieties decreases noticeably at the end of storage. On average, this change in the Chasselas white variety is 40.0 %, and in the Agadai variety – 33.3 %. These shifts are somewhat reduced in the Tabrizi and Karaburnu varieties (Table 2). In pink and red grape varieties, the decrease in the content of phenolic substances is less pronounced than in white ones.

Therefore, among the studied varieties, during the storage period the catalytic activity of ortho-diphenoloxidase decreases significantly in red and pink grape varieties. Data indicate a change in ascorbic acid content, especially in the first three months of storage. It was revealed that the vitamin C content in pink varieties decreases to a lesser extent than in other varieties. Thus, during the storage period the amount of vitamin C in the Marandi Shamakhi, Nimrang, and Taifa pink varieties decreases by 26.0–43.5 %, while in white and red grape varieties the decrease is 75.0–83.8 %, respectively.

Analysis of the above materials reveals that long-term storage of grapes in the refrigerator with weekly fumigation with anhydride causes a decrease in the catalytic activity of ascorbate oxidase in pink and red varieties to a greater extent than in white ones. According to the study, the amount of ascorbic acid gradually decreases during the storage of grapes in the refrigerator. This is more pronounced in white and red grape varieties. At the same time, it was revealed that pink and red grape varieties are richer in ascorbic acid than white ones.

As is known, sulfur dioxide partially diffuses into the berries and, therefore, enters the human body upon consumption. Therefore, in our studies, we determined the content of sulfur dioxide in grapes depending on the method of storing them in the refrigerator. Tables 2–4 demonstrate that by the end of storage, the content of total and free sulfurous acids in all grape varieties does not exceed 1.8 mg/100 cm^3, which is significantly lower than the standards allowed by health authorities for desulphated products.

It has also been established that Marandi Shamakhi, Nimrang, and Karaburnu have almost no PE activity. It is important to note that during the initial period of storage of Hamburg Muscat, Kyzyl raisin, White Chasselas, and Agadai, the activity of pectinesterase in them gradually decreases, and after 2–3 months of storage, the activity gradually recovered (Table 5, Fig. 6). As a result, pectic acid and methanol accumulate in the berries due to the breakdown of water-soluble pectin, which leads to softening and loss of taste of the grape berries.

During long-term refrigerated storage of grapes, a change in pectin substances also occurs. It was established that among the studied varieties, pectin substances are largely characteristic of red grape varieties (Hamburg Muscat and Kyzyl raisin) (Table 6).

It was revealed that with long-term refrigerated storage using weekly fumigation, the content of pectin substances in all grape varieties decreases. The amounts of pectin (including water-soluble pectin and protopectin) in berries at the end of storage decreases more noticeably in the varieties Kyzyl raisin, Hamburg Muscat, Agadai, and Chasla white (by 52.0–61.1 %). This appears to a lesser extent in pink varieties (Marandi Shamakhi, Taifi pink, and Nimrang). There is also a decrease in pectin substances in white varieties (Tabrizi and Karaburnu – by 7.1–46.1 %). A slight change in pectin substances in the above-mentioned grape varieties ensures that their berries do not lose their original freshness and are slightly susceptible to microbiological spoilage.

As mentioned earlier, when storing grapes in the refrigerator with daily fumigation with sulfur dioxide, the activity of oxyreductases is significantly reduced. However, at the time of selling, some restoration of their catalytic activity is observed (Table 7). An increase in the activity of these enzymes is largely observed in white (15–25.0 %) and red (23.3–29.4 %) grape varieties. As a result, these grape varieties experience darkening of the berries during sale, and they lose their external (marketable) appearance. In pink varieties, the activity of oxireductases changes insignificantly (by 0–12 %), including almost unchanged in the Marandi Shamakhi variety. In this regard, pink grape varieties do not darken during their sale and, in terms of keeping quality, compare favorably with white and red varieties.

These results showed that grape varieties grown in Azerbaijan are enriched with a variety of bioactive components that provide significant health benefits and can be used for future crop improvement as well as breeding programs.

The varieties studied here provided unique information about the terroir of Azerbaijan, which is scarce in the scientific literature.

The value of this study is as follows:

– the results of the study provide information on the effect of storing grapes using sulfur dioxide on its biochemical properties. This helps optimize the conditions for storing and transporting grapes to increase their shelf life and maintain quality;

– choosing varieties with high shelf life can reduce product losses and increase its commercial value, which is important for agricultural enterprises and grape producers;

– the use of grapes with high shelf life as a functional food ingredient can contribute to the creation of products with increased nutritional value, which is important for a healthy diet;

– the study of the biochemical properties of domestic grape varieties has practical, economic, and medical value, and can also become a starting point for various further studies and practical applications in agriculture.

The disadvantage is that the study identified limitations associated with the use and fixation of sulfur dioxide. With good fumigation, the grapes become pale, quite soft, easily crushed, and have a noticeable smell of sulfur dioxide. To quickly free the chamber from sulfur dioxide, it is recommended to use a fan that turns on after the end of fumigation. When the ventilation is over, you can enter the chamber but be sure to wear a gas mask since sulfur dioxide remains for a long time in the lower part of the chamber, between the boxes and between the berries in the boxes. Fumigated berries in boxes are taken out of the chamber and sent for storage. In addition, the doses of specified sulfur dioxide are approximate, and the fumigation technique cannot be mechanized or automated.

The features of the proposed method and the results obtained in comparison with those reported in [20–22] are that changes in the biochemical parameters of 9 varieties of white, red, and pink grapes were studied before planting and after storage. Changes in the activity of pectinesterase, changes in the content of pectin substances, changes in the activity of oxidoreductases during long-term refrigerated storage with weekly fumigation with sulfur dioxide during their sale were studied.

Unlike [12], in which table grape varieties (6 varieties) were stored in a refrigeration chamber under controlled gas conditions before storage, during storage, after storage, the study examined changes in the biochemical parameters of 9 varieties of white, red, and pink grapes before storage and after storage.

In the future, it is possible to continue research to determine technological regimes that allow for the most complete preservation of the nutrients of raw materials.

7. Conclusions

1. Long-term refrigerated storage of grapes using weekly fumigation with sulfur dioxide is accompanied by a decrease in the activity of oxidoreductases (ascorbate oxidase, o-diphenoloxidase, peroxidase and catalase) and a gradual increase in the activity of pectinesterase. This causes changes in the quantity and proportions of nutrients (glucose, fructose, ascorbic acid, vitamins, organic acids) and other chemical components that determine the nutritional and biological value of the final product.

2. It has been established that during the storage of grapes, metabolism continues in them. In berries, the catalytic activity of ascorbate oxidase, o-diphenoloxidase, peroxidase, catalase, and pectinesterase changes. There is a quantitative change in the content of glucose, fructose, vitamin C, phenolic and pectin substances, organic acids (tartaric, malic, citric, etc.), the pH value and other ingredients. When storing grapes using weekly fumigation with sulfur dioxide, the catalytic activity of enzymes contributes to a more intense reduction in metabolic processes. This favors less oxidation of carbohydrates, organic acids, phenolic and pectin substances, which determine the nutritional and biological value of grapes. Shifts in the quality indicators of grapes depend on many factors: varietal characteristics, environmental conditions, harvest time, the presence of microorganisms on the surface of the berries, the specificity of enzymes, storage conditions and duration.

3. The change in the activity of pectolytic enzymes in grapes under various methods of long-term storage was studied using pectin esterase (PE) as an example. The results of our analysis revealed that among the studied grape varieties, Hamburg Muscat, Kyzyl raisin, White Chasselas, and Agadai have the highest PE activity.

4. During long-term refrigerated storage of grapes, a change in pectin substances also occurs. It has been established that among the studied varieties, pectin substances are largely characteristic of red grape varieties (Hamburg Muscat and Kyzyl raisin).

5. It was determined that during the sale of ripe grapes stored using weekly fumigation with sulfur dioxide, the activity of the studied oxyreductases is slightly restored in pink varieties – Nimrang, Taifi pink, and in white varieties – in Karaburnu and Tabrizi. In the Marandi Shamakhi variety, the activity of enzymes does not change, therefore, for a long time in these grape varieties, especially in the Marandi Shamakhi variety, darkening and softening of the berries are not observed during their sale. Thus, among the studied table grape varieties, Tabrizi, Karaburnu, Nimrang, and Marandi Shamakhi, when subjected to long-term refrigerated storage using weekly fumigation with sulfur dioxide, have the longest shelf life. They have the potential for use in both processing and breeding programs as a functional food ingredient.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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