



Development of Microwave Devices with Toroidal Resonators for Treatment of Raw Materials

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Abstract

Three ultra-high frequency devices with toroidal resonators were developed on the basis of the principle of construction of quasi-stationary resonators. Two of these devices are designed for elimination of a number of pests feeding on raw material and for activation of cells of potato tubers and onion sets. The *first* device with toroidal resonator is designed for preplant treatment of potato tubers by the effect of electrophysical factors. A dielectric wire belt is placed inside the torus of circular cross section. In the central part of the resonator, represented as a capacitor space, there are rotating disk and spreader. Microwave emitters are directed through the surface of the torus, and gas-discharge lamps are directed into the capacitor space. A filling funnel is installed at the center of the resonator. An induction heater is placed under the torus; the segment of the bottom of the torus surface serves as its secondary winding. The *second* device is designed for preplant treatment of onion sets. It consists of a quasi-stationary toroidal resonator with a rectangular cross section. Inside the annular space, there are a cylinder, an air duct and an annular gas-discharge lamp. In the capacitor part of the resonator, a dispenser with dielectric scrapers is placed. On the base of the cylinder, there is a sector-shaped discharge opening connected to the evanescent waveguide. The emitters from the magnetrons are directed to the capacitor part of the resonator. The *third* device is designed to defrost cow colostrum. It contains vertical quasi-stationary toroidal resonator with a rectangular cross section of torus and a capacitor part with a gap from the lower edge of the base of the inner cylinder smaller than the distance between the side surfaces of the cylinders. The torus is formed between coaxially located cylinders of different heights and an annular non-ferromagnetic surface at the top. The disk moves inside the cylinder of small diameter. The emitters are directed to the capacitor part. The average perimeter of the annular space and the diameter of the disk should be equal to multiple half of the wavelength, and the slot should be less than one-fourth of the wavelength.

Keywords: Toroidal resonators, Preplant treatment, Gas-discharge lamp, Potato tubers, Onion sets, Cow colostrum

1 Introduction

According to the Federal Scientific and Technical Program, which implies the task of ensuring the substitution of import products by increasing national production and rising the efficiency of raw materials processing technology (approved at August 25, 2017, No. 996), it is an urgent task to develop methods and technical means for preplant seed treatment of vegetable crops and for defrosting cow colostrum.

The authors of the paper analyzed the results of the studies of different scientists, which were aimed at improving the technology of preplant treatment of potato tubers and onion sets without chemical preparations. The analysis shows that

the task remains unsolved. Therefore, the authors developed technologies that can be applied on small and medium agricultural enterprises for preplant treatment of potato tubers and onion sets by ultra-high frequency electromagnetic field (UHFEMF) in order to increase productive values at reduce operating costs. The importance of developing studies on the effects of microwave heating in Russia is confirmed by the adoption (on December 17, 2012) of the strategic research program "Microwave Technology", which determines the development of industrial equipment for technological heating.

The aim of this work is to develop and substantiate the

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parameters of the devices with toroidal resonators, providing the effect of UHFEMF on raw materials in a continuous mode at high electric field strength. Objectives of the research: (1) to study the existing technologies and technical means used for preplant treatment of vegetable seeds and for defrosting of cow colostrum; (2) to develop criteria for designing microwave equipment for treatment of raw materials in farms. (3) to develop design schemes for multi-generator microwave devices with toroidal resonators that implement microwave technologies for preplant treatment of potato tubers and onion sets and for defrosting of cow colostrum.

The object of the research includes technological processes that provide increased protection of potato tubers and onion sets from pests and defrosting of cow colostrum, as well as experimental samples of the devices with toroidal resonators, implementing the complex effect of physical factors on raw materials in a continuous mode.

2 Material and Methods

By application of UHFEMF and appropriate selection of the parameters for the resonator chambers, where the conversion of microwave energy into heat occurs, it is possible to obtain a uniform heat release in the volume, if the movement of raw materials within it is provided. The heating efficiency is directly proportional to the square of the EF strength and the loss factor of raw material at a frequency of 2450 MHz. Therefore, the studies were carried out on the basis of the analysis of the effect of electrophysical factors on agricultural raw materials, the theory of the electromagnetic field of ultrahigh frequency, induction heating, and darsonvalization. The unloaded Q-factor of the resonators was estimated using the software CST Studio Suite 2017 and its subroutines CST Microwave Studio for three-dimensional computer simulation of electric field; it was also calculated using the construction parameters of the resonators as the ratio of capacitance to surface area, taking into account the skin layer. A three-dimensional simulation of the structural designs of the microwave devices with toroidal resonators were conducted using Compass-3D V17 software. The studied raw materials were potato tubers of the “White Rose” variety (weighing 50-55 g and of 53x30 mm in size), onion-seedlings of “Bessonovsky” variety (of 15-25 mm in size) and cow colostrum.



Figure 1: Potato tuber and onion set

3 Results

The authors analyzed the results of many years of research on the development of microwave equipment and elaborated

conditions for the implementation of the technological process of the effect of UHFEMF on raw materials (Table 1). For farm enterprises, it is necessary to design radio-hermetic equipment for continuous operation, which is possible with the use of low-power air-cooled magnetrons.

Table 1: Conditions for the implementation of the technological process of the effect of UHFEMF on raw materials

Conditions	Provided by
1. Continuous operation	- Perforations of resonator; - Slot resonators; - Movement of resonators; - Use of dielectric wire belt; - Use of screw conveyor.
2. Keeping the off-duty factor of the process lower than 0.5	Use of: - Many magnetrons; - Auger resonator; - Resonator divided into zones of heating and pause.
3. Uniform heating of raw materials	use of: - Rotating mechanisms; - Vibrators.
4. High strength of electric field	use of: - Biconical resonator; - Toroidal resonator; - Quasi-stationary resonator; - Interference of waves in the resonator; - Small volume.
5. Compliance with electromagnetic safety (radiation density should not exceed 0.01 mW/cm²)	Implementation of: - Evanescent waveguides; - Slots less than a quarter of the wavelength in width; - Non-ferromagnetic flexible grids; - Remote control.
6. Reduced energy costs for the process	reduced power of - Drive of transporting units; - Fan for cooling magnetrons.
7. Increased efficiency of the device	- Use of resonators with high unloaded Q-factor; - Radio-hermetic design.

Taking into account the elaborated conditions for the implementation of the technological process of the effect of UHFEMF on the raw materials, three devices with toroidal resonators were developed. Two of them are designed for the preplant treatment of vegetable seeds; the purpose of the third one is defrosting cow colostrum. A feature of the toroidal resonator is a pronounced spatial separation of the electric and magnetic fields. The gap, where the electric field is uniform, can be considered as a flat capacitor (1). The two developed devices with different constructional designs of the toroidal resonator provide a complex effect of UHFEMF and corona discharge for preplant treatment of potato tubers and onion sets. The third device also has a toroidal resonator; it is designed for defrosting cow colostrum. The implementation of a complex effect of electrophysical factors is possible in a microwave device with a toroidal resonator containing evanescent waveguides, ensuring compliance with

electromagnetic safety when raw material moves through the resonator. A gas-discharge lamp connected to a source of kilohertz frequency provides a corona discharge and radiation of a bactericidal flux of ultraviolet rays.

Selective heating of seeds under the effect of UHFEMF is caused by losses due to dipole polarization. The depth of penetration of standing waves into potato tubers is 1.5-2 cm, and the heating is usually heterogeneous. Therefore, uniform heating is achieved due to the thermal conductivity of the raw material and by its movement inside the resonator. Multi-generator devices were developed, where the working chambers provide a multiple impact of the UHFEMF on the raw material during its movement. Moreover, the magnetrons are evenly distributed over the volume of the resonator with a shift of 120 degrees to prevent their knocking out by the reflected waves.

3.1 Device for preplant treatment of potato tubers by the effect of electrophysical factors

Nowadays, chemicals are used for preplant processing of potatoes. Tubers are treated with agricultural preparations for prevention of diseases, protection from pests and for stimulation of growth. Among the preparations that are used for disinfection the most popular ones are such products as Maxim or Fitosporin-M combined with other fungicides and growth stimulants. They protect the crop from diseases at all stages of growth, but do not exclude occurring of side effects in humans (2).

The positive effects of electrophysical methods of treating food products are known (3-6). However, the known methods of preplant treatment of potato tubers with low-frequency (8-19 Hz) magnetic fields (7) (patents No. 2415536, No. 2435349, No. 2483513 No. 2407264) are difficult for implementation on farms. There are medical sources of kilohertz frequency radiation, such as "Darsonval" and "Ultrator" (8). The research conducted by the authors of the paper shows that the effect of the effect of such sources could be increased by placing electro-discharge lamps connected to sources of a kilohertz frequency into UHFEMF (9).

The purpose of treating potato tubers before planting by complex effects of electrophysical factors is elimination of a number of pests and activation of potato tuber cells in order to accelerate their germination and increase productive characteristics with the exclusion of side effects on the physicochemical composition of grown potatoes.

The device for preplant treatment of potato tubers (Fig. 2) consists of a toroidal resonator 1 made in the form of a torus of circular cross section. The average perimeter of the torus is equal to multiple half of the wavelength. The middle part of the resonator is made of two plane-parallel circular planes forming a capacitor space 13. In this space, a disk 5 driven by an electric motor is installed coaxially with the resonator. A dielectric spreader of tubers 6 in the form of a streamlined surface is rigidly mounted above the disk. Detachable gas-discharge lamps powered by the sources of kilohertz frequency 12 are installed uniformly along the perimeter and directed through the upper circular plane into the capacitor space. Protective net surround the gas-discharge lamps preventing them from being hit by tubers. In the center of the same

circular plane, a loading funnel 14 is installed. Microwave energy emitters 2 from magnetrons are located along the torus with a shift of 120 degrees and directed through its surface. There are the wire belt 4 and the scrapers 9 inside the torus; they are moved by the driven pulley 8 and the drive gear mounted on the shaft. An unloading dielectric limiter 11 is rigidly fixed above the wire belt; the limiter directs the potato tubers to the opening 10 with the evanescent waveguide. Fluoropolymer scrapers 9 installed under the wire belt and move with it; they are designed to remove waste from the torus through the opening 15 and the evanescent waveguide. An induction heater 3 is placed under the torus, and the torus segment above it serves as the secondary winding of the inductor (10).

Thus, the device contains three different sources of electromagnetic radiation:

- microwave generators (main units: magnetron, emitter);
- induction heater (primary winding and torus segment);
- sources of kilohertz frequency (generator and gas-discharge lamps) generating high-frequency alternating pulsed current with high voltage, the value of which lies within the range of 2-15 kV, the current frequency is 110 kHz.

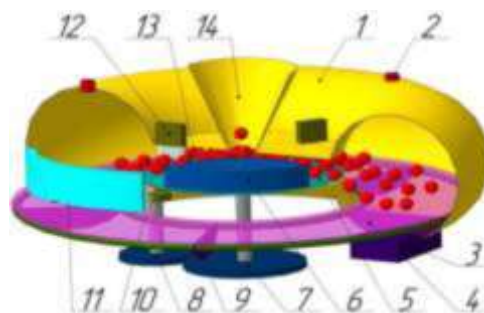


Figure 2: Device for preplant treatment of potato tubers by the effect of electrophysical factors: 1 – toroidal resonator; 2 – microwave energy emitters; 3 – induction heater; 4 – dielectric wire belt; 5 – rotating disk; 6 – dielectric spreader of tubers; 7 – drive pulley of the disk; 8 – driven pulley of the wire belt drive; 9 – dielectric scrapers for removal of wastes; 10 – unloading opening for tubers; 11 – unloading dielectric limiter; 12 – sources of kilohertz frequency; 13 – capacitor space; 14 – loading funnel; 15 – opening for removal of wastes

The technological process of preplant treatment of potato tubers is as follows. Load the potato tubers into the funnel 14. Turn on the electric drive of the disk 5; the drive pulley will rotate the driven pulley 8, which will move the wire belt 4. Turn on the sources of kilohertz frequency 12 and the induction heater 3; then turn on the microwave generators. Their emitters 2 will excite UHFEMF within the toroidal resonator. A traveling wave with a frequency of 2450 MHz is excited (11) within the toroidal resonator. Under the influence of the UHFEMF, the potato tubers are endogenously heated to 35 °C, which accelerates the enzymatic activity of the tubers. In the capacitor space 13, the electric field intensity is quite high (more than 2 kV/cm), which protects the tubers from diseases and pests.

Gas-discharge lamps 12 are located at a distance of several millimeters (3-5 mm) from potato tubers. In this case, small

electrical discharges arise between the lamps and tubers, which accelerates biochemical reactions, saturates tubers with oxygen, increases elasticity and permeability of tubers (8). The electric discharge has a bactericidal and bacteriostatic action (delays multiplication of bacteria). Discharges produce ozone with a disinfecting effect. Gas-discharge lamps provide the conversion of high-voltage to the corona discharge of the required strength. Complex physical and electrochemical processes involving inert gases in the lamps enable obtaining of several factors. Inert gas acquires the properties of an electrical conductor, which is closed to the ground through a layer of air between the lamp and potato tubers and through the tubers and the disk 5. As a result, a corona discharge occurs releasing ozone, heat and ultraviolet radiation in the capacitor space 13. This whole complex of factors contributes to the activation of cells of potato tubers, which provides increased and accelerated germination.

Due to the fact that induction heaters are installed under the segment of torus bottom, the electromagnetic coil (primary winding) generates magnetic field, and the torus bottom segment (which is at least 70% of the surface of the induction hob in size and made of a ferromagnetic material) is heated by eddy currents. The wire belt 4 with the use of mobile fluoropolymer scrapers 9 separates pests from raw material; when the pests reach the heated segment of the torus, they are destroyed by thermal burn and removed through the opening 15 and the evanescent waveguide.

The choice of modes for the effect of the factors depends on the variety and maturity of potatoes. The use of the developed device with different electrophysical factors enables obtaining of environmentally friendly products that meet all the requirements of the standards. This device is recommended for preplant treatment of potato tubers no larger than 6 cm in size. This is conditioned by the design providing high strength of electric field in the capacitor space and the depth of penetration of centimeter wave into the potato tubers, as well as by the simplified design of the evanescent waveguides that are placed in unloading openings. Uniform heating of potato tubers and continuous operation of the device is provided by the use of wire belt for transportation of the tubers within the torus.

To determine the value of dielectric loss, the dielectric characteristics of potatoes were analyzed depending on the temperature at humidity of 78% and frequency of 2450 MHz (Fig. 3) (6).

Analysis of the data shows that in the temperature range of 20–40 °C, the value of the dielectric permittivity decreases by 5% (Fig. 3). The absorption coefficient in this temperature range increases; it is explained by the fact that, at a temperature of 30 °C, the denaturation of proteins begins accompanied by the release of moisture. The decrease in the loss factor at temperatures above 60 °C is conditioned by evaporation of moisture, as well as by thermal movement of polar molecules, which prevents their dipole orientation in the electromagnetic field.

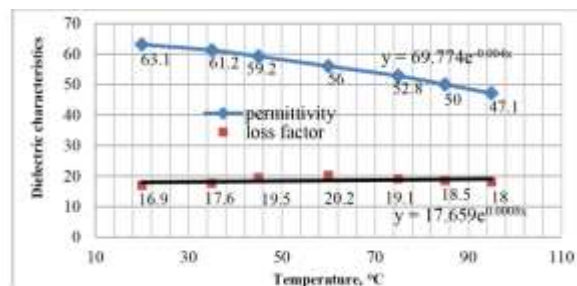


Figure 3: Dielectric characteristics of potatoes depending on temperature at humidity of 78% and frequency of 2450 MHz

The authors also studied the dependence of dielectric characteristics of potato tubers from moisture content (Fig. 4). With an increase in the content of moisture in potato tubers from 70 to 85%, the absorption coefficient increased from 10.8 to 20.4. On the basis of these data, it is possible to calculate the power of dielectric losses at electric field strength of 1.5-2 kV/cm. The technical characteristics of the device for preplant treatment of potato tubers by the complex effect of electrophysical factors are given in Table 2.

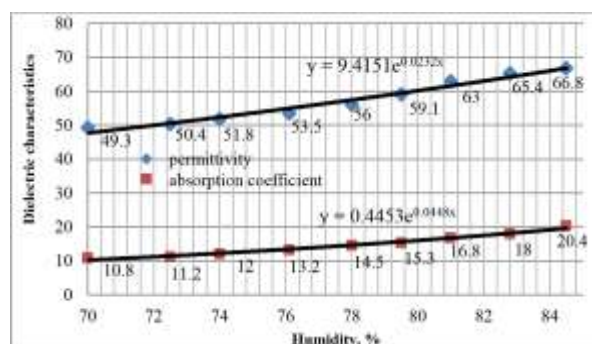


Figure 4: Dielectric characteristics of potato tubers depending on humidity content at frequency of 2450 MHz

Table 2: Device specifications

Productivity, kg/h	250-300
Power of microwave generators, kW	3.6
Power of sources of kilohertz frequency, kW	0.225
Power of induction heater at a heating temperature of 150 °C, kW	1.0
Power of motor-reduction drive MEO-6.3/12.5 moving the wire belt, 2.4/4.8 rpm	0.043
Power of device, kW	4.9
Specific energy costs, kW-h/kg	0.015-0.2

3.2 Microwave device for preplant treatment of onion sets in continuous mode

It is known that treatment of onion sets before planting is carried out in order to avoid bacterial infections, intensive formation of inflorescences and low germination. Immediately before planting, onions are heated at a temperature of 35–40 °C for 10–12 hours. Then, phytosporin is used to suppress development of pathogenic soil microflora (12). There is a way to heat onion sets in hot water (45–50 °C) for 10–12 minutes, then it is held in cold water for another 10–12 minutes and then treated with pesticides and nutrient solutions (13). At the same

time, for uniform heating and cooling of onion sets on farms it is necessary to have water heaters and additional mixing mechanisms.

There is a method of preplant treatment of onion sets by a high-frequency electromagnetic field (14). High-frequency devices with fixed frequencies (27.12 MHz, 40.68 MHz) and periodic action are used for the treatment. The working chamber of these devices is a capacitor made of two parallel-arranged plates. According to the data of long-term laboratory and field studies on the application of high-frequency electromagnetic fields for preplant treatment of onion sets, an increase in sowing and productive indicators was observed, as well as improvement of product quality.

The scientists of Stavropol State Agrarian University received positive results of scientific research on the preplant treatment of onion with a pulsed electric field aimed at improvement of sowing qualities (15).

The microwave device (Fig. 5) for preplant treatment of vegetable crops (onion sets and potato tubers) consists of a vertically located quasi-stationary toroidal resonator 1 with a rectangular cross section. Quasi-stationary toroidal resonator 1 is designed as coaxially located cylinders of non-ferromagnetic material, forming an annular space. The lower bases of the cylinders form a capacitor part 3 (the inner part) of a quasi-stationary toroidal resonator, where the distance between the walls is no less than a quarter of the wavelength, but it is also smaller than the distance between the walls of the torus of rectangular cross section.

It is known that the shape of the profile of a toroidal resonator determines the structure of the excited electromagnetic fields. The electric field is mainly concentrated in the capacitor part (the inner part) of the resonator, where the distance between the walls is small, i.e. this part of the resonator has a capacitive character. The energy of magnetic field is concentrated in the peripheral part of the quasi-stationary toroidal resonator (in the torus) (1). The annular space between the side walls of the cylinders is closed on top by a flat surface, which has openings for the dielectric air duct 11 and for evanescent waveguide of circular section 13 connected to the dielectric cylinder 2. Inside the annular space, there are a dielectric cylinder 2, a dielectric air duct and an annular gas-discharge lamp 9. The lamp is placed around the inner cylinder (at the level of its base) with a gap between them. The gas-discharge lamp 9 is connected to a source of kilohertz frequency 10 located on the inside surface of the inner cylinder. In the capacitor part 3, a dispenser 5 with radially located scrapers is placed. It is mounted on the shaft 7 of the electric motor coaxially with the base of the outer cylinder, where an unloading opening 6 in the form of a sector was made. An evanescent waveguide in the form of a regular triangular prism is docked to the unloading opening. The emitters from magnetrons 4 located on the side surface of the outer cylinder with a shift of 120 degrees are directed to the capacitor part of the quasi-stationary toroidal resonator loaded with raw material 8. The capacitance of the capacitor part of the toroidal resonator is regulated by changing the vertical position of the inner cylinder with the help of a threaded height

adjuster 12. The strength of electric field is regulated by change of the distance between the bases of non-ferromagnetic cylinders.

The technological process of preplant treatment of onion sets is as follows. Turn on the electric drives of the air duct and dispenser with dielectric scrapers. Set a certain distance between the bases of the cylinders, calibrated to the required value of the electric field strength sufficient for disinfecting onion sets or potato tubers. Turn on the kilohertz frequency source providing the occurrence of a corona discharge between the side surface of the inner cylinder and a gas-discharge lamp. Due to the discharge, air ionization, ozone formation occur. The lamp will be a source of ultraviolet rays of "C" region. Then turn on the conveyor for loading the raw material into the dielectric cylinder through the evanescent waveguide. Turn on ultra-high frequency generators 4. Raw material getting into the capacitor part of a quasi-stationary resonator is moved by the dispenser with scrapers, heated to 35–40 °C by the effect of UHFEMF and decontaminated due to the effects of ozone, electric field of high strength (above 1.5 kV/cm) and bactericidal action of ultraviolet rays. Strength of the electric field is regulated by changing the distance between the bases of non-ferromagnetic cylinders with the help of a threaded height adjuster of the inner cylinder. After one turn of the shaft of the electric drive of the spreader, the processed raw material is poured out through the unloading opening and the evanescent waveguide, which has a shape of triangular prism. The air duct provides the removal of dust, husks, etc. The technological process implies continuous mode of preplant treatment of onion sets or potato tubers.

During the operation of the kilohertz frequency source, raw material affected by pulsed currents of high voltage and low power. The current passes through the gas-discharge lamp. A corona discharge of different intensity appears between the lamp and the side surface of the inner cylinder, depending on the size of the gap between them (0.5–2 cm). This process is accompanied by release of ozone, ionization of air, and formation of ultraviolet rays (16). The amperage on the gas-discharge lamp is not more than 0.2 mA, the voltage is 12–15 kV, the pulse frequency is 110 kHz. Released ozone and ultraviolet rays of "C" region provide bactericidal effect. Bacteria and microorganisms present in the treated seed material are eliminated. The complex effect of various electrophysical factors activates the cells of potato tubers and onion sets, which increases the germination ratio and energy, growth rate and yield. When designing a quasi-stationary toroidal resonator for continuous operation, it is necessary to strive to reduce the equivalent capacitance at a given resonant frequency and to increase the equivalent inductance (toroidal surface). Due to these factors, the loss of microwave energy in a toroidal resonator can be reduced and its efficiency increased. Low radiation losses due to the presence of evanescent waveguides and losses in the walls of a quasi-stationary toroidal resonator made of aluminum lead to the fact that this resonator in the microwave range has a high value of unloaded Q-factor.

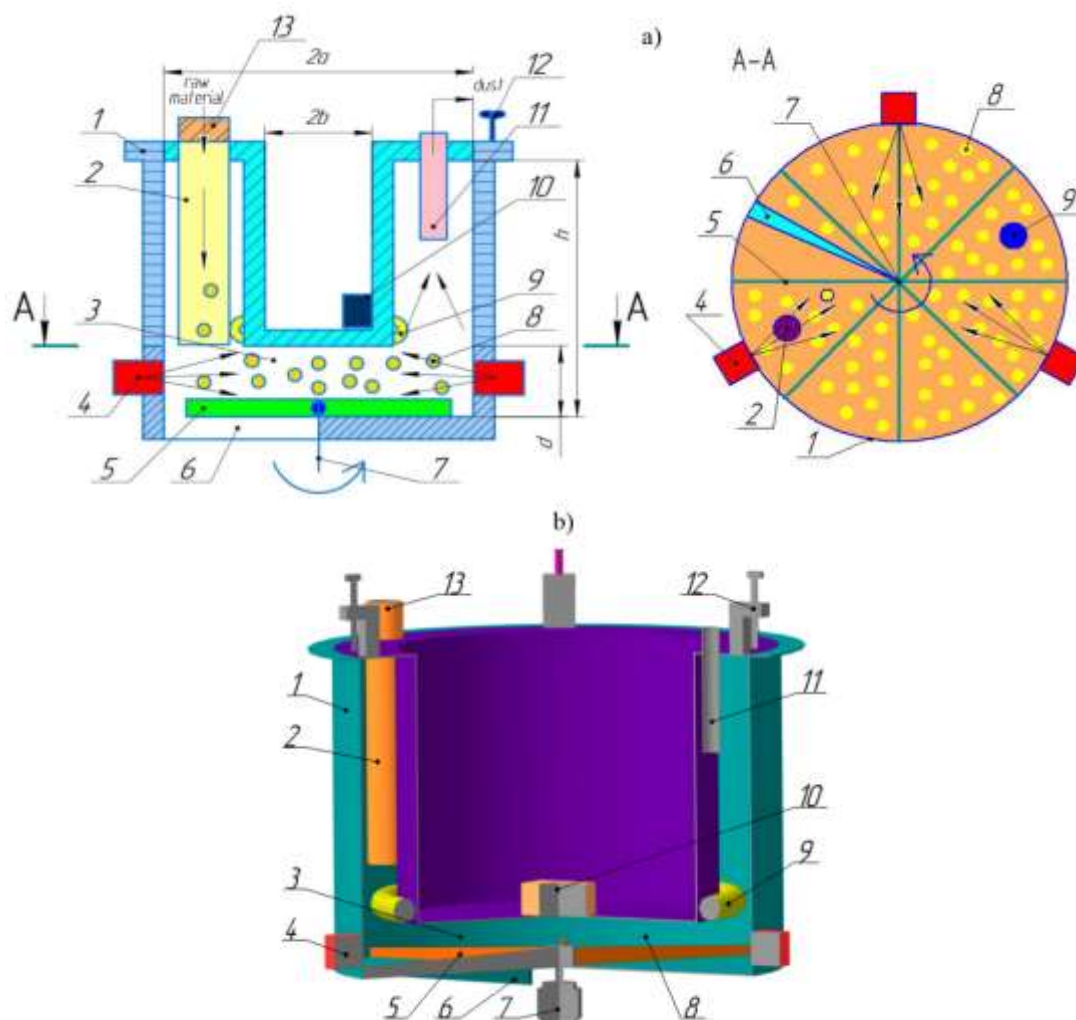


Figure 5: Microwave device for preplant treatment of vegetable seeds in continuous mode: a) technological scheme; b) spatial image; 1 – quasi-stationary toroidal resonator; 2 – dielectric cylinder for loading raw material; 3 – capacitor part of the quasi-stationary toroidal resonator; 4 – magnetrans with emitters; 5 – dispenser with radially located dielectric scrapers; 6 – unloading opening with evanescent waveguide in the form of a regular triangular prism; 7 – shaft of electric drive rotating dispenser with scrapers; 8 – raw material; 9 – annular gas-discharge lamp; 10 – source of kilohertz frequency; 11 – dielectric air duct; 12 – threaded height adjuster of the inner cylinder; 13 – evanescent waveguide of circular cross section

An experimental study of the dynamics of heating of onion sets in the UHFEMF at a specific power of 3.5 W/g was carried out. The results of the study show that the increase of temperature of the onion sets within the period of 40 s was 21 °C. The expected productivity of the device is 250-300 kg/h. Description of the device, which also contains a quasi-stationary toroidal resonator but designed for defrosting of viscous raw materials, namely cow colostrum, is given below.

3.3 Microwave device for defrosting cow colostrum

A calf on the intake receives 4–7 liters of colostrum during the first days. The average daily milk yield for cows in the first days after calving is 15–20 kg. Newborn calves can consume 30–50% of the total colostrum of cows. The remaining amount of colostrum should be frozen. The use of subsequent yields of

colostrum is not rational due to the low content of immunoglobulins.

Colostrum is taken in the first two days after calving and stored frozen (16). It differs from milk both by composition and by appearance: it is fatter, more viscous and thick; it has yellow tinge, sallow taste and different odor. Colostrum may vary by calorie, mineral and vitamin composition. It contains (17):

- Immunoglobulins;
- Iron-bound protein that inhibits multiplication of microorganisms and provides a powerful anti-viral effect;
- Substances that stimulate tissue growth, strengthen the immune system, normalize the work of the gastrointestinal tract, protect cells from the action of viruses;
- lysozymes – natural antibiotics, etc.

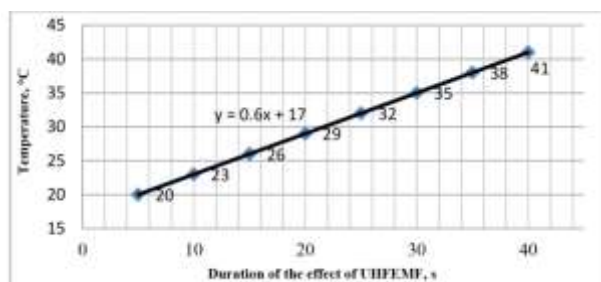


Figure 6: Dynamics of heating of onion sets in UHFEMF with a specific power of 3.5 W/g

Colostrum that is taken for freezing has a density of 1.06–1.045 g/cm³. It is frozen in plastic bags of 1.0–1.5 liters and stored for 3–4 months at a temperature of -20 °C. For a farm with a livestock of 1000 heads of a dairy herd, it is sufficient to have a freezer compartment with a volume of 250–300 liters to maintain the temperature -18–23 °C. Colostrum is stored under these conditions for up to 8 months, and it is defrosted in batches at a temperature of 35–38 °C. The raw material is defrosted before feeding, and this process takes long time. For example, it takes 1.5–2 hours for a 1.5-liter bottle of colostrum to defrost at room temperature.

Different methods and devices are used in order to defrost colostrum for newborn calves, including the defrosting machine PM-3, which enables defrosting of colostrum within 40 minutes. However, these methods apply uneven heating, which leads to destruction of the structure of immunoglobulins (18, 22, 23). There is also defrosting machine Iglus-2 (19) and colostrum bath BM-40 (20, 21). This equipment works on the principle of water bath, where a tubular electric heater heats the water; bottles with raw material are placed inside a rotating device within the water tank; such low productivity equipment works in periodic mode with high consumption of hot water and high energy costs.

Therefore, the technical task is to develop a device for uniform defrosting of cow colostrum at low operating costs by applying UHFEMF to frozen raw material in a quasi-stationary toroidal resonator with a capacitor part and rectangular cross section. It should provide a smooth increase in strength of the electric field due to a decrease in the interplate distance. The device was developed taking into account the results of studies of other authors in the field of application of electromagnetic radiation energy for heat treatment of agricultural raw materials (24, 25). It was also taken into account that the existing methods require long time for defrosting cow colostrum. Preliminary studies show that after the slow defrosting of colostrum, its quality is noticeably lower than the quality of fresh substance. With application of microwave technology, it is possible to defrost colostrum in minutes, depending on the volume of raw material. This enables to keep quality of defrosted cow colostrum almost equal to fresh product. It is known that the depth of penetration of UHFEMF (2450 MHz) into frozen colostrum increases from 1.5 cm to 42 cm with an increase in temperature from -1 °C to -50 °C (4).

The device for defrosting cow colostrum (Fig. 7) consists of a vertically located quasi-stationary toroidal resonator with

a torus of rectangular cross section and a capacitor part. The toroidal part is presented as coaxially arranged non-ferromagnetic cylinders 2, 3 of different heights without upper bases. The annular space between the cylinders is closed on top by an annular surface 5 made of non-ferromagnetic material. The upper base of the inner cylinder 2 is missing, and its lower base is a movable non-ferromagnetic disk 4. The height of the inner cylinder 2 is lower than the height of the outer cylinder 3. The gap between the edge of the lower base of the inner cylinder 2 and the lower perforated base of the outer cylinder 3 is less than the distance between the side surfaces of the cylinders 2, 3. Thus, the toroidal part of the quasi-stationary resonator is formed between coaxially located non-ferromagnetic cylinders 2, 3 of different heights and non-ferromagnetic surface 5 above them. The capacitor part of the resonator is represented by the gap between the movable non-ferromagnetic base-disk 4 and the perforated lower base of the outer cylinder 3.

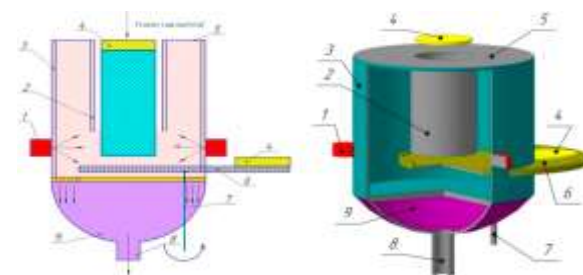


Figure 7: Microwave device for defrosting cow colostrum: 1 – magnetrons; 2 – internal non-ferromagnetic cylinder without bases; 3 – non-ferromagnetic outer cylinder with a perforated lower base; 4 – movable non-ferromagnetic base-disk; 5 – upper base of the outer cylinder, shaped as an annular surface; 6 – perforated round dielectric tray with boards; 7 – shaft of the electric drive of the tray; 8 – drain pipe; 9 – convex bottom of the device

The diameter of the movable non-ferromagnetic base-disk 4 is smaller than the diameter of the inner cylinder 2; therefore, it can move freely inside the cylinder 2. The magnetrons 1 of the microwave oscillators are located on the outer side of the outer cylinder 3; the emitters are directed inside the capacitor part of the resonator. There is a slot on the side surface of the outer cylinder 3 in the capacitor part of the resonator; a perforated round dielectric tray with boards 6 protrudes through this slot. The tray 6 is located asymmetrically in relation to the axis of the cylinder, parallel to the lower perforated base of the outer cylinder 3, and it is rotated by electric motor 7. Under the outer cylinder 3, there is a convex bottom of the device 9 with a drain pipe 8. The average perimeter of the annular space and the diameter of the base disk 4 should be equal to a multiple half of the wavelength, and the size of the slot should be less than a quarter of the wavelength.

The technological process of defrosting cow colostrum is as follows. Prepare cow colostrum frozen in cylindrical silicone containers. Load the frozen raw material without silicone container into the inner cylinder 2. Close it from above with a non-ferromagnetic base-disk 4. Open the drain pipe 8. Turn on the electric drive 7 of the dielectric perforated tray

with boards 6. Turn on microwave generators; their magnetrons 1 would excite the UHFEMF in a quasi-stationary resonator through waveguides and emitters. The quasi-stationary resonator is characterized by the fact that the width of the capacitor part is smaller than the wavelength and the electric and magnetic fields are spatially separated. The magnetic component prevails in the toroidal part and the electric component of the electromagnetic field is concentrated in the capacitor part. The presence of a capacitor (narrowed) part in the quasi-stationary resonator provides a high strength of electric field for the H_{10} wave, correlated to an increase in capacitance (when the non-ferromagnetic disk 4 moves down the internal cylinder).

This leads to an increase in the critical wavelength. The working range of a resonator with a capacitor part can be several times larger than the range of a cylindrical resonator of the same size. The concentration of the electric field in the condenser part of the resonator provides critical intensity of the electric field, which makes it possible to stop the development of bacterial microflora in thawed raw material. Frozen raw material that reached the dielectric perforated tray 6 with boards becomes partially defrosted by the effect of UHFEMF. The liquid fraction percolates through the perforations of tray 6. The tray is rotated by the electric motor 7, and the frozen pieces of raw material drop onto the perforated base of the quasi-stationary resonator, where complete defrosting occurs. Defrosted raw material in the form of a viscous fluid flow through the perforations into the convex bottom of the device 9. Large frozen pieces are not carried out through the slot in the lateral surface of the outer cylinder 3, but due to the impact, they crumble and fall on its perforated base. As the raw material thaws, the non-ferromagnetic base-disk 4 moves down along the guides (internal grooves in the inner cylinder 2). This provides a smooth increase in strength of the electric field in the capacitor part of the resonator due to a decrease of interplate distance. The base-disk 4 together with pieces of frozen raw material fall on the dielectric tray 6, where it is taken out from the outer cylinder by the centrifugal force and removed. When the frozen raw material moving through the inner cylinder 2 reaches about half of its height, a new portion of the frozen raw material without silicone containers should be loaded, and a new disk-base should be installed on the guide grooves. This process is repeated until the entire volume of the required raw material is defrosted. The disk-base 4 limits the radiation of microwave energy in the process of loading new portions of raw material. Therefore, the process of loading new portion of raw material with the corresponding base-disc should be started before the previous base-disc falls onto the dielectric tray 6. Electromagnetic safety is ensured, as the waves are closed to the frozen raw material. The number of disks depends on the number of portions of raw material. After the defrosting of raw material, the device is sanitized, including disc-bases and silicone containers for cow colostrum. The temperature of the thawed raw material for feeding calves should not be lower than 35–38 °C. Consequently, the effect of UHFEMF should provide a temperature increase from -20 °C to +35 °C.

4 Conclusion

The developed devices contain various sources of electromagnetic radiation:

- Microwave generators providing endogenous heating of potato tubers and protection from diseases and pests;
- Induction heater for destruction of beetles and other pests by thermal burn;
- High-frequency (110 kHz) alternating pulsed current generators with high voltage and electro-discharge lamps, which accelerate biochemical reactions, saturate tubers with oxygen, increase their elasticity and permeability.

This whole complex of energy sources contributes to activation of cells of potato tubers and onion sets, accelerating and increasing germination and productive indicators. With the use of one device having capacity of 300 kg/h, it is possible to carry out preplant treatment of up to 20 tons of potato tubers (no larger than 6 cm in size) with specific energy expenditures of 0.2 kW·h/kg. Application of a new method of preplant treatment of potato tubers and onion sets enables one to increase crop yields up to 15%, improve product quality, increase hygienic product safety requirements, and reduce the urgency of the environmental problem of using chemicals. Therefore, it is recommended to use the developed installation on farms.

Ethical issue

Authors are aware of, and comply with, best practice in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

Competing interests

The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work.

Authors' contribution

All authors of this study have a complete contribution for data collection, data analyses and manuscript writing.

References

1. Strekalov A.V. Electromagnetic fields and waves. A.V. Strekalov, Yu.A. Strekalov. Moscow: RIOR: INFRA-M. 2014.
2. SeloMoe.ru\kartofel/obrabotka-kartofelya-pered.
3. Rogov I.A. Electrophysical methods of food treatment. Moscow: Agropromizdat. 1989.
4. Rogov I.A. Gorbato A.V. Physical methods of food treatment. Moscow: Food industry. 1974.
5. Rogov I.A. Nekrutman S.V. Microwave heating of food. Moscow: Agropromizdat. 1986.
6. Electrophysical, optical and acoustic characteristics of food: handbook. I.A. Rogov (ed.). Moscow: Light and food industries. 1981.
7. Titenkova MS, Makarova G.V. Estimation of the main parameters of electrophysical methods for preplant treatment of potato tubers. *Innovatsii v sel'skom khozyaystve*. 4(14);2015:34–37.

8. <http://fb.ru/article/322002/instruktsiya-po-primeneniyu-ultratona-apparat-ultraton-instruktsiya-po-primeneniyu-protivopokazaniya>
9. Patent No. 2626156 of the Russian Federation, IPC A 23 N17/00. Radio wave equipment for heat treatment of raw materials. A.A. Belov, G.V. Zhdankin, G.V. Novikova, O.V. Mikhailova, I.G. Ershova; applicant and patent holder NSAA (RU). № 2016133572; declared 08/15/2016. Bul. № 21 dated 2107. 2017.
10. <http://home-gid.com/tehnika/induktsionnye-varochnye-paneli-preimushhestva-i-nedostatki.html>.
11. Belov AA, Zhdankin GV, Novikova GV. Improvement and justification of the parameters of the microwave device with a toroidal resonator and a cellular rotor, designed for the heat treatment of raw materials. Herald NGIEI. 2017;3(70):57–66.
12. StudFiles.net>preview/6726503/page:21/.
13. [liveinternet.ru>users/4632770/post413484768/](http://liveinternet.ru/users/4632770/post413484768/).
14. Ushakova SI. Justification and study of the processes of drying and preplant treatment of onion sets in high-frequency electromagnetic field: PhD theses. (05.20.02). Chelyabinsk: Chelyabinsk Institute of Mechanization and Electrification of Agriculture. 1973.
15. Starodubtseva GP. Preplant treatment of onion by pulsed electric field. Selskiy Mechanizator. 2018;3.
16. <http://fb.ru/article/427088/darsonval-ultratek-sd-otzyivyi-naznachenie-printsip-raboty-nasadki-i-instruktsiya>.
17. <https://www.syl.ru/article/314670/molozivo---etokorove-molozivo-kak-gotovit-molozivo>
18. <https://www.syl.ru/article/314670/molozivo---eto-korove-molozivo-kak-gotovit-molozivo>
19. [igloos.ru>razmorazhivatel-moloziva](http://igloos.ru/razmorazhivatel-moloziva)
20. [youtube.com>watch?v=2LZiesFq_-8](https://youtube.com/watch?v=2LZiesFq_-8)
21. [youtube.com \[MIRAGRO.BY\]](https://youtube.com/MIRAGRO.BY)
22. [eltemiks-vet.ru>product/razmorazhivatel-moloziva...2](http://eltemiks-vet.ru/product/razmorazhivatel-moloziva...2)
23. [igloos.ru>razmorazhivatel-moloziva](http://igloos.ru/razmorazhivatel-moloziva).
24. Zhdankin GV. Development of technology and microwave device with conical resonators for heat treatment of non-food waste of animal origin. G.V. Zhdankin, G.V. Novikova, M.V. Belova. Herald NGIEI. 2018;10(89):55–64.
25. Shamin EA. Development of a microwave device with cylindrical resonators for drying of fur and fur raw material in continuous mode. E.A. Shamin, B.G. Ziganshin, G.V. Novikov. Herald NGIEI. 2017;9(76):57–64.