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ION TRANSPORT INTO PLANT CELLS BY A MAGNETIC FIELD

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The results of research of the effect of magnetic field on the transport of ions in plant cells are shown. The interrelation between the changes in the concentration of ions in the plant cell with magnetic treatment and magnetic field parameters has been established.

Magnetic field, magnetic induction, magnetic field gradient, ion velocity, ion concentration.

Pre-sowing treatment of seeds makes it possible to raise agricultural crops yield, to reduce plant disease incidence and increase agricultural products quality.

To implement the technology of magnetic treatment of seeds it is necessary to reveal the mechanism of magnetic field effect on seeds, which will allow to determine optimal modes of processing. For this purpose it is necessary to research effect of magnetic field on ions transport in plant cells.

The purpose of research - study the effect of magnetic field on transport ions in the cells of plants

Results of research. It is currently believed that transport of nutrients into the cell involves two autonomous mechanisms – passive movement of substances along electrochemical gradient and their active transport against electrochemical gradient. Since ions are electrically charged, their distribution between the cell and its environment is defined both by potential difference and concentration difference. These two values are commonly designated as electrochemical gradient.

If a membrane is placed between solutions with different ions concentration, diffusion potential emerges, whose value is determined by the Henderson equation [1]:

$$\varphi = \frac{RT}{F}\frac{(U_1 - V_1) - (U_2 - V_2)}{(U_1^{/} - V_1^{/}) - (U_2^{/} - V_2^{/})}\ln\frac{U_1^{/} + V_1^{/}}{U_2^{/} + V_2^{/}}, \qquad (1)$$

where R is universal gas constant, J/mole·K; T – solution temperature , K; F – the Faraday number, C/mole;

$$U_{1(2)} = \Sigma(\tilde{N}_+ v_+)_{1(2)};\ V_{1(2)} = \Sigma(\tilde{N}_- v_-)_{1(2)};$$

$$U_{1(2)}^{/} = \Sigma(\tilde{N}_+ z_+ v_+)_{1(2)};\ V_{1(2)}^{/} = \Sigma(\tilde{N}_- z_- v_-)_{1(2)};$$

where C_+, C_- – concentrations of cations and anions correspondingly, mole/м^3; v_+, v_- – velocity of cations and anions movement, m/sec, м/с; z_+, z_- – valence of cations and anions; index 1 refers to ions in solution1, index 2 – in solution 2.

Diffusion potential is responsible for ion movement through phospholipid membranes in plant cells.

Ions are formed in the process of salts and ac-ids dissociation due to chemical reaction:

$$K_{\varsigma_+} A_{\varsigma_-} = \varsigma_+ K^{z+} + \varsigma_- A^{z-}.$$

In the process of dissociation one molecule produces ς+ cations with valence z+ and ς- with valence z-. Let us denote the product of these valuesby β:

$$\beta = \varsigma_+ z_+ = \xi_- z_-. \tag{2}$$

Part of molecules that have been broken down to ions, is determined by the degree of electrolytic dissociation [2, 3]:

$$\alpha = \frac{n}{N_a C}. \tag{3}$$

where *n* – number of molecules having broken into ions; *Na* – Avogadro's number, molecules/mole; *C*– molar concentration of substance, mole/l.

Under the effect of diffusion potential, ions start ordered motion generating electric current *I.* Current intensity is equal to the total charge of positive and negative ions passing through the membrane pores per unit time.

It is the ions that are at the distance not exceeding their motion speed, notably in the volume $v_i a^2$, that will pass through the membrane per unit time. Then current intensity will amount to:

$$I = \sum_{i=1}^{k} (n_{i_+} a^2 v_{i_+} z_{i_+} e + n_{i\_} a^2 v_{i\_} z_{i\_} e), \tag{4}$$

where *e* – elementary charge, C.

When in motion, ions are affected by forces of electric field F_e, friction F_mи and interaction be-tween ions and solvent molecules $F_в$ [2]. In accordance with the Newton's second law we get:

$$m_i \frac{dv_i}{dt} = F_{e_i} - F_{ò\,i} - F_{â_i}, \tag{5}$$

where m_I– ion mass, kg.

Electric field strength is determined by the formula [2]:

$$F_{e_i} = z_i eE = z_i e grad \varphi. \tag{6}$$

Forces of friction and interaction among ions are directly proportional to speed [2]:

$$F_{ò\,з} = k_{ò\,з} v_i; \tag{7}$$

$$F_{âз} = k_{âз} v_i, \tag{8}$$

where k_m and $k_в$– coefficients of friction and ions interaction, N·c/m, correspondingly.

Inserting (6), (7), (8) into the equation (5), weget:

$$m_i \frac{dv_i}{dt} = z_i e grad \varphi - k_{ò\,i} v_i - k_{â_i} v_i. \tag{9}$$

Having solved (9), we obtain the equation of ion motion:

$$v_i = \frac{z_i e\, grad \varphi}{k_{ò\,з} + k_{âз}} \left(1 - e^{-\frac{k_{ò\,з} + k_{âз}}{m_i} t} \right). \tag{10}$$

As coefficients of friction and ions interaction by far exceed ion mass, we can neglect the value $e^{-\frac{k_{\grave{o}\,i}+k_{\hat{a}_i}}{m_i}t}$ [2] and consider that ion is moving with uniform speed

$$v_i = \frac{z_i e \; grad\varphi}{k_{\grave{o}\,3}+k_{\hat{a}_3}}. \tag{11}$$

At *gradφ*=1 V/m and $k_{вi}$=0 ion is moving with absolute speed [2]:

$$v_i^0 = \frac{z_i e}{k_{\grave{o}\,3}}. \tag{12}$$

Interaction between ions and molecules can be considered with the use of electric conductivity coefficient:

$$f_i = \frac{k_{\grave{o}\,3}}{k_{\grave{o}\,3}+k_{\hat{a}_3}}. \tag{13}$$

Then speed of ion movement will be definedby the expression:

$$v_i = v_i^0 f_i grad\varphi. \tag{14}$$

Substituting the expression for speed of ion motion (14) in the equation (4), we shall obtain:

$$I = \sum_{i=1}^{k} (n_{i_+} a^2 v_{i_+}^0 f_{i_+} z_{i_+} e \; grad\varphi + n_{i\_} a^2 v_{i\_}^0 f_{i\_} z_{i\_} e \; grad\varphi). \tag{15}$$

As the Faraday number is determined by theexpression

$$F = eN_a, \tag{16}$$

the formula (15) can be written in the following form:

$$I = \frac{a^2 F grad\varphi}{N_a} \sum_{i=1}^{k} (n_{i_+} v_{i_+}^0 f_{i_+} z_{i_+} + n_{i\_} v_{i\_}^0 f_{i\_} z_{i\_}). \tag{17}$$

In the process of dissociation one molecule produces ς+ cations and ς- anions, therefore

$$n_{i_+} = \varsigma_{i_+} n_i ; n_{i\_} = \varsigma_{i\_} n_i. \tag{18}$$

Substituting the expression (18) into the membrane pores area and degree of electrolytic dissociation are increased.

When in motion, ions are affected by forces of electric field F_e, friction F_m, interaction between ions and solvent molecules $F_{в}$и and Lorentz force $F_л$. In accordance with the Newton's second law of thermodynamics for normal velocity component we get:

$$m_i \frac{dv_{\tilde{o}_i}}{dt} = F_{e_i} - F_{\grave{o}\,i} - F_{\hat{a}_i}, \tag{21}$$

or

$$m_i \frac{dv_{\tilde{o}_i}}{dt} = z_i e \; grad\varphi - k_{\grave{o}\,i} v_i - k_{\hat{a}_i} v_i. \tag{22}$$

If we neglect coefficients of friction and ions interaction [2], the solution of the equation (22) will be:

$$v_{\tilde{o}_i} = v_i^0 f_i grad\varphi. \tag{23}$$

Correspondingly, for tangential component we get:

$$m_i \frac{dv_{y_i}}{dt} = F_{\ddot{e}_i} - F_{\grave{o}_i} - F_{\hat{a}_i}, \tag{24}$$

or

$$m_i \frac{dv_{y_i}}{dt} = z_i eBv - k_{\grave{o}_i} v_i - k_{\hat{a}_i} v_i. \tag{25}$$

Having solved the equation (25), we get:

$$v_{y_i} = v_i^0 f_i Bv. \tag{26}$$

Per unit time through membranes pores whose area will increase under magnetic field effect and will amount to (*a*+*K*$_м$*gradB*)^2, those ions will pass that are in the volume (Fig. 1)

$$V_1 = \grave{a}S_{ABCD} = v_{x_i}.(a + K_{\grave{i}}\ gradB)^2 + \frac{1}{2}K_{\hat{a}} v_{y_i}(a + K_{\grave{i}}\ gradB) grad\varphi, \tag{27}$$

where*K*$_в$– coefficient of proportionality between distance that ions pass and the gradient of diffusion potential, m^2/T.

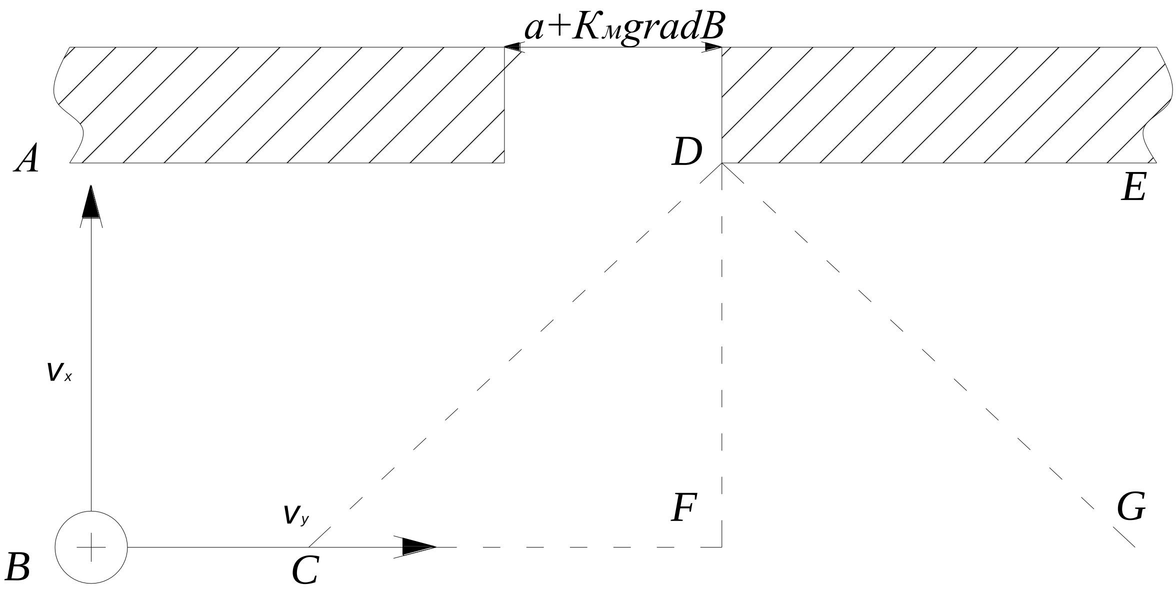

Fig. 1. The diagram of ions motion through the membrane

Under the effect of Lorentz force, ions that are in the *CDF area* (Fig. 1), will move to the *DEG* area where concentration will increase. Therefore, it is advisable to change the direction of magnetic field action for these ions to pass the membrane. In this case ions that are in the following volume, will pass through the membrane:

$$V_2 = v_{x_i}.(a + K_{\grave{i}}\ gradB)^2 + \hat{E}_{\hat{e}} \hat{E}_{\hat{a}} v_{y_i}(a + K_{\grave{i}}\ gradB) grad\varphi, \tag{28}$$

where *K*$_к$ – coefficient considering the number of ions remaining in the *DEG* area, of their total number that have moved from the CDF area. In the general case coefficient *K*$_к$ is in the range from 0.5 to 1.0.

Intensity of current passing through cell membrane under the effect of magnetic field will amount to:

$$I = \sum_{i=1}^{k} (n_{i_+} v_{x_{i+}} (a + K_{\grave{\imath}}\ gradB)(a + K_{\grave{\imath}}\ gradB + \hat{E}_{\hat{e}} \hat{E}_{\hat{a}} v_{y_{i_+}} grad\varphi) z_{i+} e + \\ + n_{i\_} v_{x_{i\_}} .(a + K_{\grave{\imath}}\ gradB)(a + K_{\grave{\imath}}\ gradB + \hat{E}_{\hat{e}} \hat{E}_{\hat{a}} v_{y_{i\_}} grad\varphi) z_{i\_} e). \quad (29)$$

Substituting the expressions for component of ions motion speed (23) and (26) in the equation (29), we get:

$$I = \sum_{i=1}^{k} (n_{i_+} v_{i_+}^0 f_{i_+} (a + K_{\grave{\imath}}\ gradB)(a + K_{\grave{\imath}}\ gradB + \hat{E}_{\hat{e}} \hat{E}_{\hat{a}} Bv) z_{i_+} e\, grad\varphi + \\ + n_{i\_} v_{i\_}^0 f_{i\_} (a + K_{\grave{\imath}}\ gradB)(a + K_{\grave{\imath}}\ gradB + \hat{E}_{\hat{e}} \hat{E}_{\hat{a}} Bv) z_{i\_} e\, grad\varphi). \quad (30)$$

Under the effect of magnetic field concentration of mineral elements that enter plant cells, is changed. The speed of changing ions concentration will be defined by dependence following from the expression (30):

$$\frac{dn_{i_2}}{dt} = n_{i_1} v_i^0 f_i (a + K_{\grave{\imath}}\ gradB)(a + K_{\grave{\imath}}\ gradB + \hat{E}_{\hat{e}} \hat{E}_{\hat{a}} Bv) grad\varphi, \quad (31)$$

where n_{i2} - number of ions that have moved from the solution *1* to the solution *2.*

In this case the change of ions number in the solution 2 will be:

$$\Delta n_{i_2} = \int_0^{t_{\hat{\imath}\acute{a}\eth}} n_{i_1} v_i^0 f_i (a + K_{\grave{\imath}}\ gradB)(a + K_{\grave{\imath}}\ gradB + \hat{E}_{\hat{e}} \hat{E}_{\hat{a}} Bv) grad\varphi\, dt. \quad (32)$$

If magnetic induction is changed along seeds motion trajectory, for periodic magnetic field [4]

$$grad\hat{A} = \frac{2\hat{A}}{\tau}, \quad (33)$$

where τ– pole pitch, m.

In this case the number of ions in plant cells will increase by the value

$$\Delta n_{i_2} = n_{i_1} v_i^0 f_i (a + \frac{2K_{\grave{\imath}}\ B}{\tau})((a + \frac{2K_{\grave{\imath}}\ B}{\tau}) t_{\hat{\imath}\acute{a}\eth} + \frac{1}{2} \hat{E}_{\hat{e}} \hat{E}_{\hat{a}} \hat{A} N_{\ddot{\imath}}\, \tau) grad\varphi, \quad (34)$$

where $t_{обр}$– time of seeds processing in magnetic field, c; $N_п$– number of magnetic reversals.

Considering (3) and (18) the expression (34) can be written in the following form:

$$\Delta n_{i_2} = \alpha_i N_a C_{i_1} \varsigma_i v_i^0 f_i (a + \frac{2K_{\grave{\imath}}\ B}{\tau})((a + \frac{2\hat{E}_{\grave{\imath}}\ B}{\tau}) t_{\hat{\imath}\acute{a}\eth} + \frac{1}{2} \hat{E}_{\hat{e}} \hat{E}_{\hat{a}} \hat{A} N_{\ddot{\imath}}\, \tau) grad\varphi. \quad (35)$$

Change of ions concentration in the solution *2* will be defined by the dependence:

$$\Delta \tilde{N}_{i_2} = C_{i_1} v_i^0 f_i (a + K_{\grave{\imath}}\ gradB)(a + \frac{2K_{\grave{\imath}}\ B}{\tau})((a + \frac{2\hat{E}_{\grave{\imath}}\ B}{\tau}) t_{\hat{\imath}\acute{a}\eth} + \frac{1}{2} \hat{E}_{\hat{e}} \hat{E}_{\hat{a}} \hat{A} N_{\ddot{\imath}}\, \tau) grad\varphi. \quad (36)$$

As the time of seeds in magnetic field is

$$t_{\hat{\imath}\acute{a}\eth} = \frac{l}{v} = \frac{N_{\ddot{\imath}}\, \tau}{v}, \quad (37)$$

where *l* – the path that seeds pass in magnetic field, m,
the expression (36) will have the following form:

$$\Delta C_{i_2} = C_{i_1} v_i^0 f_i N_{\ddot{\imath}}\, \tau (a + \frac{2K_{\grave{\imath}}\ B}{\tau})(\frac{a}{v} + \frac{2\hat{E}_{\grave{\imath}}\ B}{\tau v} + \frac{1}{2} \hat{E}_{\hat{e}} \hat{E}_{\hat{a}} \hat{A}) grad\varphi. \quad (38)$$

Conclusions

Under the effect of magnetic field current passing through plant cells membranes, intensifies. Current intensity depends on diffusion potential, gradient and value of magnetic induction, as well as the speed of seeds motion in magnetic field.

This leads to increased concentration of mineral substances involved in chemical reactions, thus increasing their speed.

References

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Наведено результати досліджень впливу магнітного поля на транспорт іонів у клітині рослини. Встановлено взаємозв'язок зміни концентрації іонів в клітині рослини при магнітній обробці і параметрів магнітного поля.

Магнітне поле, магнітна індукція, градієнт магнітного поля, швидкість іонів, концентрація іонів.

Приведены результаты исследований влияния магнитного поля на транспорт ионов в клетке растений. Установлена взаимосвязь изменения концентрации ионов в клетке растения при магнитной обработке и параметров магнитного поля.

Магнитное поле, магнитная индукция, градиент магнитного поля, скорость ионов, концентрация ионов.