Study of the influence of ionized fruit air

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Abstract. The article presents the results of studying the process of storage of grapes in a fruit storage, identifies the main factors affecting the quality of storage of the product. The mechanism of the effect of ionized air on the stored product is considered and fruit storage modes are determined. The results of studies show the possibilities of determining the operating modes of ionization of fruit storage air.

1. Introduction
Studies on the long-term storage of fruits and grapes by ionization of the air were carried out both in the near abroad as Moldova, Belarus, Georgia, Bulgaria, and in our Republic [1, 2, 3, 4, 5, 6]. Long-term storage technology is being developed taking into account the biological characteristics of the product. For example, when storing grapes in wooden boxes, they should receive air, the released humidity and heat should freely go outside and also the amount of loss of moisture and dry matter should be minimal. When ionizing the air of fruit storages, first of all, air ions must be distributed evenly, ions must reach each product, only then the stored product must be stored for a long time qualitatively [7, 8, 9]. The fruit storage air must be periodically ionized according to a certain mode.

2. Research Methodology
Studies of the process of long-term fruit and grapes are carried out in refrigerated storage chambers with a capacity of 30 and 50 tons and in storage with natural storage conditions with a capacity of 10 tons. For each option, 10 m³ of the volume is allocated, where 50 kg of product is laid. To obtain reliable results, the experimental and control variants are carried out fivefold [10, 11]. Corona discharge ionizers with tip electrodes were installed in the experimental chambers. The air is ionized periodically, with negative ions, with different modes, with a maximum concentration of space charges of $5 \times 10^{13}$ ion / m³. The object of the study is chosen from the Toyfi Pink grape grown in the Syrdarya district of the Syrdarya region and the Kibray district of the Tashkent region. The product is laid in wooden boxes with dimensions of 580x420x120 mm, in one row at an angle of 50°–60°. For storage, the grapes are harvested only by hand with scissors and the same day is laid on pre-cooling chambers. After cooling the product to a temperature of zero degrees, it is laid on the main camera for long-term storage. Toifi Pink grapes in the conditions of Uzbekistan ripen at the end of September and were distinguished by high keeping quality [12]. Well-ripened grapes contain a sufficient amount of sugar and dry substances and were well stored for up to 3-5 months [13, 14, 15].

The studies have 8 experimental and 2 control options. For each option, 500 kg of grapes were selected. The experiments were carried out according to the experimental design. For experiments, the temperature 0 ° C, relative humidity 90%, and when stored under natural conditions, temperature 10 ° C.
C, relative humidity 70-80%, were selected for experiments. In studies, the volume concentration of ions was measured by an ion counter of the AIS type [16, 17], and was also monitored by the ion current of the measuring probe. The results of the experiments are determined by the appearance of commodity and chemical-biological indicators of the product.

The dose of product treatment, i.e. the volume concentration of air ions and the duration of ionization are established so that the natural qualitative indicators of the product are preserved and the pathogenic microorganisms are completely destroyed. Grapes are often affected by the bacteria Pensillium glaucum and Botrgtis cinerea [18]. At the same time, Botrgtis cinerea bacteria can infect grapes in bushes and storages, and Pensillium glaucum bacteria can infect grapevine only during storage. Therefore, in studies, the effect of the flow of ionized air at various values of ionization intensity on the survival of bacteria Pensillium glaucum and Botrgtis cinerea was studied, and the treatment dose increased until the complete destruction of microorganisms [19]. In studies, microbiological analyzes with the determination of bacterial survival were carried out jointly with the Tashkent State Agrarian University, Department of Biochemistry and the Scientific and Production Association of Horticulture, Viticulture, and Winemaking named after M.M. Mirzaev.

From the experiments, it is seen that during the treatment of bacteria Pensillium glaucum and Botrgtis cinerea with a concentration of air ions of 0.5 $10^{-12}$, their viability was significantly slowed down. And with air ionization with a volume concentration of ions of 0.5 $10^{-13}$, and the duration of air ionization for 1-1.5 hours or more, the bacteria Pensillium glaucum wa Botrgtis cinerea were completely destroyed (Figure. 1 and Table 1). In experimental variants, bacteria were infected artificially, placed in separate chambers, and treated with various doses. The volume concentration of ions changed from $10^{-12}$ to $10^{-14}$, lasting 0.5; 1, 1.5, 2 ... up to 4 hours. At the same time, a technique was adopted to study the vital functions of microorganisms in the food industry. Samples of grapes artificially affected by bacteria, after processing, were stored in similar storage conditions for 20 days. Treated with positive and negative ions.

In the studies, the following factors of product safety and operating parameters of ionization were monitored: air temperature, °C, contact thermometer and M-16 thermograph, relative humidity, two-thermometer psychrometer and recorded with the M-21 instrument, the voltage of discharge electrodes with a S-3 static kilovoltmeter, the volume concentration of air ions with an aspiration ion counter, ion/m³, processing time, hour. The bacterial samples Pensillium glaucum and Botrgtis cinerea were processed in various modes in a chamber with a volume of 0.5 m³. The volume concentration of air ions changed from $10^{-13}$ to $10^{-11}$ ion/m³ and processing time up to four hours.

| Table 1. Influence of the dose of electron-ion treatment and bacterial survival |
|---------------------------------|-------------------------------|
| Indicators                      | Measuring points |
| Processing time t,              | 0.5  1.0  1.5  2.0  2.5  3.0 |
| Bacterial survival,             | 0.75  0.5  0.42  0.3  0.28  0.26 |
| N, %                            | 0.8  0.65  0.55  0.4  0.37  0.36 |
| At 0.5 $\cdot 10^{13}$ ion $\cdot$ m$^{-3}$ |                          |
| At 0.5 $\cdot 10^{12}$ ion $\cdot$ m$^{-3}$ |                          |
Figure 1. Dependence of the dose of electron-ion treatment and the survival of bacteria Penicillium glaucum and Botrytis cinerea under cooling conditions, during air ionization with a volume concentration of air ions of $1 - 0.5 \cdot 10^{12}$ ion $\cdot$ m$^{-3}$; $2 - 0.5 \cdot 10^{13}$ ion $\cdot$ m$^{-3}$.

3. Conducting experimental research

Bacteria that affects on grapes during cultivation and storage, when it is processed with a volume concentration of air ions from $10^{12}$ to $10^{13}$ ion $\cdot$ m$^{-3}$, and processing times of up to four hours were completely destroyed [20]. At the same time, the metabolism from the surface of the product is still slowing, due to which the loss of moisture and dry nutrients of the stored product is reduced. The spread of diseases in parties laid for long-term storage is prevented. In experimental and control batches, physicochemical parameters and commodity-dietary qualities of the product were determined.

According to the results of preliminary studies, experiments on long-term storage of grapes were performed according to the following options:

- Under refrigerated storage conditions, at a temperature of 0 °C and relative humidity of 90%, ionization with a negative ion polarity, an integral concentration of air ions of $10^{12}$ ion $\cdot$ m$^{-3}$, once and twice, lasting 2 and 4 hours;

- The same modes of air ionization, only with positive ions;

- The same modes of ionization, only heated in storage, at a temperature of 10 °C and relative humidity of 70-80% ;

Storage chambers were loaded with the maximum ionization intensity before loading the products. In these modes, ozone is also formed, which together with ions sterilizes the internal volume of the storages. In the ready cameras for laying, they were loaded with grapes in batches, according to the plan of the experiment. For each option, five rows, ten rows in each row; in total, for each option, 50 product boxes were laid. In total, in experimental and control lots, 10 tons of grapes were put into the refrigerator for storage. So much in storage without cooling. Once a month, since January, the appearance was examined twice a month, organoleptic indicators were determined, and the absence of lesions was checked. Losses in mass were determined by weighing the boxes on the balance.

Storage chambers were ionized by electoral ionizers with tip electrodes [21]. Ionizers are equipped with fans and controlled the uniformity of ionization throughout the room. Control points of measurements of the air parameters of the storage are selected at a height of 0.5 from the floor; 1.0; 1.5 m, along the centerlines of the room. The temperature in the cooling conditions changed within the limits of $(0.7 – 0.8) ^{0}$C. The operation of the ionizer for 4 hours was not affected by the microclimate
parameters inside the storages. The modes of operation of the electric ionizer were regulated by changing the voltage across the potential electrode. Turning on and off according to the plan of the experiment automatically. The voltage at the tip electrodes varied within (4-5) kV, and the length of the discharge gap was 25 mm, while the volume concentration of air ions varied from $0.5 \times 10^{12}$ to $10^{13}$ ion / m$^3$. The volume concentration of air ions was measured using a portable counter of air ions by the aspiration method. In the studies, all the boxes were numbered, and the results of the experiments were recorded in a separate journal. Before storage, the weight of each box and the weight of the product in the box were determined. The ionizer was turned on manually and turned off automatically using a time relay. We also used a software time switch, which allows the automatic operation of the ionizer.

To identify the main factors of the storage process, we filled out a questionnaire survey of experienced professionals. They determined the ranks of factors; evaluated the influence of factors on storage results, for example, in percent. Experts also indicated their optimal values. Summarizing the results of a survey of experts identified the main factors in the process of storage of grapes. (Table 2).

| Table 2. A number of key factors in the process of storage of grapes |
|---------------------------|-----------------|-----------------|-----------------|
| Name of factor            | Symbol          | Unit of measurement | Change interval |
| Air temperature           | $X_1$           | °C               | -1...+4         |
| Relative humidity         | $X_2$           | %                | 85...92         |
| Volumetric concentration of air ions | $X_3$      | ion/m$^3$         | $10^{12}$...$10^{13}$ |
| Processing time           | $X_4$           | coat             | 2...6           |
| Air speed                 | $X_5$           | m/s              | 0.1             |
| Chemical composition of air | $X_6$       | %                |                 |
| Room lighting             | $X_7$           | lk               |                 |
| Grape harvesting technology | $X_8$       |                   |                 |

Analyzing the table materials, the main factors highlighted are the temperature and relative humidity of the air, the volume concentration of air ions, and processing time (Table 3). It should also be noted that the air flow rate should be minimal, so that moisture loss is minimal, the light sources must be turned off they were included only during inspections. For storage is laid a well-ripened grape grown in dry soil, a standard product, hand-picked in high quality.

When compiling a table of the main factors, the relative humidity is removed, because it is dependent on air temperature. The possible limit of variation of each factor and the investigated interval of variation of the parameters were determined. The unaccounted parameters remained the same in the experimental and control variants.

| Table 3. Key Factors Table |
|---------------------------|-----------------|-----------------|-----------------|
| Name of factor            | Symbol          | Unit of measurement | Change interval |
| Volumetric concentration of air ions | $X_1$-n  | ion/m$^3$         | $10^{11}$...$10^{12}$ |
| Processing time           | $X_2$- $\tau$  | coat             | 1...8           |
| Air temperature           | $X_3$- $t$     | °C               | -2...+10        |

The air temperature in the cooled fruit storages was maintained at about zero degrees. Lowering the air temperature to -2 ... -5°C significantly reduces the metabolic processes of the product with the environment, however, while containing water in the cells begins to freeze and ice forms in the cells, which poses a risk of their destruction. An increase in air temperature to +2°C and higher leads to an
acceleration of metabolic processes and the release of moisture and warmth of respiration of the product. Grapes and many fruits are well stored at an air temperature of 0°C. In studies, the air temperature was 0°C and relative air humidity (90 ... 92) %, in storages with natural conditions the air temperature was (8 ... 10) °C, and relative humidity (75 ... 80) %.

With aero-ionic technology for long-term storage of fruits, the main factor is the volume concentration of air ions. As a result of the research, the optimal values of the volume concentration of air ions in the range of $10^{12} ... 10^{13}$ ion / m³ were determined. For the complete destruction of pathogens, the duration of ionization is 2-6 hours. With these parameters, the Toifi Pink grapes are well preserved from September 27 to March 30.

In industrial studies, electrical ionizers are mounted to the valves of the ventilation system, located in the upper part along the length of the room. The parameters of the technology of electro-ionic processing and storage, such as temperature, relative humidity, the volume concentration of air ions were controlled along the axial lines at the level of 0.5; 1.0; 1.5 meters from the floor. In this case, the room temperature varies from 0 °C to (0.7 - 0.8) °C. The duration of ionization is up to 6 hours. The operating parameters of the electric ionizer were regulated by the voltage of the discharge electrodes in the range of 4-6 kV. The design of the potential electrode and the discharge gap allows to obtain sufficient ionization of the air at a voltage of 4-6 kV. At the same time, a volume concentration of air ions is created on the surface of the product in the range $0.5 \times 10^{12}$ ion • m⁻³ - $10 \times 10^{13}$ ion • m⁻³. After the luggage room was fully loaded, the doors closed tightly. An electric ionizer with a fan was turned on. The premises were periodically ionized according to the experimental design according to the established regime (Table 4).

**Table 4. Experimental research matrix**

| $X_1$ | $X_2$ | $X_3$ | $X_4$ | Y |
|-------|-------|-------|-------|---|
| Code value | Actual value | Code value | Actual value | Code value | Actual value | % |
| +     | 0.5    | +     | 4     | +     | 10    | 76.5 |
| +     | 0.5    | -     | 2     | +     | 10    | 73.34 |
| -     | 0.1    | +     | 4     | +     | 10    | 74.24 |
| -     | 0.1    | -     | 2     | +     | 10    | 66.2  |
| +     | 0.5    | +     | 4     | -     | 0     | 89.25 |
| +     | 0.5    | -     | 2     | -     | 0     | 86.68 |
| -     | 0.1    | +     | 4     | -     | 0     | 87.1  |
| -     | 0.1    | -     | 2     | -     | 0     | 81.43 |

Electric technological processing was repeated from twice a week to once every two weeks. Before switching on, the ionizer externally examined the product, checked the absence of microbiological deterioration of the product. At the end of storage, the product in experimental and control versions was sorted, the quantity of the commercial product and losses were determined by weighing on an electronic balance. The chemical composition of grapes was determined in refrigerators and the storage of cooling bases. The average values of the research results for three years after 150 days of storage are shown in table 5.

**4. Research result**

During prolonged storage of grapes, the air was ionized with positive and negative ions. As the results of the research, dry substances, the number of total sugars, titratable acid, pectin, and vitamins in the composition of grapes were determined. (Table 5).

The following factors were controlled:

- $X_1$ is the volume concentration of air ions, ion m⁻³;
- $X_2$ is the duration of ionization, hour;
- $X_3$ is the storage air temperature, °C;
- $X_4$ is the relative humidity, %
The grapes were laid for storage in wooden boxes. From the results of the studies it is seen that at the end of storage from the initial mass \((M)\), the product loses a significant amount of mass \((M1)\), part of the product goes into spoilage \((M2)\) and the rest remains as a commercial product \((M3)\), i.e. total laid down for storage has three components: \(M = M1 + M2 + M3\).

The research results showed that the best indicators were obtained with ionization of air with negative ions. Losses in the mass in the control variants were in the range of 6 – 6.5%, and in the control up to 10%. The best result was obtained in version 8, when the volume concentration of air ions was \(0.5 \times 10^{13}\) ion \(\cdot m^{-3}\), and the processing time was 4 hours, the storage air temperature was 0 °C and the relative humidity was 90% (Table 6).

Table 5. The average values of the results of studies on the long-term storage of Toyfi Pink grapes (the results are obtained after storage for 5 months)

| Options                  | Solid | Total sugar | Titrita soluble acid | Pectin substances | Vitamins mg.% |
|--------------------------|-------|-------------|----------------------|-------------------|---------------|
| Before storing           | 21.13 | 18.7        | 0.47                 | 1.18              | 1.9           |
| After storage, experience| 20.92 | 18.4        | 1.05                 | 0.79              | 0.95          |
|                          | 20.89 | 18.51       | 1.01                 | 0.86              | 0.98          |
|                          | 20.88 | 18.39       | 1.025                | 0.77              | 0.94          |
| After storage, control   | 20.3  | 17.9        | 1.1                  | 0.56              | 0.93          |

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Table 6. The average values of the results of studies on the long-term storage of grapes after 150 days of storage

| Options                  | Ionization Modes | Storage modes | Product yield at the end of storage, % |
|--------------------------|------------------|---------------|----------------------------------------|
|                          | X1, 10^{13} ion \(\cdot m^{-3}\) | X2, \(\circ C\) | X3, % | X4, % | Standard | Waste | Mass losses |
| Negative ionization air   | 0.5              | 2             | 10   | 75   | 72.2     | 27.8  | 8.9        |
|                          | 0.1              | 2             | 10   | 75   | 64.2     | 35.8  | 9.45       |
|                          | 0.5              | 4             | 10   | 75   | 77.5     | 22.5  | 8.5        |
|                          | 0.1              | 4             | 10   | 75   | 72.3     | 27.7  | 8.9        |
| Negative ionization air   | 0.5              | 2             | 0    | 90   | 79.6     | 20.4  | 6.85       |
|                          | 0.1              | 2             | 0    | 90   | 85.9     | 14.1  | 5.9        |
|                          | 0.5              | 4             | 0    | 90   | 85.5     | 14.5  | 5.9        |
|                          | 0.1              | 4             | 0    | 90   | 88.4     | 11.6  | 5.76       |
| Positive ionization air   | 0.5              | 2             | 0    | 90   | 78.4     | 21.6  | 6.4        |
|                          | 0.1              | 2             | 0    | 90   | 78.9     | 21.1  | 5.86       |
|                          | 0.5              | 4             | 0    | 90   | 72.15    | 27.85 | 6.5        |
|                          | 0.1              | 4             | 0    | 90   | 77.32    | 22.68 | 6.17       |
| The control              | -                | -             | 10   | 75   | 62.8     | 37.2  | 11.7       |
|                          | -                | -             | 10   | 75   | 64.5     | 35.5  | 10.34      |
|                          | -                | -             | 0    | 90   | 73.2     | 26.8  | 6.65       |
|                          | -                | -             | 0    | 90   | 70.7     | 29.3  | 6.48       |
There are materials in the literature to study the effect of the electrostatic field on the shelf life of the product [21, 22, 23]. To study the effect of electrostatic fields of various sizes on the preservation of grapes, studies were conducted. In this case, the potential electrode was located at a height of 0.35 m from the upper level of stacks of wooden boxes. In this case, the product located at the upper level will be under the electrostatic field strength $E = 25 \text{ kV/m}$, the product below the row will be under the electrostatic field strength equal to $E = 20 \text{ kV/m}$, the product located in the third row will be under the electrostatic field equal to $E = 15 \text{ kV/m}$, and so on. The results are shown in Table 7.

Control options were protected from the electrostatic field by a grounded electrode. The results showed that an electrostatic field with a strength of 10 to 25 kV/m does not affect the preservation of grapes (Table 7).

| Electrostatic field strength, E kV/m | Storage modes | Product yield at the end of storage, % |
|-------------------------------------|---------------|---------------------------------------|
|                                     | $X_3$, storage air temperature $^\circ \text{C}$ | $X_4$, relative humidity, $\%$ | Standard | Waste | Mass losses |
| 10                                  | 0             | 90                                     | 72.9     | 27.1  | 5.95        |
| 15                                  | 0             | 90                                     | 69.3     | 30.7  | 6.4         |
| 20                                  | 0             | 90                                     | 68.28    | 31.72 | 6.1         |
| 25                                  | 0             | 90                                     | 73.1     | 26.9  | 5.85        |
| The control                         | 0             | 90                                     | 72.4     | 27.6  | 6.05        |
| The control                         | 0             | 90                                     | 71.4     | 28.6  | 6.7         |

In further studies, grapes were stored for storage in various containers. At the same time, wooden, cardboard, and metal containers were used. The best results were obtained in wooden crates. Cardboard and metal containers do not meet the requirements of grape storage technology (8-table). In further studies, experiments were carried out in wooden containers. The experimental studies were carried out according to the full three-factor experimental design (matrix). All results are obtained as the average of five replicates. In Table X1, X2, X3 the factors of the experiments, and at the end of storage in percent (Y) determined the yield of the product, as well as waste and mass loss. The quality of the commercial product is determined by tasting a five-point system. The obtained research results were the basis for determining the possibilities of using electric ionizers in long-term storage technology and establishing optimal product storage conditions. For free penetration of the space charge between the boxes into the stack, wooden boxes at the edges have projections of 40 ... 60 mm.

| Options          | Ionization modes | Storage modes | Product yield at the end of storage, % |
|------------------|------------------|---------------|---------------------------------------|
|                  | Ion Concentration, $10^{13}$ ion m$^{-3}$ | Duration, hour | Air temperature $^\circ \text{C}$ | Humidity $\%$ | Standard | Waste | Mass Losses |
| Wooden boxes     | 0.5              | 2             | 0                                      | 90                  | 87.8     | 12.7  | 5.88       |
| Carton boxes     | 0.5              | 2             | 0                                      | 90                  | 81.85    | 18.15 | 6.2        |
| Metal container  | 0.5              | 2             | 0                                      | 90                  | 72.2     | 27.8  | 8.45       |
The upper boxes abut against them. Thus, an air space of 60 mm is left between the rows of drawers. To remove moisture and heat, as well as to penetrate the space charge to the lower parts of the stack.

Statistics of process and analysis of research results. All values of the operational parameters of the table were monitored and the research results were analyzed. Commodity and dietary indicators were evaluated according to a five-point system by tasting the experimental and control lots (9-table). The variance of the results is defined as the average value of row variances:

$$S_2 = \frac{1}{N} \cdot \sum_{i=1}^{N} S_2^N$$

(1)

According to table 6, the average value of row variances is: $S_2^N = 11.48$. The uniqueness of the values of row dispersions is determined by the Cochren criterion [10]. To do this, calculate the following expression:

$$U_{max} = \frac{S_2^N \cdot \max}{\sum_{i=1}^{N} S_2^N}$$

(2)

With the degrees of freedom of the numerator and denominator, the formulas are respectively equal: $f_{numerator} = n - 1$, $f_{denominator} = N$, and with the degree of reliability of the results $\alpha = 0.05$, we calculate the variance and compare it with the critical values. Since in all the series $U_{max} < U_{(tabl)}$, we accept the results as reliable. Statistically processing the research results for the long-term storage process, we obtain the regression equation of the following form:

$$y = 79 + a_1 \cdot x_1 + a_2 \cdot x_2 - a_3 \cdot x_1 \cdot x_1' + a_12 \cdot x_1' \cdot x_2 + a_13 \cdot x_1' + a_23 \cdot x_3' + a_23 \cdot x_2' + a_23 \cdot x_3'$$

(3)

| Options                  | Storage modes | Storage Results,% | Degustation assessment |
|--------------------------|---------------|-------------------|------------------------|
|                          |                | n, ion/m³ | τ, time | t, °C | Commodity Product | waste | Mass losses |                        |
| In vivo air ionization    | 0.5·10¹³      | 10       | 0       | 90   | 89.1              | 10.9   | 5.46        |                        |
|                          |               | 2        | 0       | 90   | 85.6              | 14.4   | 6.1         |                        |
|                          |               | 0        | 0       | 90   | 70.2              | 29.8   | 9.7         |                        |
| Metal container          |               | -        | -       | 0    | 74.3              | 25.7   | 6.3         |                        |
| Carton                   |               | -        | -       | 0    | 71.25             | 28.75  | 6.8         |                        |
| Wooden boxes carton      |               | -        | -       | 0    | 71.62             | 28.38  | 10.3        |                        |
| Metal container wooden   |               | -        | -       | 0    | 71.5              | 28.4   | 9.1         |                        |
| Metal container carton   |               | -        | -       | 0    | 73.82             | 26.18  | 8.41        |                        |
| Metal container carton   |               | -        | -       | 0    | 74.54             | 25.46  | 8.25        |                        |

Table 9. The results of storage of grapes in ionized air
Having calculated all the coefficients of the regression equation, we obtain the following equation:

\[ y = 79 + 2.44 x_1 + 2.34 x_2 - 6.4 x_3 - 0.7 x_1^2 + 0.2 x_2^2 + 0.68 x_3^2 + 0.3 x_1 x_2 + x_3 \]

The coefficients of the regression equation (4) are determined from the following expression:

\[ a_{ij} = \frac{1}{N} \sum_{t=1}^{N} x_{ij}^t \cdot y_{ij}^{\frac{N}{2}} \]  

where: \( x_{ij} \) is the code value of the factor.

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To determine the significance of the coefficients of the regression equation, we use Student's criterion (t), while for each coefficient we calculate the following relations:

\[ t_i = \frac{a_i}{S_{[a_i]}} \]
\[ S_{[a_i]} = \frac{1}{N} \sum_{i=1}^{N} S^2_{y[a_i]} \]

where: \( S_{[a_i]} \) is the geometric mean value of row dispersions;

From the data of the table of values of the criterion \( t_i \), we determine for the degree of reliability of the results \( \alpha = 0.05 \) and for the degree of freedom \( f = N(n-1) \).

For the accuracy of the coefficients of the regression equation should be:

\[ t \text{ (estimated)} > t \text{ (tabular)} \]

Checking for the certainty of reliability we obtain the final regression equation:

\[ Y = 79 + 2.44x_1 + 2.34x_2 - 6.4x_3 \]

The variance of the adequacy of the obtained regression equation is determined from the following expression [11]:

\[ S_{ad[y]} = \frac{n}{N-d} \sum_{i=1}^{N} (Y_i - Y_N)^2 \]

| Options | Solids, % | General sugars, % | Titratable acid, % | Pectin substances, % | Vitamin C, mg % |
|---------|-----------|-------------------|--------------------|----------------------|-----------------|
| Before storage | 21.13 | 18.7 | 0.47 | 1.18 | 1.9 |
| At the end of storage with air ionization | 20.92 | 18.4 | 1.05 | 0.79 | 0.95 |
| The control | 20.3 | 17.9 | 1.1 | 0.56 | 0.93 |

The best results were obtained with air ionization with an ion concentration of \( n = 0.5 \cdot 10^{13} \text{ion/m}^3 \) and with a treatment time of 4 hours, while the yield of a commercial product was 90.3%, and the waste was 9.7%. For clarity of the results of storage, we use a graph of the dependence of the storage result (y) on the processing intensity (x). At the same time, on the abscissa axis, we postpone the impact complex of electrotechnological processing as the treatment dose \( (n \cdot t) \), on the ordinate axis, we postpone the yield of the product (y). As you can see from the graph \( y = f (n \cdot t) \) with increasing volume.
Figure 2. Dependence of the yield of commercial product at the end of storage on the dose of grape processing

As you can see from the graph $y = f(n \cdot t)$ with increasing volume the concentration of air ions and the duration of processing the yield of a marketable product increases, but to a certain limit, and with a further increase in the dose of treatment, the quantity of yield of a marketable product remains unchanged. After 5 months of storage, the best yield option for a commercial product remains at 90%. In control variants, without ionization – 70%.

5. Conclusions
1. Based on the research results, a mathematical model of the process of storage of grapes with air ionization for cooled fruit storages was obtained. The direct proportional dependence of storage efficiency on the volume concentration of air ions and the duration of the processing of the product is determined.
2. The volumetric concentration of air ions in the storage was determined based on the complete suppression of microorganisms, for example, the bacteria Pensillium glaucum and Botrgtis cinerea were completely destroyed within the concentration of air ions from $0.5 \times 10^{12}$ to $10^{13}$ ion/m$^3$, both during cooling and without cooling of the storage.
3. The results showed that an electrostatic field with a strength of 10 to 25 kV/m does not affect the storage of grapes. When storing grapes in various containers, the best results were obtained in wooden boxes. Cardboard and metal containers do not meet the requirements of the technology for long-term storage of grapes.
4. The best results were obtained during the storage of Toifi Pink grapes under cooling conditions, during ionization of air with a volume concentration of air ions $n = 0.5 \times 10^{13}$ion / m$^3$ and with a processing time of 4 hours, while the yield of a commercial product was 90.3%, and the waste 9.7%.

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