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Enhancing Root Formation in "Kishmish Black" Grape Cuttings Using Alternating Electric Current

Abdurahim Berdishev[1], Nuriddin Markayev[1], Mukhabbat Abdirova[2*], Aidos Mussabekov[3], Nodira Nuraliyeva[1]

[1] Department of Electrotechnologies and Operation of Electrical Equipment, "Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University, Tashkent 100000, Uzbekistan
[2] Department of Energy Saving and Automation, Kazakh National Agrarian Research University, Almaty 050010, Republic of Kazakhstan
[3] Department of Biology, South Kazakhstan State Pedagogical University, Shymkent 160012, Republic of Kazakhstan

Corresponding Author Email: mukhabbatabdirova@gmail.com

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ABSTRACT

This study aims to scrutinize the influence of electric alternating current on the yield of "Kishmish Black" grapes. To dissect the structural elements, an array of methods was deployed, including logical analysis, analogy, abstraction, deduction, induction, and synthesis. The findings reveal that several factors such as the distance between the electrode and vine stem (l1), stem length (l2), inter-electrode distance (l3), area covered by water electrodes (S1), vine stem surface area (S2), processing voltage (U), and processing time (τ) should be considered — with the inter-electrode distance (l) meriting particular attention. Moreover, it was observed that pre-planting treatment of grape cuttings with alternating current accelerates root formation by 15-20%. This enhancement subsequently increases the survival rate of grape cuttings by 20-22%. Furthermore, this treatment was associated with increased length of the main branch of grape seedlings (45-60 cm), an increase in the number of roots (8-10), and an extension in root length (21-24 cm). These improvements collectively augment the efficiency of seedling cultivation. The study illuminates the positive effects of electric alternating current application on the yield and growth of grape cuttings. This treatment strategy expedites root formation and bolsters seedling growth. The practical implications of these results provide valuable recommendations geared towards elevating the cultivation efficiency of "Kishmish Black" grapes.

1. INTRODUCTION

Viticulture remains a progressively evolving industry. As noted by Dauletova et al. [1], the creation of new vineyards and the replanting of existing ones are continually occurring phenomena. These activities necessitate a consistent demand for high-quality grafted and own-rooted seedlings. Various growth regulators have been explored in an attempt to enhance their productivity and quality [2]; however, these regulators often fall short of achieving the desired effects in production conditions. Tastanbekova et al. [3] point out the limitations of these regulators; not only are they expensive, but their compliance with environmental, medical, and production requirements is not always guaranteed.

The regeneration processes in grape cuttings during rooting require close attention, particularly to indicators such as the degree and intensity of overwintering bud opening [4]. This significance, as explained by Azhitaeva et al. [5], is attributable to the fact that shoots derive from these wintering buds. Synthesized auxins within these swollen buds migrate to the lower part of the cuttings, thereby facilitating root formation.

Grape seedlings can be propagated through various means, including in vitro seeds, vegetative methods, and other cultivated plants. The rate of root formation serves as a significant indicator of the ability of grape cuttings to root [6]. To expedite the development and enhance the quality of seedlings, grape cuttings are often treated pre-planting to accelerate root formation [7]. However, cuttings planted without treatment may fail to root, or they may initially sprout leaves and stems only to subsequently wither. This scenario arises when the root formation is insufficient, and the nutrient and moisture reserves accumulated in the previous year are depleted before root formation [8].

These observations suggest that pre-planting treatment of grape cuttings can enhance both the rate of root formation and the number of roots. Currently, a variety of methods such as mechanical, physiological, chemical, and traditional have been deployed to augment the activity of regenerative processes in grape cuttings. However, under production conditions, these methods often fail to yield the expected outcomes.

Mechanical methods pose the risk of physically damaging grape cuttings, potentially not uniformly eliciting the sought responses. Physiological methods, though designed to augment the plant's natural processes, can yield unpredictable results, as grape varieties exhibit differential responses. Chemical methods, involving growth regulators, may not consistently achieve effectiveness and can introduce cost, environmental, and health concerns. Traditional methods, while historically rooted, may not satisfy the requirements of contemporary viticulture or demonstrate universal effectiveness.

The literature presents evidence of the potential benefits of electrophysical methods (including electric current, electricity, magnet, pulsed electromagnetic field, and electromagnetic fields) on plant-related materials [9]. However, to date, the theoretical and practical aspects of the optimal electrotechnology pre-treatment method for grape cuttings remain under-researched and are not widely incorporated into seedling cultivation technology [6].

Given this context, the aim of the current research is to investigate the influence of alternating electric current on the root formation of "Kishmish Black" grape cuttings.

2. MATERIALS AND METHODS

The initial experiments were carried out on cuttings of grape varieties “Kishmish Black”. Before planting, electrodes were placed on grape cuttings in 4 working chambers of the same volume (dielectric container, capacity 3.8 l) for treatment with electric current. The length of the electrodes in the working chambers is 16cm, the height is 8.5cm, the distance between the electrodes is 24cm (Figures 1 and 2).

Figure 1 depicts a representation of the initial setup used for the preliminary trials on grape cuttings.

Figure 1. Stand for preliminary experiments

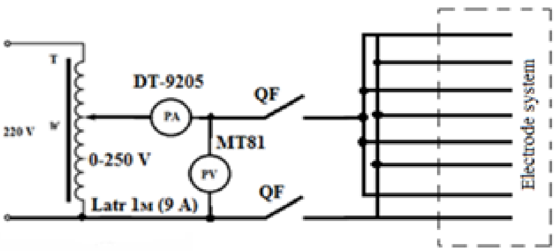

Figure 2. Schematic diagram of the experimental device

Figure 2 provides a visual representation of the apparatus, including the placement and spacing of electrodes.

The rate of root formation, the number of roots and the level of resistance in grape cuttings were determined by the electric field strength (E) at each value (14, 37, 71, 94, 103 V/m) and the initial treatment time (τ) 4, 8, 12, 15 processed and studied within 24 hours [10]. After treatment, the grapevine cuttings were kept under the same conditions, and the rate of root formation, the number of roots formed, and the degree of rooting of the grapevine cuttings were measured [11]. To consolidate the results obtained in the initial experiments, 20 12-liter dielectric containers of the same volume were prepared. Electrodes made of stainless material were placed in the vessels (Figure 3).

Figure 3. General view of the equipment for pre-treatment before planting grape cuttings of the “Kishmish Black” variety

Figure 3 offers a broader view of the equipment setup for the actual experiments, following the preliminary trials.

The experiments were carried out on 4-5-eye cuttings of grapes 45-50 cm long and with an average diameter of 1.2-1.5 cm. processing up to 10, 20, 30, 40 and 50 V, distance between electrodes up to 45, 50, 55, 60 and 65 cm. One of the most effective ways to deliver useful energy to cuttings in the process of electrifying grapevine cuttings is through an electrically conductive liquid. In this technological process, that is, before planting, grape cuttings are treated with alternating current, a two-component agent-conductive liquid (water) and grape cuttings [12]. In this technological process, the energy absorbed by the sludge does useful work. The energy absorbed by the liquid is used to heat the water and is wasted. To achieve maximum efficiency of electrical stimulation of the level of root formation in cuttings, it is necessary to determine the optimal volumetric ratio of water and cuttings. Kudryakov [6] suggested that the level of root formation in cuttings can be found using the following formula when determining the ratio between the electrical conductivity of a two-component system (water and cuttings):

$$\gamma = \gamma_1 \cdot X_1 + \gamma_2 \cdot X_2 \tag{1}$$

where, γ_1 -electrical conductivity of the grape stem; X_1 -volumetric concentration of grape cuttings; γ_2-conductivity of an electrically conductive liquid; X_2-volumetric concentration of electrically conductive liquid.

In a two-component system, the volume concentration of grape stalks and the volume concentration of an electrically conductive liquid can be put forward the following hypothesis:

$$\sum_{i=1}^{2} (\gamma_i - \gamma_{ec}) \cdot X_i \approx 0 \tag{2}$$

where, γ_i-electrical conductivity of component I of the system; γ_{ec} -electrical conductivity of the system; X_i -volumetric concentration of the i-th component of the system.

If in the technological process (2) the formula X_i is the volume concentration of the I component of the system X_i^{sh} the system can be considered as less than or equal to the effective volume concentration of the I component:

$$X_i^{sh} \leq X_i \tag{3}$$

where, X_i^{sh} -effective volume concentration of the i-th component of the system.

So, the formula for this case is as follows:

$$\sum_{i=1}^{2}(\gamma_i - \gamma_{ec}) \cdot X_i^{sh} = 0 \tag{4}$$

where, X_i^{sh} -determine what the effective volume concentration of the i-th component of the system is equal to:

$$X_i^{sh} = \frac{X_i}{f\left(\frac{\gamma_i}{\gamma_{ec}}\right)} \tag{5}$$

The function $f(y)$ can be expressed:

$$\sum_{i=1}^{2}(\gamma_i - \gamma_{ec}) \frac{X_i}{1 + d_i \frac{\gamma_i}{\gamma_{ec}}} = 0 \tag{6}$$

For this case, the solution of the equation (*i*=2) will look like:

$$\gamma_{ec} = A(X_i, \gamma_{i,} d_i) + \sqrt{A^2(X_i \cdot \gamma_i \cdot d_i) + \gamma_1 \cdot \gamma_2(d_i \cdot X_2 + d_i \cdot X_i)} \tag{7}$$

$$A = (X_i, \gamma_i, d_i) = \frac{\gamma_1(X_1 - d_i \cdot X_2) + \gamma_2(X_2 - d_i \cdot X_1)}{2} \tag{8}$$

Then γ_{ec}, the total electrical conductivity of the system, can be written as follows:

$$\gamma_{ec} = \frac{(3X_1 - 1) \cdot \gamma_1 + (3X_2 - 1) \cdot \gamma_2}{4} + \sqrt{\frac{[(3X_1 - 1) \cdot \gamma_1 + (3X_2 - 1) \cdot \gamma_2]^2}{16} + \frac{\gamma_1 \cdot \gamma_2}{2}} \tag{9}$$

The second component, water, is used to supply cuttings with useful energy in AC technology before planting vine cuttings. In this case, part of the entire energy used in the process is absorbed by a high concentration of water and goes to heat it. To characterize an efficient electrical technology for growing grape seedlings (pre-treatment with alternating electric current before planting on grapevine cuttings), it is necessary to determine the energy absorbed in a two-component system and optimize the process. Turchanin et al. [12] studied the total amount absorbed in a two-component (water and stalk) system W_{um} used the Joule-Lenz formula to describe the energy when calculating energy consumption:

$$W_0 = \gamma_{ec} \cdot U^2 \tag{10}$$

Therefore, according to the law of conservation of energy, the technology uses a second system of components, which is absorbed by the cuttings of the vine. W_0 useful energy can be expressed as follows:

$$W_1 = W_0 - W_2 \tag{11}$$

where, W_1 -useful energy absorbed by grape cuttings; W_2 -energy used for electric water heating.

In his research, Kudryakov [6] determined the Eq. (12) in the electrical processing of cuttings of fruit trees, that is, the level of electrical conductivity in the electrical processing of cuttings of fruit trees (S_1) is described as follows:

$$S_1 = 1 - \left(S_0 - \frac{\gamma}{\alpha}\right) \cdot e^{-\alpha(W - W_0)} - \frac{\gamma}{\alpha} \tag{12}$$

It is possible to record the energy used to electrically stimulate grapevine cuttings:

$$P_1 = I \cdot U \cdot cos\,\phi = U \cdot I \cdot \frac{g}{y} = U \cdot I \cdot Z \cdot g = g \cdot U^2 = \frac{1}{R_q} \cdot U^2 \tag{13}$$

The useful energy (Wqal. foy) absorbed by the vine when the vine stems are electrically heated was expressed as follows:

$$W_1 = P_1 \cdot \tau = \frac{\tau}{R} \cdot U^2 = U^2 \frac{\tau}{R} = U^2 \frac{\tau}{\rho_q \frac{l}{S}} \tag{14}$$

where, τ-time of electrical treatment of vine cuttings; *l*-vine stem length; *S*-pen cross-sectional area; ρ_q -vine branch resistivity.

The energy expended on electric heating of water should be determined, according to the Joule-Lenz formula for a system of flat parallel electrodes:

$$W_2 = P_2 \cdot \tau = U^2 \frac{\tau}{R_s} = U^2 \frac{\tau}{\frac{\rho_s l}{S}} = U^2 \frac{\tau}{\frac{\rho_s l}{(v \cdot h)}} \tag{15}$$

where, ρ_q -resistivity of water; *l*-distance between straight parallel electrode system; *v*, *h*-geometric dimensions of the electrode system.

If Eqs. (10) and (15) would be substituted into Eq. (12), it will be:

$$S_1 = 1 - \left(S_0 - \frac{\gamma}{\alpha}\right) \cdot e^{-\alpha\left(\gamma_{yc} \cdot U^2 - U^2 \frac{\tau}{\frac{\rho_s l}{(v \cdot h)}}\right)} - \frac{\gamma}{\alpha} \tag{16}$$

If the illustrated Eq. (16) would be simplified, the theoretical Eq. (17) will be obtained:

$$S_1 = 1 - \left(S_0 - \frac{\gamma}{\alpha}\right) \cdot e^{-\alpha\left(U^2 \frac{\tau}{\rho_q \frac{l}{S}}\right)} - \frac{\gamma}{\alpha} \tag{17}$$

The study of the geometric dimensions of grapevine cuttings showed that according to GOST 1191-2009 (O'zDSt 1191: 2009) and GOST 28181-89, cuttings should be 1.2-1.5 cm in diameter. At the same time, the value of the cross-sectional area (S) of the cutting is in the range of 113.04-176.625 mm^2, with a specific resistance (ρ) and 106.73-164.85 Ohm-It has been established that it varies within m. It can be seen from this expression that the level of stability of grapevine cuttings depends on the processing voltage (U), processing time (τ), shows that the distance between the electrodes depends on (l). Theoretical Eq. (17) characterizes the efficiency of treatment with alternating electric current before planting on vine cuttings. E59 No. 92729 (45-55Hz) was used as a milliammeter, and measuring equipment E59 No. 92716 (45-55Hz) was used to determine the energy parameters. The measuring equipment was checked for error using DT-9205 A and LINI-T UT51 multimeters. All studies were carried out on cuttings of the grape variety "Kishmish Black". To maximize the acceleration of root formation and increase the number of roots, experiments were carried out to change the treatment time (τ), exposure voltage (U) and the distance between the electrodes. According to the results of the research, the level of root formation in grape cuttings (the number of roots N and the root formation rate Z) was determined by the activity of the root formation rate (S, %).

The experiment involves the utilization of three primary components: electrodes, dielectric containers, and an electrically conductive liquid. Electrodes are conductive materials that allow the flow of electric current. In the context of this experiment, electrodes are placed on grape cuttings to facilitate treatment with an electric current. Their dimensions and spacing are crucial for the success of the experiment. Dielectric Containers serve as the vessel where the grape cuttings are placed for treatment. These containers are designed to prevent the flow of electricity, ensuring that the electric field is confined within the bounds of the container and interacts directly with the grape cuttings. Electrically Conductive Liquid, in this case water, acts as a medium to transmit electrical energy. When grape cuttings are treated with alternating current, this two-component system (conductive liquid and grape cuttings) plays a vital role in the electrification process.

The methods describe an experiment on grape cuttings, specifically the "Kishmish Black" variety, which were subjected to electric current treatment using a specific setup. Crucial to the reproducibility of the experiment are the specific details about conditions like temperature, humidity, and light. This is essential to ensure consistent results when replicated by other researchers. Grape cuttings, with specific lengths and diameters, were treated using electrodes placed in dielectric containers. These cuttings were then subjected to various electric field strengths and treatment times. Following the treatment, observations related to root formation and rooting degree were made. One significant goal was determining the optimal ratio of water to cuttings for efficient electrical stimulation of root formation.

3. RESULTS

Based on the results of the above theoretical studies, in order to improve the resistance of grapevine cuttings, the following main factors representing the influence of alternating electric current were adopted: treatment voltage (U), treatment time (τ) and electrode distance (l). To assess the efficiency of AC treatment and the characteristics of the treated cuttings, the rooting rate (S) was taken as the number of roots (N) and the rooting rate (Z) formed in the vine cuttings. The experiments were carried out in the classical way, i.e., one of the factors changed, while the other two remained fixed. The results of the experiments carried out are expressed in graphical form. The results of the experiment were processed by the methods of mathematical statistics. When applying the methods of mathematical statistics, the program "Regression Analysis" was used in the spreadsheet editor Excel using EXM. By means of regression analysis, it was established that the randomly changing parameter Y is directly related to the independently changing value (factor) x. The dependence of the number of roots formed on the cuttings of the "Kishmish Black" grape variety on the processing voltage and present the corresponding graph will be analysed (Figure 4).

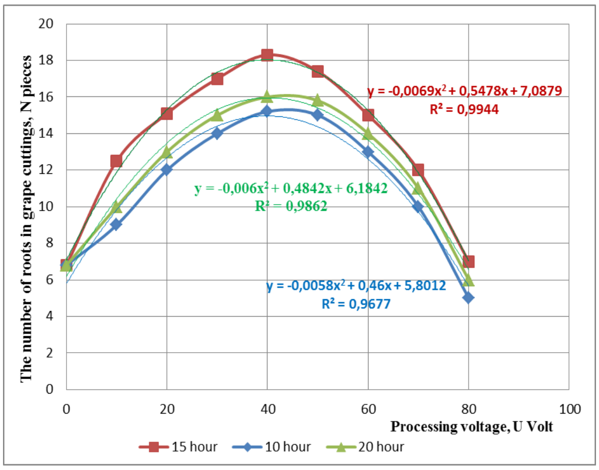

Figure 4. Dependence of the number of roots formed on the cuttings of grape variety "Kishmish Black" on the processing stress

From the graphical analysis $N = f(U)$ the following was established. When pre-treatment with alternating current before planting on vine cuttings, it is necessary to take into account the values of the treatment voltage. At the same time, increasing the processing voltage to 40 V increases the number of roots formed in the cuttings. When the voltage value from 40 V is increased, the number of roots formed decreases. This is due to the fact that the amount of current flowing through the cutting increases with increasing voltage, and the cell tissue begins to die under the influence of a large current. As a result, the grape cuttings dry out. To analyse the dependence of the number of roots formed on the cuttings of the grape variety "Kishmish Black" on the processing time, one can refer to the corresponding graph shown in Figure 5.

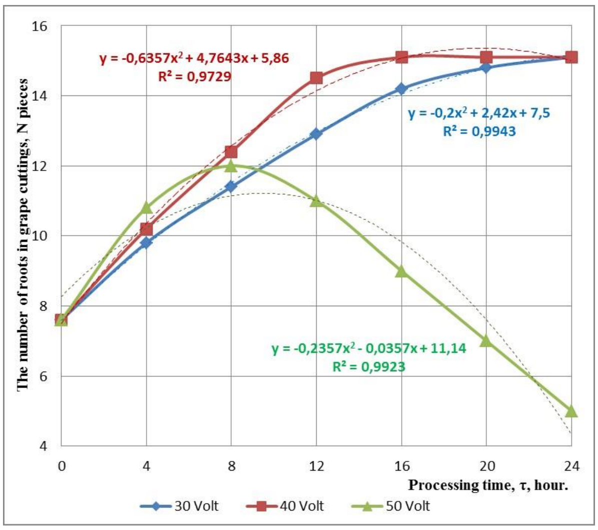

Figure 5. Dependence of the number of roots formed on the cuttings of grape variety "Kishmish Black" on the processing time

The number of roots formed in the cuttings during electro propagation depends on the processing time. There is an increase in the number of roots with an increase in the duration of treatment up to 15 hours. A large number of rhizomes formed quickly absorb water and minerals dissolved in the soil, while their capacity increases. Treatment time exceeding 15 hours will cause damage to cells and tissues, which will reduce its physiological activity. As a result, the number of roots will be drastically reduced. To illustrate the dependence of the number of roots formed on the cuttings of the "Kishmish Black" variety of grapes on the distance between the electrodes, one can use the corresponding graph shown in Figure 6.

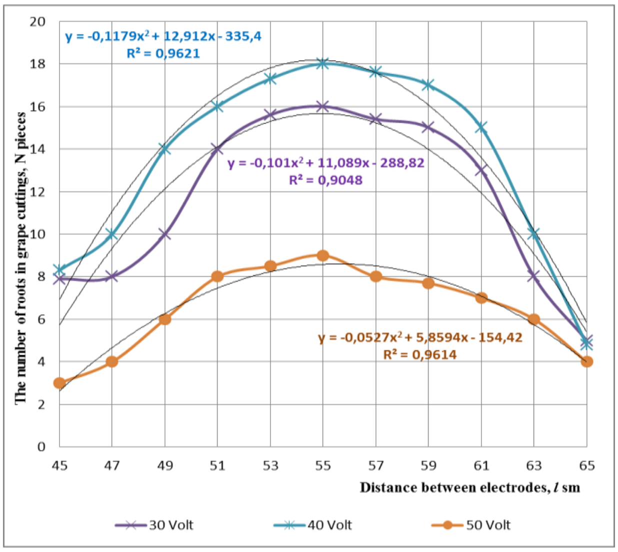

Figure 6. Dependence of the number of roots formed on the cuttings of grape variety "Kishmish Black" on the distance between the electrodes

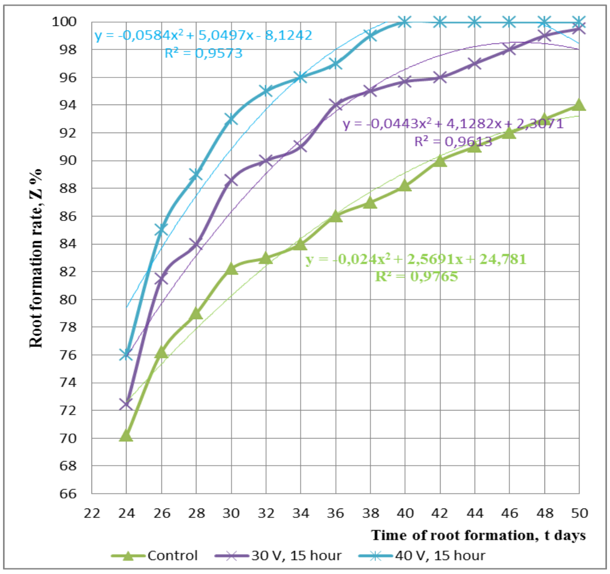

Figure 7. The degree of root formation of grape cuttings of the "Kishmish Black" variety, depending on the time of root formation

By analysing the results of the experiment in the form of graph $N = f(l)$ the following was established. Before planting grapevine cuttings, it is important to consider the distance between the electrodes when treating with alternating current. Changing the length of the handle and the distance between the electrodes affects the amount of electricity passing through the handle. The functional relationship between the number of roots formed in the cuttings and the distance between the electrodes was studied, and the following indicators were determined. When the distance between the electrodes and the handle is 2-2.5 cm (the distance between the electrodes is 55cm), the number of roots formed in the handle increases. Increasing or decreasing the distance will cause a change in the resistance between the electrodes and the cuttings and will reduce the impact force (Figure 7).

From the analysis of the results of the experiment in graphical form $N = f(\tau)$ the following was established: When exposed to alternating electric current, cells in the tissues of grape stems are excited due to the energy supplied, the activation of physiological processes enhances the physicochemical reactions in the stems. As a result, the rate of root formation in pre-treated vine cuttings is accelerated. The best result is achieved when the rooting acceleration is equal to a treatment time of 15 hours and a treatment voltage of 40V. When studying the functional relationship between the degree of root formation (speed) and the time of root formation, the following indicators were identified. When the processing voltage of grape cuttings before planting is 40V, the duration of processing is 15 hours, the root formation rate is accelerated by 15-20% due to the enhancement of physicochemical reactions in the cells of the cutting tissue. To illustrate the dependence of the degree of resistance on treatment with alternating electric current before planting on the cuttings of grape varieties "Kishmish Black", the graph shown in Figure 8 can be presented.

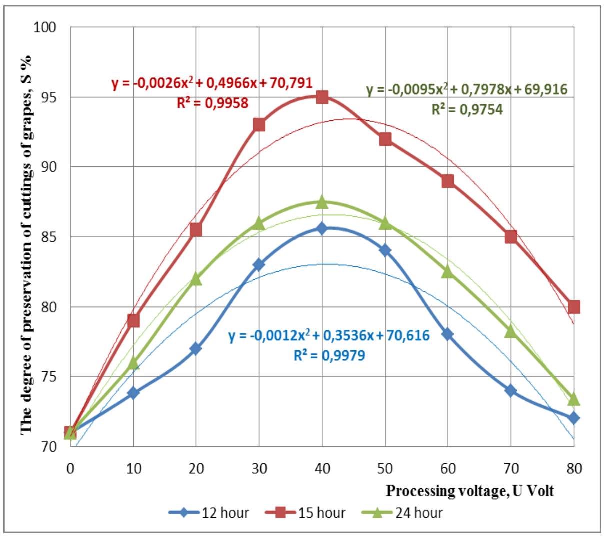

Figure 8. Dependence of the degree of electrical resistance on the voltage treatment of grape cuttings of the "Kishmish Black" variety before planting with alternating electric current

From the analysis of the results of the experiment in the form of graph $S = f(U)$ the following conclusion can be drawn. Under the action of an electric current, the elastic transport of absorbents through intercellular contact is enhanced, ions migrate along additional ion channels through the cell membrane, and cells are excited due to electrical stimulation. As a result, high chemical activity leads to complex physiological reactions and certain morphological, i.e., biochemical and biophysical phenomena, depending on the stress of exposure. Based on this, the dependence of the operating voltage on the capacitance was studied during treatment with alternating electric current before planting grape cuttings. With a processing voltage of 40V, the degree of root formation of grape cuttings is 94-95%. Exceeding the voltage value of 40V will damage the elements. negatively affects the level of root formation. Electrical stimulation affects plant cells by altering the balance of charged particles inside and outside the cell. This modification can activate pathways inside the cell that influence growth, speed up cell division to assist root formation, direct the growth of roots through the effect on plant hormones, and make plants more resilient to stress, overall promoting better growth. Essentially, using electrical stimulation encourages plants to produce roots more rapidly and in a more robust manner. As a result, the adhesion of the cuttings is reduced. To illustrate the dependence of the degree of resistance on treatment with alternating electric current before planting on the cuttings of grapes of the “Kishmish Black” variety, the graph shown in Figure 9 is presented.

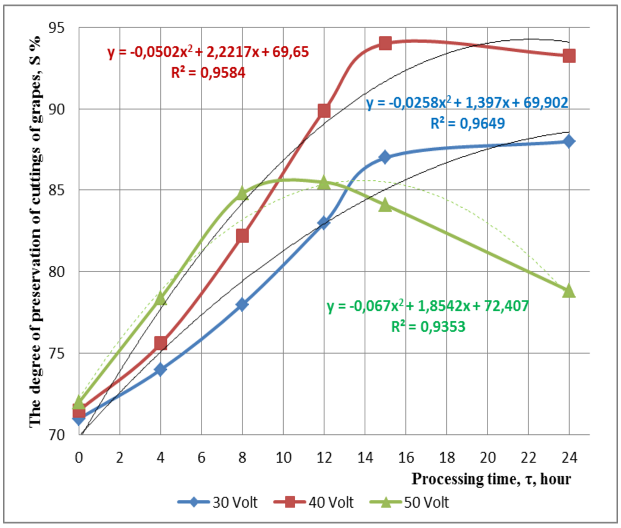

Figure 9. Dependence of processing time on the degree of stability when treated with alternating electric current before planting grape cuttings of the “Kishmish Black” variety

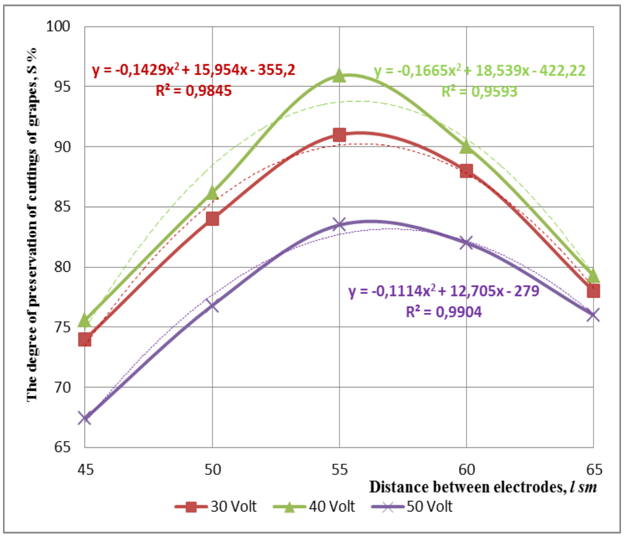

Figure 10. Dependence of the conductivity level on the distance between the electrodes when treated with alternating electric current before planting grape cuttings of the “Kishmish Black” variety

Obtained on the basis of $S = f(\tau)$ experiments from graphical analysis, the following was found. By increasing the stability of grape cuttings by increasing the time of treatment with alternating electric current up to 15 hours before planting, it is possible to increase the stability of cuttings to 92-94% due to increased physical and chemical reactions. Increasing the treatment time from 15 hours does not increase the retention rate, but rather wastes energy. To illustrate the dependence of the resistance level on the distance between the electrodes when treated with an alternating electric current before planting the cuttings of the “Kishmish Black” grape variety, the graph shown in Figure 10.

Described according to the results of experiments and the results of studies $S = f(l)$ from graphical analysis, it can be concluded that the distance between the electrodes should be 55cm, depending on the length of the cuttings (50cm) and the processing voltage (40V) during primary treatment with alternating electric current before planting on the cuttings grapes. Changing the distance between the electrodes causes a change in the amount of electric current acting on the pen. The distance between the electrodes at the optimal value (55cm) results in efficient absorption of the input energy by the handles and increases retention up to 95%. Exceeding the distance between the electrodes by 55cm during processing reduces the positive effect of alternating electric current on the handles and leads to a decrease in their capacity. This conclusion was made by the analysis of the study and its results. The faster the number of roots and root formation of the planted cuttings, the higher the capacity of the cuttings. To get acquainted with the results of this study, the dependence of the number of roots formed on the cuttings of the “Kishmish Black” grape variety when treated with alternating electric current before planting can be seen (Figure 11).

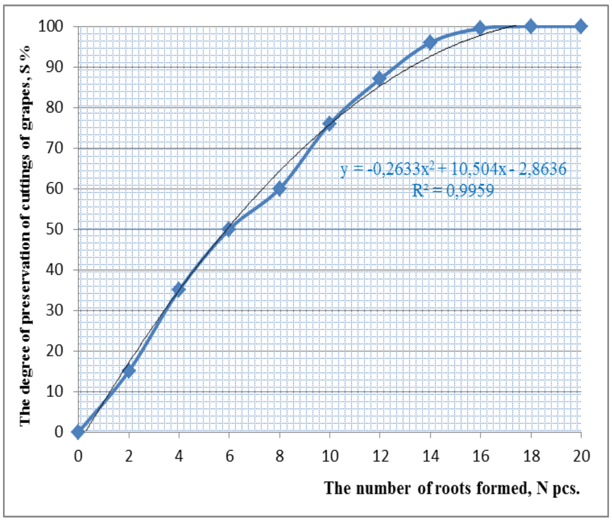

Figure 11. Dependence of the number of roots formed during the treatment with alternating electric current before planting cuttings of grapes of the “Kishmish Black” variety, on the degree of resistance

According to the results of research and experience 55 from graphical analysis, it can be concluded that during the primary processing of the grape stalks of the “Kishmish Black” variety with alternating electric current, the cells in the tissues of the stalk are excited due to electrical stimulation. The action of excited radicals and molecules causes certain morphological or biochemical and biophysical phenomena, depending on the amount of absorbed energy, i.e., affecting during development, with high chemical activity, high physiological reactions. This accelerates the formation of roots in cuttings (by 15-20%) and increases the number of roots (4-6 pieces). As a result, the activity of taking mineral substances into the soil increases, and due to the increase in the intensity of photosynthesis, the stalk grows steadily and the level of its retention increases.

Electric stimulation significantly impacts the root growth of grapevine cuttings. The study focused on treatment voltage, treatment time, and electrode distance. An optimal voltage of 40 V was identified, with higher voltages harming the cuttings due to excessive current. The best treatment duration is 15 hours, as longer times can damage cells and reduce root growth. The distance between the electrodes also matters, with 55 cm being optimal, closely matching the grapevine's length. Overall, electrical stimulation accelerates root formation, allowing cuttings to better absorb minerals and water. Grape cuttings treated in this manner grow roots 15-20% faster, leading to healthier and more resilient plants.

4. DISCUSSION

Electrophysical factors affect the stimulation of plant growth. One of the possible ways to implement this effect is the use of electric current on a part of the shoot with buds for vegetative propagation. With this treatment, physiological processes are activated when the current passes directly through the cutting in the longitudinal direction. The results of the analysis of the application of such an impact on the cuttings of grapes and other crops show that the most effective is the supply of electrical energy to the cuts of the cuttings through a conductive liquid. Thus, only the lower part of the cuttings was treated with electric current. However, given the biological characteristics of the root formation of cuttings, it can be established that this method has some disadvantages. The problem is that root formation in grape cuttings is largely dependent on the hormonal activity of the kidneys [13-15]. During the period of swelling of the grape cuttings, auxins are formed, which, moving to its lower part, stimulate the formation of root tubercles [16-19]. However, if an electric current is applied only to the basal part of the cutting, then the upper active part, which plays an important role in the hormonal relationship, remains unaffected. In order to have an electrical effect on both the lower and upper ends of the cuttings, it is worth placing them in a horizontal current-carrying substance.

As Cataldo et al. [20] wrote, the effect of electricity on plants has been carefully studied. The main characteristics that determine the various forms of exposure to electricity on plants include the method of exposure, the time of exposure in the agrotechnical cycle, the target plant organs and the type of plant response. Morphological and physiological changes caused by exposure to electricity depend on the dose and can be divided into three groups: stimulation, inhibition of functional activity and destruction of the cellular structure [21, 22]. According to the position of Mayán [23], at present, the possibility of using the treatment of plant objects with electric current has been established to stimulate root formation and survival rate of grafting fruit crops, as well as to increase the yield of grain and vegetable crops. With this treatment, accelerated germination of seeds, cuttings and tubers, activation of vital processes, increased yields and reduced ripening time occur. This processing method is characterized by low energy consumption, the ability to change modes and accurately dose the intensity of exposure, and also has a short exposure time. In all known processing methods, an electric current act on living plant tissue [24]. The direct effect of electricity can occur through the direct action of the current and its fields on the entire plant structure or individual organs of the plant, with the aim of stimulating, inhibiting or destroying the cellular structure.

Based on the opinion of McLachlan et al. [25], in the pre-sowing phase of the agro technical cycle, electric, magnetic and electromagnetic fields are widely used to stimulate seeds and vegetative organs (tubers, cuttings). In this case, germination, growth and subsequent development of plants become more intense, especially when processing low-quality material. Seed treatment in such fields enhances the activity of enzymes, intensifies the metabolism in germinating seeds, promotes faster growth and development of plants, and also increases their productivity [26]. In the process of ontogenesis, it is possible to control the development of plants using electric fields. There are known cases of positive influence of electromagnetic fields of power lines on plants. In agricultural production, special devices are used, which allow electric fields to act on plants both in protected and open ground [27, 28]. In addition to the stimulating effect, electric fields can also have a depressing effect under appropriate modes, which is used for active electrophysiological control of plant life. In the pre-harvest phase of the agro technical cycle, it is possible to change the parameters of fields and electric current, which previously caused stimulation in the process of ontogenesis, in order to achieve oppression, slow down sap flow, to ensure uniform and simultaneous fruit ripening and increase the efficiency of mechanized harvesting [29]. For example, the treatment of tobacco and sunflower stalks with electrical discharges makes it possible to create an interruption in sap flow, which leads to a starvation metabolism and uniform ripening of sunflower seeds or tobacco leaves [30, 31]. It also improves the quality of subsequent mechanized harvesting.

As Sun et al. [32] wrote, currents less than 100μA do not cause destruction of plant tissue; at currents from 100μA to units of milliamps, a spontaneous increase in the current value to a certain limit value occurs, accompanied by the destruction of plant tissue; at currents from 6 to 46 mA, the spontaneous increase in the current value does not stop, up to the rupture of plant tissues; lethal outcome occurs at low voltage values; the time required to damage the plant is tens of minutes. According to the opinion of Fuentes and Gago [33], the lower the value of the voltage applied to the treated plant, the longer the treatment time; processing time in the first approximation can be considered inversely proportional to the square of the voltage applied to the plant. Even with the same geometric dimensions of plants of the same species, there is a significant scatter in the initial and final treatment currents, a change in the time to reach a lethal outcome, as well as a significant scatter in the final values of plant resistance after treatment. During processing, the increase in current occurs unevenly: first there is an area with a low rate of increase, then an area with a higher rate of increase, followed by a region of constant current strength, continuing until the destruction of plant tissue, after which the current drops to zero [34, 35].

In turn, according to the opinion of Tardaguila et al. [36], the energy dose required for the death of a plant during electrical damage varies from 40 to 3000. Depending on the growing season, the lethal dose for the same plant species can differ by 10-15 times. With an increase in the growing season, the magnitude of the damaging dose of electrical energy increases. When processing plants with a branched root system, the efficiency of electrical influences decreases, which is also typical for processing plants with high soil moisture [37]. The destruction of plant tissue is observed only in that part of the plants through which the electric current flowed. However, despite the fact that the efficiency of using direct current is not inferior to alternating current, the most preferable is the treatment of cuttings with alternating current with a frequency of 50Hz and an electric field strength of 14V/m. This is due to the fact that this approach does not require additional technical devices to convert AC voltage to DC. Thus, the biological effect of electromagnetic fields is not in doubt, both with a direct effect on plants, and when exposed through irrigation water or soil substrate [38]. But at the same time, in most cases, the choice of optimal modes of electromagnetic stimulation is carried out on the basis of experience. Such an empirical approach can lead to conflicting results. Despite the studies on the effect of non-thermal effects of electromagnetic fields on biological systems and the growing interest in such studies, the problem itself remains a subject of discussion.

The studies in the text are related to this study in the sense that they all explore the effects of electrical stimulation on plant growth and development. They investigate various factors such as treatment voltage, treatment time, and electrode distance, which are similar to the factors you examined in your study. Additionally, they discuss the physiological and morphological changes in plants caused by electrical stimulation, which aligns with your focus on root formation and cellular responses. These studies collectively contribute to the understanding of how electricity can be used to enhance plant growth and productivity, providing valuable insights that can inform the research.

5. CONCLUSIONS

When processing grape cuttings with alternating electric current before planting, the level of resistance of grape cuttings depends on the magnitude of the processed voltage, processing time and distance between the electrodes, and the functional relationship between these indicators is determined. As a result, a methodology has been developed for calculating the parameters of processing with alternating electric current in order to increase the level of resistance of grape cuttings. Based on the results of the experiment, a mathematical model of the process of primary processing by alternating electric current before planting on grape cuttings was developed. On the basis of the created mathematical model, the optimal parameters of the process of primary processing of grape stems with alternating electric current were determined: processing voltage 40V, processing time 16 hours, distance between electrodes 55cm. If it is present, the maximum retention of the grape stem is ensured. According to the proposed technology, the formation of roots in cuttings is accelerated by 15-20% due to the treatment of cuttings with alternating electric current before planting, and therefore the level of safety of grape cuttings increases up to 20-22%. At the same time, the length of the main branch of grape seedlings grown according to the proposed technology is 45-60 cm up to 8-10 roots, the length of the root is 21-24 cm. Up to 100% increases the efficiency of growing seedlings. As a result, this makes it possible to improve the agrotechnical performance of seedlings grown from grape cuttings in a vegetative way. The methodology developed for calculating processing parameters, including voltage, time, and electrode distance in grape cuttings, was statistically validated based on the experiment's results.

Future research in this area should explore the nuanced effects of varying processing voltage, time, and electrode distance to optimize grape cuttings' resistance and root formation. Additionally, investigating genetic factors that influence grape varieties' responses to electrical stimulation could lead to tailored approaches. Finally, field trials and large-scale implementation should be conducted to validate the technology's practicality and impact on grapevine growth and yields in real agricultural settings.

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