Magnetic Treatment of Sugar Beet to Reduce Weight Loss during Storage

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Abstract. Sugar beets are grown for sugar production. After harvesting, sugar beets are placed in closed storage for long-term storage. The main purpose of storage is to preserve sugar as much as possible in order to further ensure the profitability of processing beets for sugar. However, during storage of sugar beets, there is a rapid loss of moisture and weight. Beets, which have a weight loss of 13 ... 17%, lose 5 times more sugar during storage than beets of good quality. One way to reduce the weight loss of sugar beet tubers is to use the magnetic field of a neodymium permanent magnet. Experimental studies on the treatment of sugar beet tubers with a magnetic field showed that the minimum weight loss of sugar beet tubers when treated with a negative magnetic field reached 15.3%, the minimum weight loss of sugar beet tubers when treated with a positive magnetic field reached 17.6%, and the weight loss of tubers sugar beet, not treated with a magnetic field, reached 25.6%. Thus, the nature of the influence of the magnetic field of a permanent neodymium magnet of positive and negative polarity on the weight loss of sugar beet tubers has been established.

1. Introduction
Sugar beet is a plant whose root contains a high concentration of sucrose and is grown commercially for sugar production. After harvesting, sugar beets are placed in closed storage for long-term storage. The main purpose of storage is to preserve sugar as much as possible in order to further ensure the profitability of processing beets for sugar. In the Russian Federation, there are only two ways of storing sugar beets – storage in sides and cages. In the process of storing sugar beets, to increase sugar production, it is necessary to reduce the weight loss of beets and sugar at the stage of storing root crops and maintain high technological qualities of beet raw materials supplied to the plant for processing, in accordance with state quality standards for beet raw materials [1–2].

Optimal storage conditions for beets are: temperature of 0 ... 2 °C, relative humidity of 90...95 %, carbon dioxide content of 0.18...0.20 % and oxygen content of 18 ... 20 % [3–4].

When storing sugar beet with violations of optimal storage conditions, especially in the warm season, there is a rapid loss of moisture and weight-wilting. Withering of root crops negatively affects the course of the life process, the physiological state, the chemical composition, and the resistance to microbial damage. The loss of 10% of weight during wilting leads to a decrease in the content of dry substances by 1.1 %, the amount of reducing substances increases by 10 ... 25 % compared to their original content. When wilting, accompanied by the loss of 10% of the mass of root crops, the sugar content in molasses
increases by 0.06%. Beets that have withered by 13 ... 17% lose 5 times more sugar during storage than beets of good quality, and the number of root crops affected by kagat rot reaches 60% [5–7].

In the initial period of storage, beets breathe intensively, therefore, forced ventilation is used in kagats, which is carried out with air humidification. To improve the quality of storage, ventilation with an air-ammonia mixture is also used. However, such ventilation methods are very expensive, since they require a large number of electric motors, fans, air ducts and high-precision sensors to monitor the air parameters in storage facilities [8–9].

Currently, a promising direction for storing beets is the use of various biostimulants that are part of plants and have a natural form of origin. Being in plants in small quantities, they regulate their growth and development, accelerate or slow down the ripening period, enhance the synthesis of plastic substances, including sucrose, and also provide better preservation of plant materials during long-term storage. They are environmentally friendly, safe for humans and the environment. However, such biostimulants are expensive and their use in the storage of sugar beets can be unprofitable [10–11].

There is evidence that in many countries studies are being carried out to study the effects of electric and magnetic fields, as well as ozone, on the conservation of various plants such as potatoes, carrots and onions [12–14]. Preliminary research results show that treatment with electric, magnetic fields or ozone can reduce the weight loss of various plants during storage, as well as reduce the cost of energy resources during storage [15–17]. The purpose of the experimental studies in this article was to study the nature of the influence of the magnetic field of a permanent neodymium magnet on the weight loss of sugar beet.

2. Materials and methods

When conducting experimental studies, standard well-known research methods were used - the method of multivariate experiment, statistical analysis and determination of adequacy. The following devices were used for measurements: high-precision electronic scales, devices for measuring the parameters of permanent magnetic fields – magnetic induction and magnetic field strength, devices for measuring temperature and humidity. The measuring instruments used in the experiment are certified in the Russian Federation. The effectiveness of the treatment was assessed by the residual mass of sugar beet tubers [18–19].

The Rondo sugar beet variety was used for magnetic field treatment. The treatment was carried out by the magnetic field of a permanent neodymium magnet of negative polarity with a magnetic induction of 400 mT. Permanent magnets were placed in a rectangular container at the bottom. Sugar beet tubers weighing 3 kilograms for each sample were placed directly on magnets at the bottom of the container and kept for a period of time in accordance with the experiment plan. The experiment plan provided for the following processing options: 15 s, 30 s, 45 s, 60 s, 120 s, 180 s.

After processing, the beet tubers were placed in plastic bags for storage. Storage took place at a temperature of 20...22 °C and a humidity of 75...80%. These values of temperature and humidity were chosen to accelerate the processes of mass loss, and to monitor these processes. The duration of experimental storage was 30 days. During the experiment, mass measurements and their fixation were made every day, and a visual assessment of the appearance of sugar beet tubers for the presence of rot or other damage was also made [20].

The mass loss of sugar beet tubers at the end of the experiment was determined by the formula (1):

$$\Delta = 100 - \left(\frac{m_{\text{END}}}{m_{\text{BEG}}} \cdot 100\right), \%$$

where $m_{\text{END}}$ – weight of sugar beet tubers at the end of the experiment, kg;

$m_{\text{BEG}}$ – weight of sugar beet tubers at the beginning of the experiment, kg.

Similar experimental studies were conducted to determine the mass loss of sugar beet tubers after exposure to a magnetic field of a permanent neodymium magnet of positive polarity. The magnetic induction was +400 mT, the weight of the treatment variant was 3 kilograms, the processing time also varied from 15 s to 180 s. After processing with a magnetic field of a neodymium magnet of positive
polarity, sugar beet tubers were also placed in bags for storage for 30 days. The mass of sugar beet tubers was also measured and their appearance was evaluated.

For the statistical analysis the STATISTICA 12 program was used[21].

3. Results and discussion
As a result of experimental studies to determine the effect of the magnetic field of a permanent neodymium magnet of positive and negative polarity, the nature of the effect of the magnetic field on mass loss during 30 days of storage is established. The main results of the study of sugar beet mass loss are presented in table 1.

Table 1. The influence of the magnetic field of a permanent neodymium magnet on the mass loss of sugar beet.

| Magnetic signature, mT | Processing time, seconds | Weight loss, % |
|------------------------|--------------------------|----------------|
|                        | 15                       | 22.5           |
|                        | 30                       | 22.1           |
|                        | 45                       | 18.8           |
| + 400                  | 60                       | 17.6           |
|                        | 120                      | 22.7           |
|                        | 180                      | 27.9           |
| - 400                  | 15                       | 16.7           |
|                        | 30                       | 22.3           |
|                        | 45                       | 15.3           |
|                        | 60                       | 20.9           |
|                        | 120                      | 23.7           |
|                        | 180                      | 17.2           |
| Untreated control      | 0                        | 25.6           |

The influence of the magnetic field of a permanent neodymium magnet for positive and negative polarity are different and have a variable character. The minimum weight loss for sugar beet tubers was observed when treated with a negative magnetic field of – 400 mT and a processing time of 45 s. The weight loss of sugar beet tubers under such processing conditions was 15.3 %. The maximum weight loss for sugar beet tubers when treated with a negative magnetic field of – 400 mT was observed for a processing time of 120 s and reached 23.7 %.

The maximum weight loss of sugar beet tubers for the magnetic field of the neodymium magnet of positive polarity and the value of + 400 mT were observed for the processing time of 180 s and reached 27.9 %. The minimum weight loss of sugar beet tubers for the magnetic field of the neodymium magnet of positive polarity and the value of + 400 mT were observed for the processing time of 60 s and reached 17.6 %. The weight loss of sugar beet tubers for the non-magnetic field – untreated control variant reached 25.6 %. Thus, the magnetic field, depending on the polarity and processing time, both increases the weight loss of sugar beet tubers and reduces the weight loss of sugar beet tubers.

Analysis of the time range for processing sugar beet tubers with a magnetic field allowed us to establish that with a positive magnetic field polarity, in four of the six variants, weight loss of sugar beet tubers was observed by more than 20 %. When processing sugar beet tubers with a magnetic field of negative polarity, in three of the six variants, weight losses of sugar beet tubers of more than 20% were observed. Obviously, in the future, it is necessary to focus on the study of the influence of the magnetic field of a permanent neodymium magnet of negative polarity. It will be necessary to investigate the treatment modes with a negative magnetic field having a magnetic induction of more than 400 mT and a processing time of more than 180 s.

It is also necessary to conduct additional studies to determine the sugar content in sugar beet tubers before and after magnetic treatment.
Since the study of the influence of the magnetic field of negative polarity is not limited to sugar beets, and can be extended to potatoes, carrots, apples, etc., the authors of the article propose a magnetic processing device that can be used for processing any vegetables and fruits.

Figure 1 shows a general view of the device for magnetic processing of sugar beet tubers of the barrel type. Figure 2 shows a top view of the working container with the placement of permanent neodymium magnets.

**Figure 1.** A general view of the device for magnetic processing of sugar beet tubers of the barrel type.

**Figure 2.** A top view of the working container with the placement of permanent neodymium magnets.
The device for magnetic processing of sugar beet tubers of the barrel type contains a base 9 with wheels 6, a mechanism for deflecting and fixing 1 in a vertical plane for loading and unloading sugar beet tubers, a working container 2 mounted on a shaft 8, driven by an electric motor 5 by means of a drive 4 and a gear drive 3, containing flat rectangular permanent neodymium magnets 11 of class n35, a fixed non-magnetic cylinder 7 with metal inserts 12, a cardboard insert 10 to prevent injury to sugar beet tubers.

Working container 2, cylinder 7 are made of non-conductive non-magnetic material, permanent magnets 11 are neodymium with axial magnetization, attached with glue. The cardboard insert 10 is designed to protect the sugar beet tubers from bumps on the walls when the container 2 rotates. The base 9, the deflection and locking mechanism 1, the drive 4, the gear 3, the shaft 8 are made of metal.

The device for magnetic processing of sugar beet tubers of the barrel type works as follows. After loading a batch of sugar beet into the working container 2 with the help of an electric motor 5 by means of a drive 4 and a gear 3, the latter begins to rotate on the shaft 8 around its axis. When rotating the working container 2, the potatoes are in the zone of magnetic influence created by flat rectangular permanent neodymium magnets 11 of class n35 and reinforced by metal inserts 12 located on a stationary non-magnetic cylinder 7. Potatoes subjected to magnetic processing, after switching off the electric motor 5, by tilting the deflection mechanism and fixing 1, are removed from the working container 2, and the next batch is loaded. If it is necessary to move for short distances, the wheels 6 serve.

To achieve the maximum effect, the processing of potato tubers should be carried out in the negative field of a flat permanent neodymium magnet 11 with a magnetic induction of -400 mT, and a processing time of about 45 seconds.

The effectiveness of magnetic processing of sugar beet tubers in this device depends on the value of the magnetic field polarity, the duration of exposure, and the magnitude of the magnetic field induction.

4. Conclusion
1. The influence of the magnetic field of a permanent neodymium magnet for positive and negative polarity are different and have a variable character.
2. The minimum weight loss for sugar beet tubers was observed when treated with a negative magnetic field of -400 mT and a processing time of 45 s and amounted to 15.3 %.
3. The maximum weight loss for sugar beet tubers when treated with a negative magnetic field of -400 mT was observed for a processing time of 120 s and reached 23.7 %.
4. The maximum weight loss of tubers of sugar beets for the magnetic field of a neodymium magnet of positive polarity and values +400 mT was observed for treatment time of 180 s and reached 27.9 %.
5. Minimum weight loss of tubers of sugar beets for the magnetic field of a neodymium magnet of positive polarity and values +400 mT was observed for treatment time of 60 s and reached 17.6 %.
6. Weight loss of tubers sugar beet for untreated control reached 25.6 %.
7. The magnetic field, depending on the polarity and processing time, both increases the weight loss of sugar beet tubers and reduces the weight loss of sugar beet tubers.
8. It is necessary to conduct additional studies to determine the change in the sugar content in sugar beet tubers during storage for those treated with a magnetic field of positive and negative polarity and for those untreated with a magnetic field.

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