On the designing method for express assessment of the state of winter crops in the process of their overwintering

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Abstract. Winter crops, having high yields in comparison with spring crops, determine the overall grain harvest, thereby providing significant contribution to strengthening the country's food security. But at the same time, climatic metamorphoses of recent years seriously affect the preliminary forecast of the amount of collected products and its final result. Therefore, the problem of current control over the safety of cereals cultivated using the technology of winter sowing is very acute today. The review of existing control methods in the autumn-winter-spring period shows that almost all methods are laborious, time-consuming, many are the result of a visual subjective assessment, there is no possibility of express assessment of the state of plants in the place where cultivated crops grow. Analysis of the mechanism of intracellular processes under plant tissue exposure to negative temperature allows saying that intracellular changes occur in it, leading to a change in the electrical conductivity of the "intercellular substance and cell contents" solution. Based on the already used methods for assessing the physiological state of plants by measuring the resistance of plant tissue, it was decided to use the same approach to create algorithm for the functioning and technical means for monitoring the winter hardiness of cultivated crops. Conducted studies have shown that the electrical resistance of plant tissue has a systematically repeating nonlinear character during freezing and thawing during measurement. Resistance measurements must be carried out at different frequencies, but due to the limited capabilities of measuring instruments to measure the high resistance of plant tissue, preference should be given to frequencies from 0.5 kHz and higher.

1 Introduction

Today, in addition to the pandemic spread on the planet and the manifestation of negative climatic factors, as well as due to the overpopulation of certain regions, the food crisis has become an acute topic. According to statistics provided by the Food and Agriculture Organization of the United Nations (FAO), over 1 billion people suffer from various forms and stages of malnutrition in the world, and about 240 million people are doomed to illness and death due to hunger. The production of crop products and raw materials in the required quantity and the required quality is just that vital necessity that can help stabilize the situation at the acceptable level for existence and create the groundwork for its improvement. At present, the agricultural sector is everywhere concerned about the preservation of plantings and sowing of plants, their protection from pests and diseases, seeks to reduce crop losses during harvesting and storage.

In many countries of the world, large percentage of arable land is allocated for winter crops, since it is well known that the latter are more productive than spring crops are. In accordance with their agricultural techniques, winter crops must be regularly monitored, their condition evaluated, and a variety of measures for their care, protection and health improvement should be designed. To take measures, it is necessary to conduct systematic surveys, which are carried out in the autumn and spring periods of the year, with mandatory control in the winter for winter crops. The features of the implementation of such surveys and methods of their implementation are to be considered.

Winter control of the state of winter crops is carried out at specified periods, as well as after each severe frost. To do this, soil samples with plants for subsequent assessment of their viability, are taken using the appropriate methods [1].

The method of monoliths or direct growing of plants in soil is the most reliable among the existing ones. In the field, monoliths with cultivated plants are cut from the frozen ground, which are transported to a room, where they are thawed at a slight positive temperature, covering the boxes with wet bags. After complete thawing, the boxes are moved to the dry, bright room with an air temperature of +16°C and after 2-3 days, when the plants grow back, all old and dead leaves are cut off. Two weeks later, the number of living and dead plants is counted, referring to living plants only those in which new leaves have grown [2].

The method of growing plants on water allows quickly assessing the viability of winter crops. As with the previous method, soil samples with plants are cut down, which are covered with burlap and delivered to the

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premises. After separating the plants from the soil after thawing, they are washed with water, the roots and leaves are cut off, and placed in the growth chamber with water, which is changed once a day. Through the holes in the lid, the plants grow in good light and at temperature of about +15°C. Viability is determined after 7 days, taking into account the plants that form new leaves and roots [2].

The sugar method practically repeats the water method, but with the difference that the washed plants are placed instead of water for 14 hours in a 2-5% sugar solution, and only after that they are transferred to clean water at room temperature. In living plants, regrowth of roots can be seen on the second day, and leaves - after five days, but the assessment of viability is also determined after a week [2].

The tillering node growing method is an accelerated method based on the ability of tillering nodes to grow back under favorable conditions. The sampling and thawing process is the same as for growing on water. After thawing and washing the plants, the shoots of the latter are cut off at some distance from the tillering node, and the roots are cut off at the tillering node. The nodes themselves are placed in Petri dishes or in glass jars with filter paper at the bottom. The containers are closed and kept for 16-24 hours at the positive temperature of +24-28°C. Viability is determined by the fact that sprouts appear from the meristem tissue in living plants, but not in those that have not wintered [2].

There are other methods that make it possible to determine the viability of the plant at any stage of its development, these include, for example, the electrometric method of Nizenkov based on measuring the electromotive force (EMF) taken from a pair of electrodes introduced into the plant and evaluating, according to the deflection of the arrow of the galvanometer, which is previously calibrated, the degree of vitality: the greater the deflection of the arrow, the higher the frost resistance [3].

A survey of crops in the spring is carried out before harrowing, two weeks after the beginning of the spring growing season carried out visually with the quantitative assessment. Visual control of overwintered and healthy plants is carried out based on such signs as: the plants must be green; they should actively and amicably resume vegetation, but some may have frozen tops of leaves; the tillering node is white in appearance, dense - when growing, new (white) nodal roots appear from it. In plants that have not overwintered, the underground part is brown, the tillering node is yellow-brown, watery, new roots are not formed. Dead plants usually appear from under the snow in a green state, but with the onset of warmth they quickly turn brown. The distribution of dead plants in crops is diffuse, in which the dead are more or less evenly distributed among living plants throughout the field, or spotty - in the form of bald patches with dead plants [4].

Assessment of the condition of winter plants in winter and winter-spring time is of very great practical importance for planning and carrying out field work to care for winter crops. At the same time, all widely applicable methods of winter control are very laborious and time-consuming to assess, because of which the results obtained cannot be operational. It is obvious that some new methods and approaches are needed for a rapid assessment of the state of winter crops.

The purpose of the article is to substantiate and experimentally test the possibility of implementing the method of operational assessment (express assessment) of the state of winter crops in the winter and spring before the start of the active phase of field work.

2 Materials and methods

To design technical tool and substantiate the algorithm for its functioning, it is necessary to establish a physical phenomenon or law of natural science, based on which the device can work properly and provide reliable results for analysis [5]. Let us consider the essence of the processes occurring in the plant organism when exposed to negative temperatures.

It is well known from the course of plant physiology and morphology that ice formed during slow freezing in the intercellular spaces and cell walls of plant tissue draws water from the cells; the cell sap becomes concentrated, and as a result, the pH of the medium changes. At the same time, there is a loss of a very large amount of calcium ions by the membranes, above the threshold value. As a result, the number of calcium ions in the cytoplasm increases and the normal functioning of membrane structures is disrupted - "proton pumps" in membrane walls are inactivated, and a group of enzymes that catalyze the hydrolysis of phospholipids, on the contrary, are activated, which causes ion leakage, thereby stimulating the degradation of membrane lipids. The main reasons for the death of plants exposed to negative temperatures are an irreversible increase in membrane permeability, damage to cell metabolism and the accumulation of toxic substances [6, 7].

Having analyzed the processes occurring in the intracellular and intercellular spaces during freezing and thawing of plant tissue, they will be correlated with the theory of electrical conductivity.

It is well known from the courses of biophysics and electrophysiology of plants that the electric substitution circuit of the cell is a mixed (series-parallel) connection of active and capacitive elements, as well as sources of EMF. The sources of EMF characterize the fact established by research that there is an ion exchange between the intra- and extracellular environment, creating a potential difference of 60-80 mV on the membrane surface. Capacitive properties in the cell are possessed by the cell membrane, the membrane of the vacuole and the nucleus, and the active resistance - by the electrolytic components: the intracellular and intercellular environment [8].

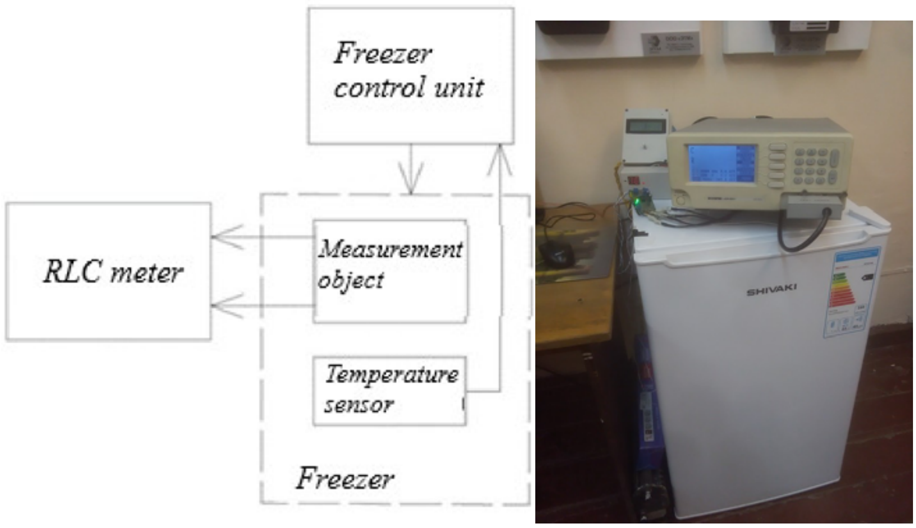
As already noted, organic intracellular and intercellular spaces are filled with liquid media, which in their electrical conductive properties are close to electrolyte solutions or to conductors of the second kind, and which, depending on the amount of dissolved salts, sugars or other minerals, changes in the pH value of the medium, the presence of water change their characteristics, thereby affecting the electrical conductivity not only of the individual cell, but also of the plant tissue as a whole.

In the practice of electrical technology, methods for determining damage to plant tissue, for example, by electric or thermal effects, are known and are successfully used, which are based on fixing the change in the impedance of tissue resistance (or its components) by the frequency of the measuring current, as well as assessing the depth of damage determined by the ratio of tissue resistance measured at high and low frequencies of the measuring current [9]. In addition, the measurement of electrical conductivity or electrical impedance and its components is widely used to determine the physiological state of plant tissues, for example, to detect damage to apples [10]; assessment of the ripening of various fruits [11, 12]; determination of the state of water in tomatoes [13]; determination of the objective dependence of the resistance of plant tissue on temperature [14], etc.

Thus, having considered the mechanism of intracellular reactions and studied the behavior of the cellular structures of plant tissues exposed to low, negative temperatures, the possibility of designing the algorithm and creating technical means that fixes changes in electrical conductivity characteristic of "intracellular and intercellular electrolytic solutions" depending on temperature can be disscussed.

To implement the above provisions, series of experiments was carried out to study the effect of negative and positive temperatures on the electrical resistance of plant tissue of cultures during freezing and thawing, as well as the behavior of experimental dependences as a function of the measuring current frequency.

The dependences were obtained experimentally on winter wheat plants in winter and spring using a SHIVAKI SFR-81W freezer. To control the freezer, or rather to set, regulate and maintain the required temperature, a special control unit was made. The resistance of plant tissue to an alternating measuring current with a variable frequency during freezing and thawing was monitored using a GW Instek LCR-821 RLC-meter, and the air and soil temperature was monitored with the DS1820 digital sensor [15]. The block diagram and appearance of the experimental setup are presented in Figure 1.



(a) (b)

Fig. 1. Block diagram (a) and external view (b) of the experimental setup.

In the educational farm "Gornaya Polyana" of Volgograd State Agrarian University, monolith (40x40x15cm) was cut down on the field of winter wheat crops, which was warmed up under room conditions and divided into seedling pots. In turn, the pots were placed in the SHIVAKI SFR-81W freezer and frozen at temperatures: -5; -10; -15; -17.5 and -33°C. Then it thawed at room temperature. Both during freezing and thawing, the resistance of plant tissue to alternating current was measured at frequencies: 0.012; 0.02; 0.1; 0.5; 1 and 2 kHz. Preliminary studies have releaved that at the temperature of -10°C all winter wheat plants were alive, at the same time at -17.5°C they perished. The temperature range from -12 to -13 ° C was taken as the survival limit.

3 Results and discussion

Basing on the results of the conducted studies, the dependences of electrical resistance on temperature were built.

As an example, the graphs of changes in the resistance of plant tissue at frequencies of the measuring current of 12 Hz and 1 kHz, obtained during freezing to -10 and -17.5 ° C, were considered (Fig. 2).

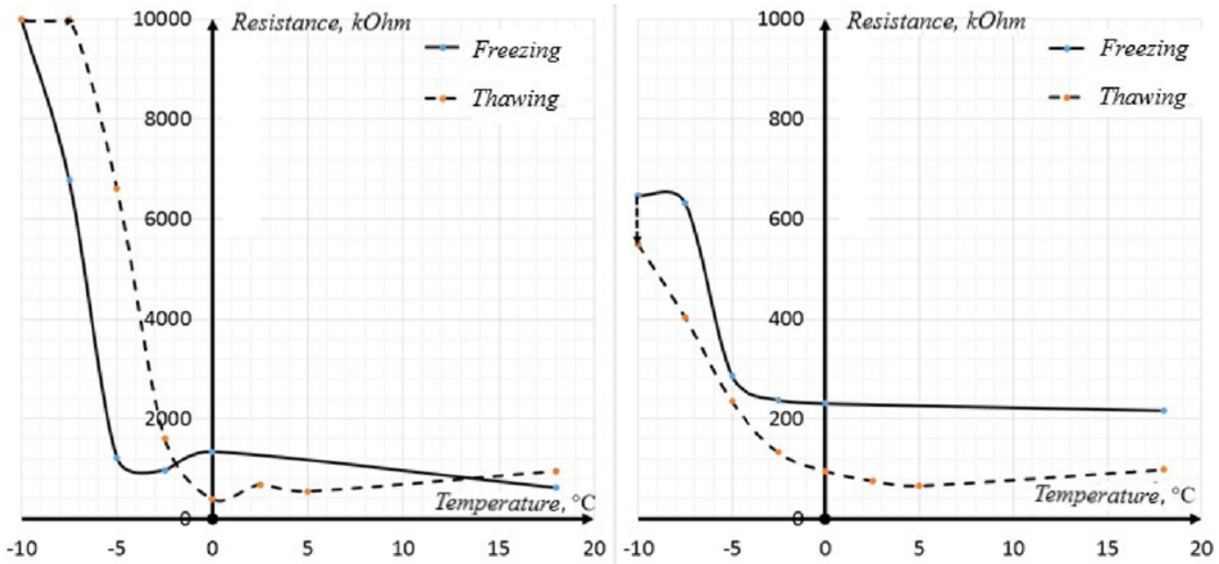


Fig. 2. Change in the plant tissue resistance during freezing at up to -10°C and subsequent thawing at frequencies of 12 Hz (a) and 1 kHz (b).

From the analysis of the first two graphs (Fig. 2), it can be seen that changes in the electrical resistance of plant tissue with the decrease in temperature at first appear insignificant, and only after the temperature in the freezer reaches -5°C we observed a sharp increase. The behavior of the dependences of changes in the plant tissue resistance at both frequencies is practically the same, but with the increase in the measuring current frequency, the difference in the numerical values of tissue resistances during freezing and thawing increases. At the same time, the plant remained alive.

In the next pair of graphs (Fig. 3), this resistance difference has increased significantly. The nature of the change in resistance is almost the same as in Figure 1, but in numerical values, the difference in resistances before and after freezing changed almost tenfold. In this case, the plant perished.

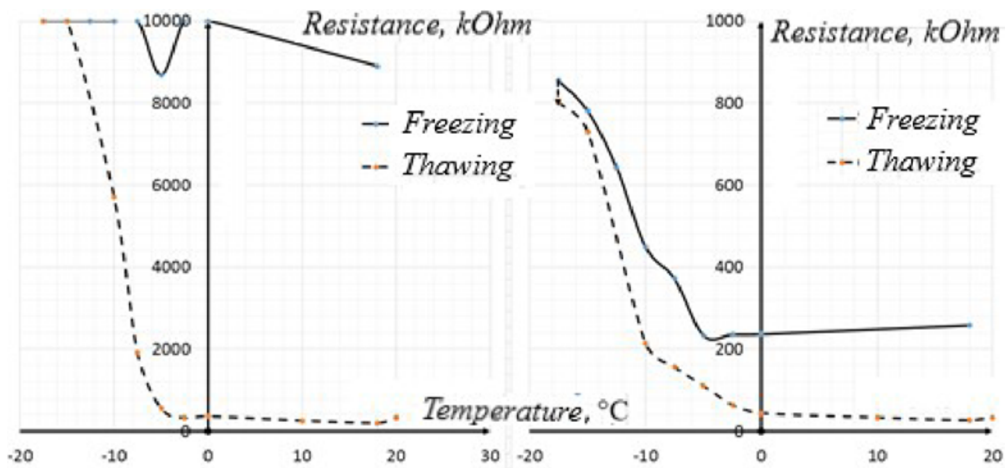


Fig. 3. Change in the plant tissue resistance during freezing at up to -17.5°C and subsequent thawing at frequencies of 12 Hz (a) and 1 kHz (b).

The summary graph of all the taken experimental data is presented in the form of changes in the electrical plant tissue resistance after thawing relatively the resistance before freezing (Fig. 4). Experimental studies were carried out at 6 frequencies of the measuring current in the temperature range from 0 to -34°C (the minimum is taken from the possibility of the available freezer).

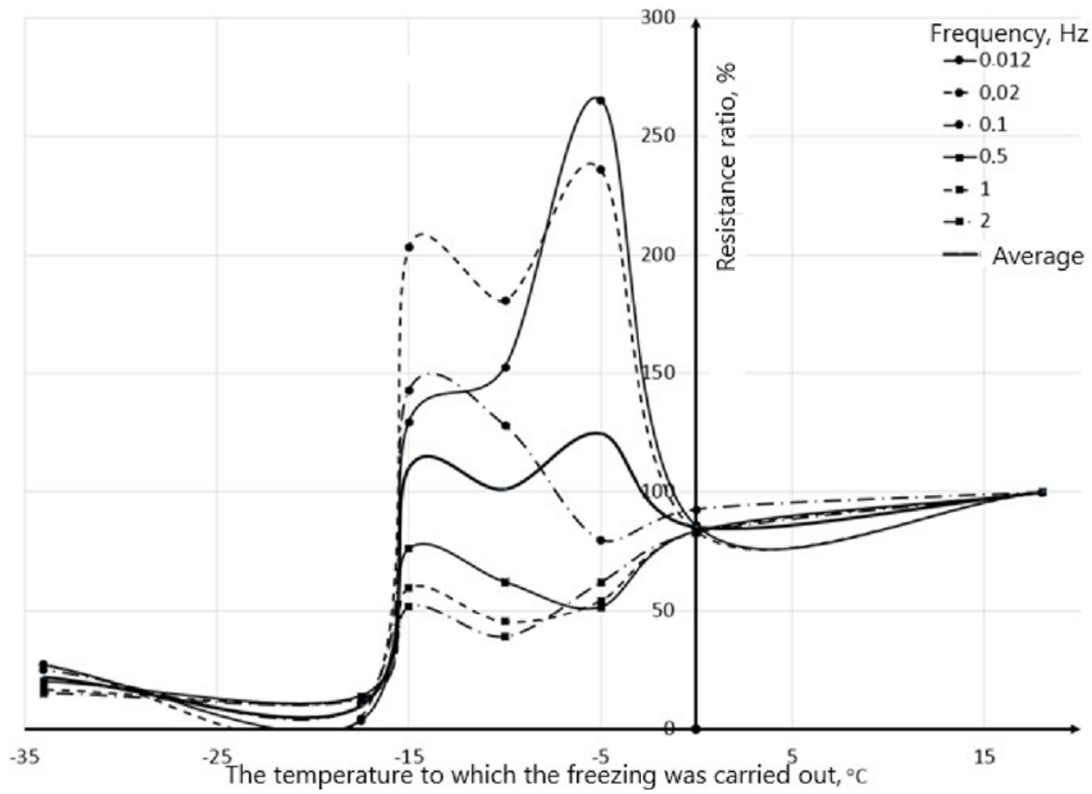


Fig. 4. Change in the plant tissue resistance after exposure to negative temperatures at different frequencies.

From the analysis of the behavior of the dependences presented in Figure 4, it can be seen that all graphs in the temperature range from 0 to -15 ° C are sharply nonlinear. It is this nonlinearity that should be used to find an objective way to assess the plant tissue state of winter crops. And although the nature of the nonlinearity is different for various plots, significant numerical differences in the relative resistances at the frequencies adopted for measurement allow one to continue research, collection and processing of experimental results for the final substantiation of the method for determining the plant viability by measuring the electrical resistance of its tissue and creating a portable technical means for its implementation.

4 Conclusion

Basing on the results of the carried out research and the analysis of the obtained results, the following can be stated:

1) Plant tissue resistances during freezing and thawing under laboratory conditions at different frequencies are nonlinear.

2) Resistance measurements must be carried out at different frequencies, but due to the limited capabilities of measuring instruments to measure the high resistance of plant tissue, preference should be given to frequencies from 0.5 kHz and higher.

3) In further studies, special attention should be paid to the range of negative temperatures of -17.5...-10°C.

4) The obtained results of experimental studies make it possible to substantiate the measurement of the electrical conductivity of plant tissue as a way to determine the state of winter crops and assess their viability.

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