ENGINEERING MANAGEMENT OF MACHINE FOR FORMATION OF ARTIFICIAL SHELL ON SEED VEGETABLE CULTURES
/
ІНЖЕНЕРНИЙ МЕНЕДЖМЕНТ МАШИНИ ДЛЯ ФОРМУВАННЯ ШТУЧНОЇ ОБОЛОНКИ НА НАСІННІ ОВОЧЕВИХ КУЛЬТУР

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ABSTRACT

The article analyses the universalization of the seed material by its physical and mechanical properties by means of pre-sowing treatment, resulting in the formation of an artificial shell. As a result of the generalization, a technological scheme of obtaining an encapsulated seed and a design of a seed coating machine was proposed. A simulation model of the sowing accuracy process from the internal friction coefficient of seeds at different root mean square deviations of seed sizes is proposed. The regression equation for the influence of the dynamic mode of operation of the developed experimental sample of seed coating machine is established. According to the experimental studies' results, the static and dynamic friction coefficients of the encapsulated vegetable seeds on the steel and plastic working surfaces of seed coating machine were established. Under the production conditions, experimental tests were conducted to compare the seedlings of untreated, coated, branded and encapsulated seeds of vegetables by the quality of prepared seed material and sowing time.

РЕЗЮМЕ

В статті виконано аналіз універсалізації посівного матеріалу за фізико-механічними властивостями шляхом передпосівного оброблення в результаті чого утворюється штучна оболонка. В результаті узагальнення запропоновано технологічну схему отримання капсульованого насіння та конструкцію дражиратора. Запропоновано імітаційну модель процесу точності сівби від коефіцієнта внутрішнього тертя насіння при різних середньоквадратичних відхиленнях розмірів насіння. Встановлено рівняння регресії з впливу динамічного режиму роботи розробленого експериментального зразка дражиратора. За результатами експериментальних досліджень встановлено статичний і динамічний коефіцієнти тертя капсульованого насіння овочевих культур по сталевих і пластмасових робочих поверхнях дражиратора. У виробничих умовах проведено експериментальні випробування з порівняння сходів необробленого, дражированого фірмового та капсульованого насіння овочевих культур за якістю підготовленого насіннєвого матеріалу і часу посіву.

INTRODUCTION

The process of coated seeds is a perspective, but compared with inlaid less common way of coating seeds (*Arsenoaia V.N. et al, 2019*). Coated seeds are characterized by the fact that the shape and size of the seeds changes significantly (*Dihingia P.C. et al, 2017*). The weight of the seeds can be increased 10 - 25 times (mini pill) or 15 - 100 times (standard pill) (*Gaganpreet K. et al, 2011*). Coating helps unify the seeds in shape and size (*Kroulík M. et al, 2016*), which allows for even and accurate sowing (*Pruteanu A. et al, 2020*) and also reduces seed costs and the costs of thinning the seedlings (*Vlăduţ D.I. et al, 2018*).

Studies have shown that the yield of standard root crops is increased by 40% by sowing with coated beet seeds (*Hevko B.M. et al, 2018*).

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Therefore, modern seedling growing technologies in many countries are based on the use of coated seeds (*Pedrini S. et al, 2017*). In this case, the yield of cucumbers, lettuce and tomatoes can increase by 15% (*Tolvaly-Roșca F. et al, 2017*). According to research (*Stroescu Gh. et al, 2018*), coated vegetable seeds reduce the rate of seeds by 3 - 4 times and increase the yield by 25%.

The organic and mineral mixture for coating as filler includes 50 - 90% expanded perlite particle size of 0.01 - 0.25 mm with a bulk density of 70 - 150 kg/m^3 (*Amirkhani M. et al, 2019*). The prepared components of the mixture are mixed with water in a ratio of 10:1 to obtain a homogeneous mass with moulding humidity (*Halber A. et al, 2018*).

The mixture is then provided into a seed coating machine with seeds and pumped with seeds mixed with the mixture (*Rogovskii I. et al, 2019*). In the process of pumping in the seed coating machine, a light bulk dragee with a kernel-seed is formed (*Belc N. et al, 2016*). The mixture is provided using an auger. The process of pumping takes 15 - 20 minutes; 1 - 2 minutes before the end of the process in the seed coating machine is provided bentonite clay to obtain a smooth outer shell of the dragee (*Hevko R.B. et al, 2017*). Ready dragee is sent for drying (*Rogovskii I.L. et al, 2019*).

The author of the method of "clay balls" - Masanabu Fukuoka (1913-2008), a Japanese farmer, creator of "natural farming" was looking for a way to sow rice without filling the fields, without digging and without fertilizing the soil (*Tutunaru L.F. et al, 2014*). Fukuoka came to think of making a clay shell for seeds. Subsequently, Fukuoka organized a large campaign to green the desert soils and personally tested the method of "clay balls" in Africa, Southeast Asia, Australia, America and others. In Greece, the "greening" case continues with Panos Manikis, Fukuoka's student. The essence of the method of "clay balls". Seeds of perennial and annual plants are mixed with clay and water. From the resulting mixture, by hand or concrete mixer, make small balls. They are dried in the sun, harvested, manually or airborne scattered over a desert area. The cost of this method is around EUR 250 per hectare (including the cost of seeds, clay and food for volunteers). Fig. 1 presents a scheme for obtaining vegetable seeds encapsulated in clay.

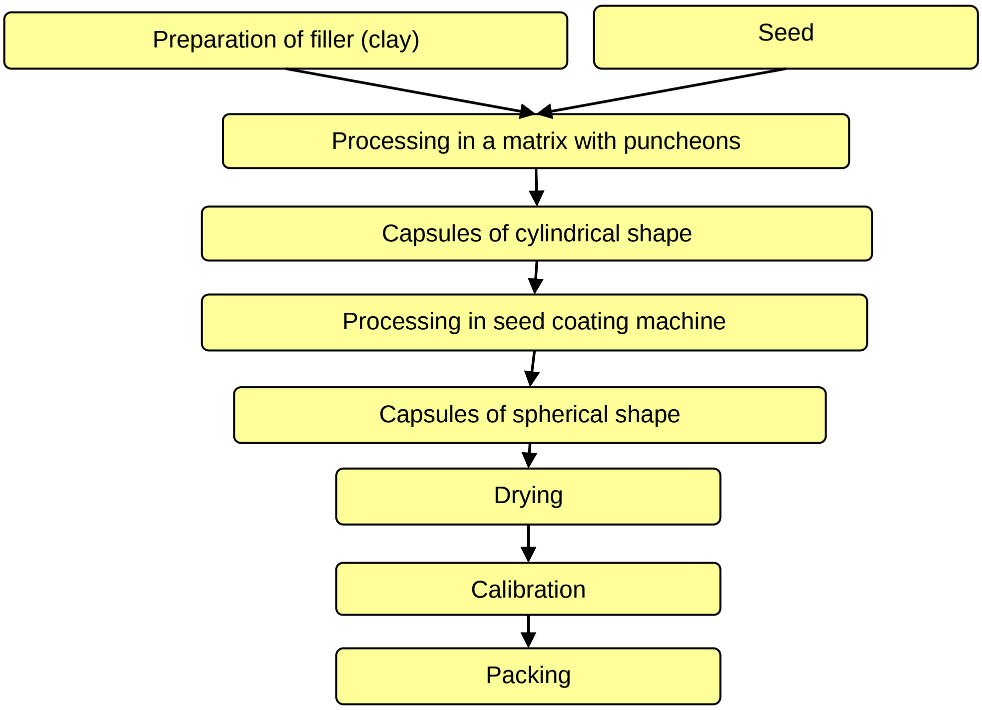


Fig. 1 - Technological scheme of obtaining encapsulated seeds

The development of modern designs of machines for pre-sowing seed treatment with the application of artificial shell on it is a result of improvement of the most common machines for the implementation of this technological operation – seed coating machines. Despite the benefits of seed coating machines, there are many unresolved issues (*Rogovskii I.L. et al, 2019*).

The main of these issues is the influence of the design and mode parameters of the seed coating machine on the formation of artificial shell on seed surface in the case of small-seeded vegetable crops.

As a result of the analysis of research and design works, it can be concluded that the creation of theoretical foundations and the development of a machine for the pre-sowing treatment of vegetable crop seeds with the formation of artificial shell on their surface, is current.

The purpose of the study is to increase the efficiency of the artificial shell formation process on the seed surface by reasoning the technological process, parameters and operation modes of the seed coating machine.

MATERIALS AND METHODS

Theoretical studies were conducted using mechanical-mathematical modeling and are based on the provisions of theoretical mechanics, methods of mathematical analysis, methods of multivariate experiment planning and statistical processing of experimental data using Statistica 7.

To obtain cylindrical capsules containing seeds, a device (matrix with puncheon) was developed. To obtain spherical capsules, it is necessary to carry out the treatment of cylindrical capsules in the working unit of the experimental installation (Fig. 2 a).

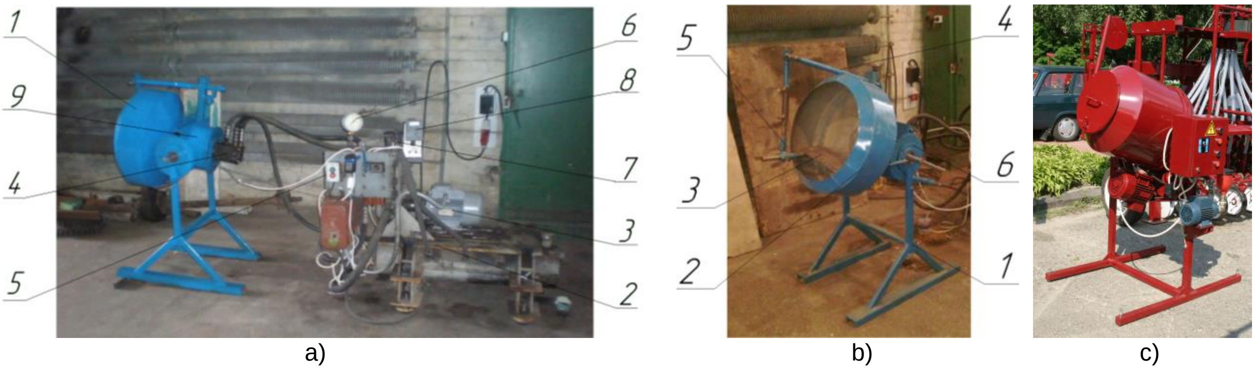


Fig. 2 - General views of the experimental installation (a, b) and production model of the seed coating machine (c)
a: 1 - drawer; 2 - hydrostation; 3 - electric engine; 4 - hydraulic motor; 5 - control unit; 6 - manometer; 7 - adjustable throttle; 8 - device for controlling the speed of rotation; 9 - a box block; b: 1 - bedplate; 2 - drum; 3 - board; 4 - bracket; 5 - hinge; 6 - mechanism for adjusting the angle of the drum

The main tasks of developing the installation:

- providing the possibility of varying the speed of the seed coating machine drum;
- providing the ability to measure the speed of the drum;
- providing the possibility of changing the angle of inclination of the drum;
- ensuring the efficiency of the process of artificial shell formation on the seed surface due to the additional working elements of the installation.

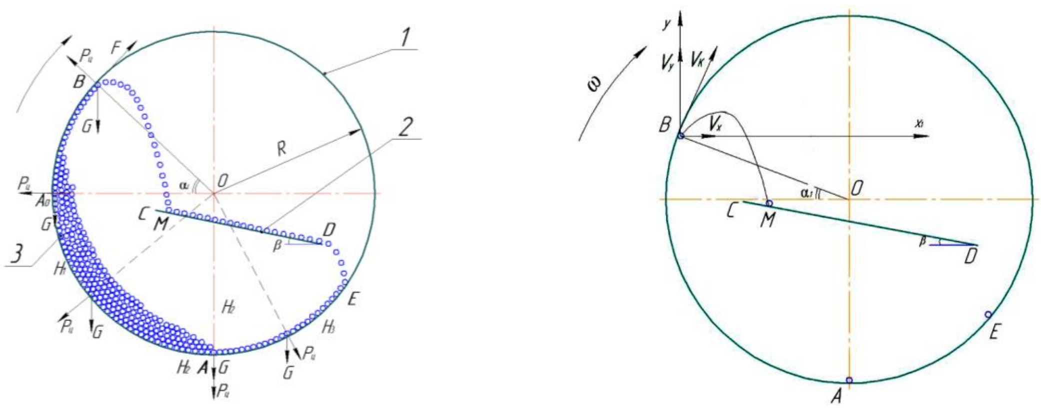
To intensify the process of forming the shell in the drum *2* (Fig. 2 b), a slope board *3* is placed, which with the help of the bracket *4* is secured to the bedplate *1* and is intended to increase the surface for forming an artificial shell on the seeds. The position of the slope board is adjustable by the hinge *5* (Fig. 2 b), which allows you to change the angles relatively to the axis of rotation and relatively to the bottom of the drum of the seed coating machine. To investigate the influence of the drum angle of inclination on the formation of encapsulated seeds in the design of the experimental setup, there is a mechanism *6* to change the position of the seed coating machine drum.

To determine the static and dynamic coefficients of friction, the measuring device was developed, and the methodology provided for the use of video equipment and the computer program Movie Maker.

The movement of the encapsulated seeds in the seed coating machine drum is a waterfall mode. The working areas on which the artificial shell is formed are *AB* and *EA* (Fig. 3). Thus, to increase the performance of seed coating machine, it is necessary to increase the diameter of the drum, and as a consequence, it will increase its size and cost. We suggest installing an additional working element in the seed coating machine drum - a slope board. Section *CD* (Fig. 3) is an additional working surface for forming capsules of spherical shape.

When the drum is tilted, the conditions $\omega^2 R/g$ and the conditions of detachment of the capsules change slightly (*Dugaesescu I. et al, 2019*).

Since the drum of seed coating is angled, and in analytical studies we found that the efficiency of seed coating machine is affected by the angle of the drum, we considered the movement of the capsules in an inclined drum (Fig. 4).



a) b)

Fig. 3 - The scheme of the seed coating machine and the various positions of the capsules:
1 - drum; 2 - board; 3 - lifting capsule

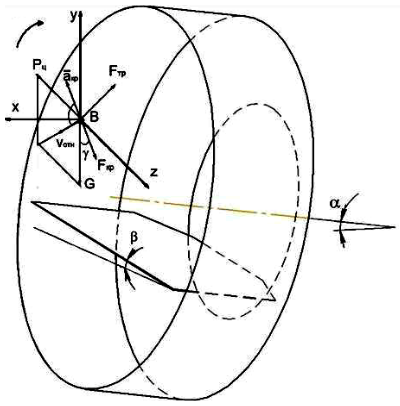


Fig. 4. - The calculated scheme of the forces of seed coating machine at an angle to the horizon and the flight path of the capsule

Equation of the separation condition of the capsule from the drum's inner wall:

$$P_c \sin\beta - mg - \overline{F}_{cor}\cos\gamma = 0\ , \tag{1}$$

$$m\omega^2 R\sin\cdot\sin\beta - mg - F_{cor}\cdot\cos\gamma = 0\,, \tag{2}$$

where F_{cor} – Coriolis force, H; β – the installation angle of the slope board, deg.; γ – the angle between the Coriolis force and the gravity, deg.

$$\sin\alpha_1 = \frac{mg + F_{cor}\cos\gamma}{m\omega^2 R\sin\beta} = \frac{mg + ma_{cor}\cos\gamma}{m\omega^2 R\sin\beta} = \frac{g + a_{cor}\cos\gamma}{\omega^2 R\sin\beta}\,. \tag{3}$$

Then the angle at which the capsule rises is:

$$\alpha_1 = \arcsin\frac{(g + a_{cor}\cos\gamma)}{\omega^2 R\sin\beta} \tag{4}$$

where a_{cor} – Coriolis acceleration, m/s^2.

At the point of separation, the free flight begins in the plane of the forces acting: gravity, inertia, and friction (*Fan G.J. et al, 2017*). Because part of the initial data is almost very difficult and, even, it is not possible to determine mathematically - we choose the way to solve the problem by the method of multivariate experiment.

In view of the above, we will theoretically consider the motion of the capsule in the horizontal drum of the seed coating machine (Fig. 3 a).

Consider the motion of a single capsule in sections (Fig. 3):

I) AB - the area on which the capsules with seeds from the resting state move on the inner surface of the drum; II) *BC* - the area on which the encapsulated seed breaks away from the drum wall and falls on a slope board along the parabolic trajectory; III) *CD* - movement of capsules on an inclined plane - a slope board; IV) *DE* - the area on which the encapsulated seed breaks away from the slope board and falls on the drum wall; V) *EA* - the movement of the capsules on the inner wall of the drum.

The external forces applied to the material point - units of the capsule are: gravity *mg,* friction force *F*. As can be seen from Fig. 3 a, the drum *1* rotates clockwise and captures the capsules that hit the lower part of the drum. Before the drum rotation, only the gravitational force *G* acted on the capsules vertically downwards. For each capsule, the force of gravity *G* directed downwards, the friction force *F*, and the centrifugal inertia force P_c are directed from the centre of rotation *O* to act upon the rotation of the drum. Upon further rotation of the drum, the new position of the capsule will be at point B after rotation of the radius OA_0 and its transition to the position *OB*. Such a change in the position of the capsule may detach it from the surface of the drum. This separation will occur by the equality of the geometric sum of the forces $\overline{P_c} + \overline{G} + \overline{F}$ with zero.

In position B, the capsule will be in relative rest, if the sum of these forces' projections on the horizontal and vertical is zero, then we have:

$$\left.\begin{aligned} mR\cos\alpha_1 - F\sin\alpha_1 = 0 \\ -mg + F\cos\alpha_1 + mR\omega^2\sin\alpha_1 = 0 \end{aligned}\right\}, \tag{5}$$

where *g* – the acceleration of free fall, m/s^2; α_1 – the angle A_0OB (Fig. 3).

After making a number of transformations we get:

$$R\omega^2\cos^2\alpha_1 = g\sin\alpha_1 + R\omega^2\sin\alpha_1 . \tag{6}$$

Then:

$$\frac{R\omega^2}{g} = \sin\alpha_1 \cdot \tag{7}$$

Denote $\omega^2 R/g$ the relation by *k* and call it an indicator of the dynamic mode of the seed coating machine.

After separation of the capsule from the inner surface of the drum, the capsule flies free on a slope board to point *M* (Fig. 3 b). To derive the flight equations of the capsule on a slope board, we make the coordinate system *xBy* starting at point *B*. Let the capsule fall along the parabolic curve. The capsule is subjected to a force *G*, equal *mg*; air resistance is not taken into account. Let`s make the differential equations of capsule motion for this case:

$$\dot{y} = \omega R\cos\alpha_1 - gt , \tag{8}$$

$$y = \omega Rt\cos\alpha_1 - gt^2/2 . \tag{9}$$

Excluding *t,* we obtain the equation of the capsule flight trajectory:

$$y = xctg\alpha_1 - \frac{gx^2}{2\omega^2 R^2\sin^2\alpha_1} . \tag{10}$$

The capsule speed, taking into account the indicator of the dynamic mode of operation of the seed coating machine is equal to:

$$v_x = v\sin\alpha_1 = \omega R\cdot k , \tag{11}$$

$$v_y = v\cos\alpha_1 = \omega R\cdot\sqrt{1-k^2} . \tag{12}$$

Then the equation of the flight path of the capsule in the coordinate system *xOy*, taking into account the indicator of the dynamic mode of operation of the seed coating machine will be:

$$y = \frac{R(1+k)\sqrt{1-k^2}}{k} - \frac{x^2(R\cos\alpha_1 + x)^2}{2k^3\cdot R} . \tag{13}$$

Immediately after the fall, the capsule moves on the slope board *CD* to the right, starting from point *M* (Fig. 3). In this case, there is an overcoming of resistance due to rolling friction, but provided that this rolling occurs on an inclined plane at an angle *β* (Fig. 3).

Determine the equation of motion on the slope board *CD* (Fig. 3):

$$y_c = R\sin\alpha + R = R(1+k) , \tag{14}$$

$$y_c = R(1+k) . \tag{15}$$

The following condition needs to be done for constant movement on a slope board:

$$\beta \geq f , \tag{16}$$

where *f* – the coefficient of friction of the capsules.

Then, the equation of motion on the slope will look like:

$$y = y_0 - (R\cos\alpha_1 + x)\cdot f\ . \tag{17}$$

After making the conversion, we obtain the equation of motion of the capsule on the slope board, taking into account the indicator of the dynamic mode of operation of the seed coating machine:

$$y = R(1+k) - f(R\sqrt{1-k^2} + x)\ . \tag{18}$$

The speed of movement of the capsule on the slope board (Fig. 5) is determined by:

$$v = gt(\cos\beta - f\sin\beta) + R\omega k\cos\beta + \sqrt{2g(h_{\max} - y_m)}\cdot\sin\beta\ , \tag{19}$$

where h_{max} – the maximum capsule rise during parabola drop, m; y_m – the coordinate of the capsule at the point *M* (Fig. 3) falling on the slope.

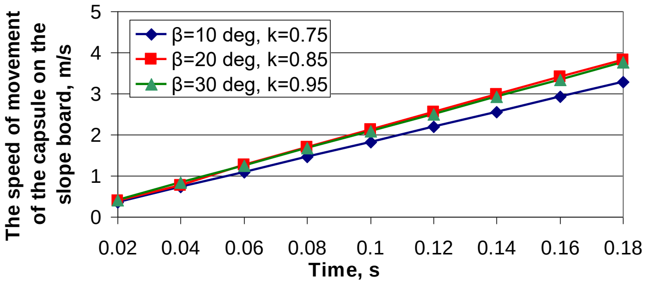


Fig. 5 - The speed of the capsule movement on a slope board

RESULTS

Requirements for dimensional characteristics and coefficients of friction of the seed material, that ensure the high quality of sowing. The main thing is based on simulation modeling for a mesh-disk seeding machine. As a result of simulation, a graph was obtained (Fig. 6), the analysis of which shows that the accuracy of sowing is practically ensured under the condition of obtaining seeds, the coefficient of friction equal to 0.5 and the standard deviation of the sizes of capsules σ + 0.1…0.2 mm. Thus, we formulated requirements for encapsulated seeds for accurate sowing of the mesh-disk seeding apparatus: the coefficient of friction shouldn't be more than 0.6, and the coefficient of variation of capsule sizes shouldn't be more than 5…8 %.

According to the experimental research programme, a second-order Box-Behnken plan was drawn up for the implementation of the experiments (Table 1). During the experimental studies, the effect of the dynamic mode of the seed coating machine *k*, the angle *α* of the drum slope to the horizon, and the angle *β* of the slope board installation *β* on the output of 6 - 6.5 mm spherical capsules were studied.

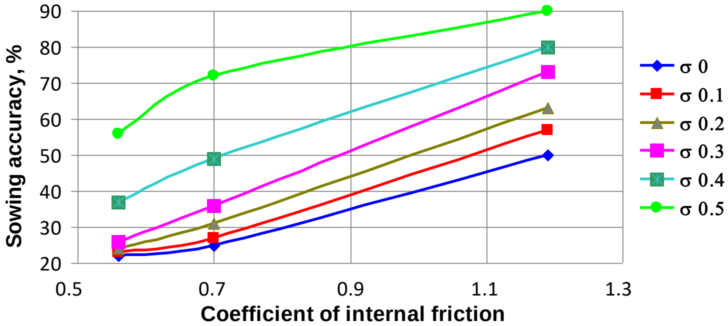


Fig. 6 - Dependence of sowing accuracy on the coefficient of internal friction of seeds at various standard deviations of seed sizes

Table 1

Levels of variation by factors

Levels and interval of variation	The coded value	Factors and their designation		
		Dynamic mode indicator, k (x_1)	Tilt angle of the seed coating machine α, deg. (x_2)	Angle of installation of the slope board β, deg. (x_3)
Upper level	+1	0.95	27	30
Basic level	0	0.85	18	20
Lower level	-1	0.75	9	10
Variation interval		0.10	9	10

At the end of the experiments, the obtained data were processed on PC using application packages Statistica 7. The result is a regression equation:

$$Y = 94.21 + 0.34x_1 + 0.59x_2 - 0.69x_3 + 0.86x_1x_2 + 2.2x_1x_3 + 0.75x_2x_3 - 1.99x_1^2 + 0.06x_2^2 - 0.92x_3^2. \quad (20)$$

The response surfaces of the dependence of the output of capsules with a 6 - 6.5 mm diameter on the controlled parameters are presented in Fig. 7.

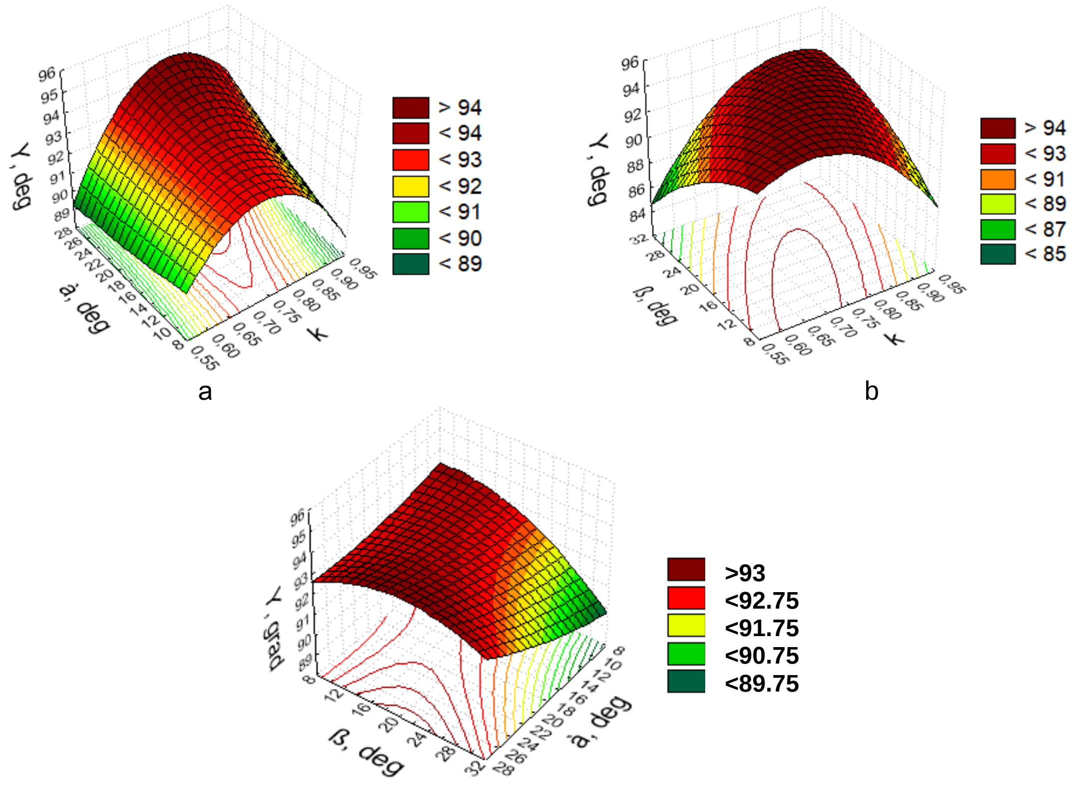


Fig. 7 - The dependence of the output of seed capsules with a diameter of 6-6.5 mm:
(a) - on k - dynamic mode and α - the angle of inclination of the drum; (b) on k - the dynamic mode of operation and β - the angle of installation of the slope board; (c) on α - the angle of inclination of the drum and β - the angle of installation of the slope board

The statistical analysis made it possible to make a regression equation, which normally describes the process of forming a capsular seed with 95% probability. The analysis of theoretical data with experimental data is presented in Fig. 8.

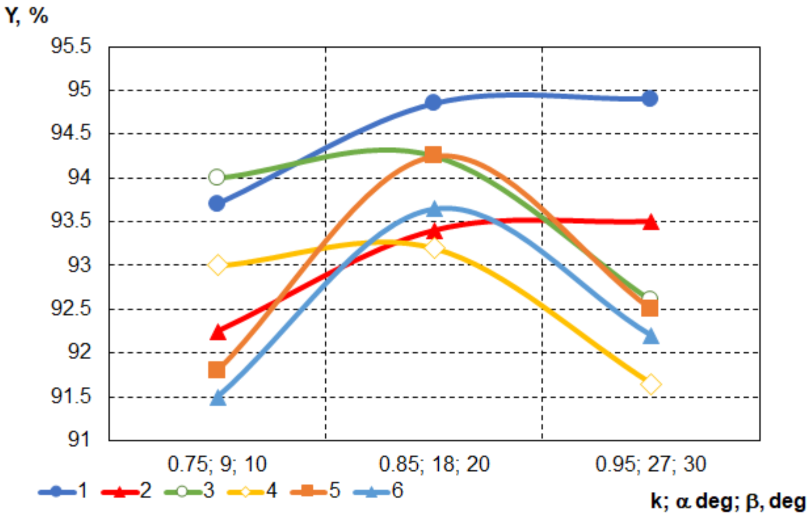


Fig. 8 - Comparison of experimental data with theoretical ones (dependence of the dynamic indicator of the seed coating machine k, the angle of drum installation, the angle of the slope board installation from Y, %:
1 - the dependence of the angle of installation of the drum α on Y, % (k=0.85; β=200); 2 - experimental data of the dependence of the dynamic operation indicator of the seed coating machine on Y,%; 3 - theoretical data of the slope board angle of installation on Y, % (k=0.85; α=180); 4 - experimental data of the dependence of the slope board angle of installation on Y,%; 5 - theoretical data of the dependence of the dynamic indicator of the seed coating machine k on Y, % (α=180; β=200);
6 - experimental data of the dependence of the operation dynamic indicator of the seed coating machine k on Y,%

In the process of seed encapsulation, cylindrical capsules of the same volume are used for the purpose of obtaining capsules of the spherical shape of the same size, but during the processing of cylindrical capsules in the drum of the seed coating machine, they can be erased against the walls of the drum or rolled as a result of connection with clay residues. This leads to the distribution of capsules by size (Fig. 9).

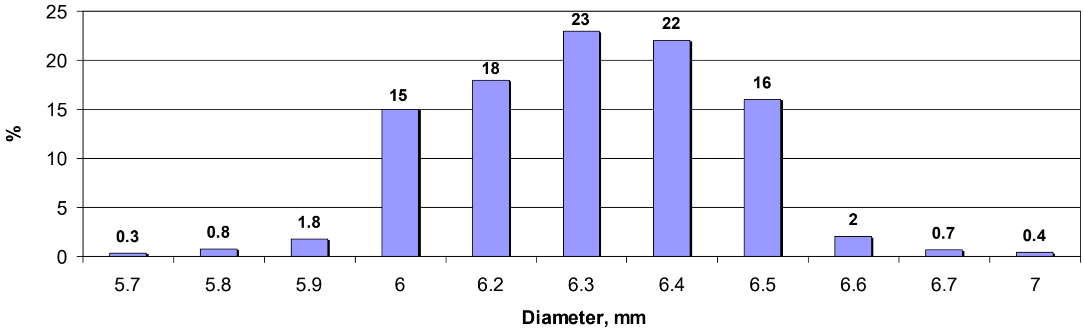


Fig. 9 - The distribution of the capsular seeds depending on the diameter

The absolute mass of seeds in the artificial shell, depending on the diameter is 36 - 42 times greater than the weight of ordinary seeds (Fig. 10), so the seeds in the capsule provide the exact distribution of the sowing mechanism in the row, as the probability of seed drift by wind is reduced.

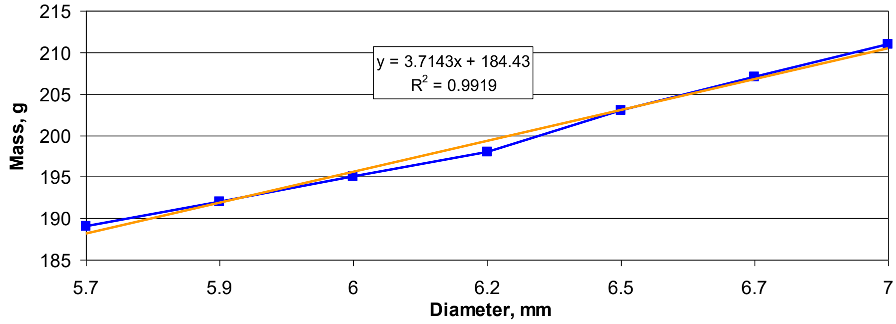


Fig. 10 - Dependence of the mass of the encapsulated seeds on the diameter

Static and dynamic coefficients of friction on steel and plastic (Fig. 11-12) were determined during the study of seeds in artificial shell (Figs. 11-12). The graph shows that the static coefficient of friction of the encapsulated seeds decreased in comparison with the untreated seeds of vegetable crops 2 - 3.8 times (depending on the culture). The comparative graph shows that the dynamic coefficient of friction of seeds in the artificial shell has decreased 4.5 - 8 times (depending on the culture) compared to ordinary seeds. Thus, the reduction of friction coefficients to one value makes it possible to universalize the working units of the planter.

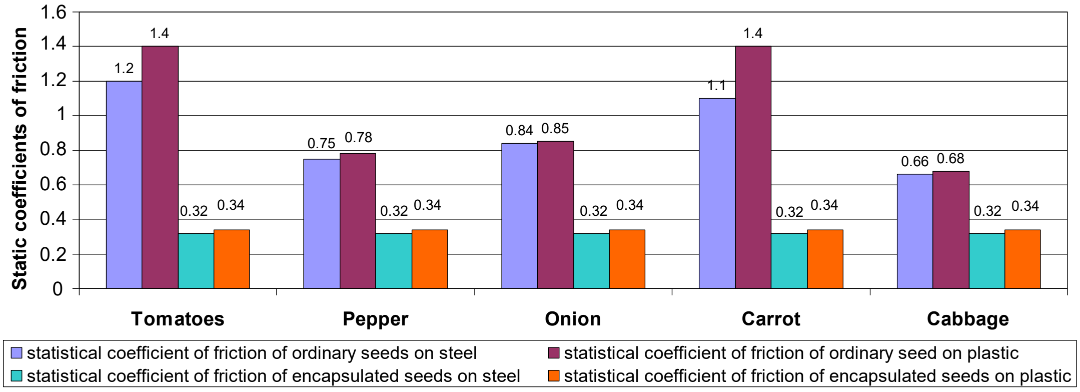


Fig. 11 - Static coefficients of friction of conventional and encapsulated vegetable seeds

The experimental research programme provided for the determination of the dynamics of the appearance of the seed capsules. As a result of researches, the dynamics of seedling emergence was determined: carrots, peppers, tomatoes of untreated seeds, coated company seeds and capsular seeds, and comparative graphs of the percentage of seedlings of plants (carrots) from the time of sowing were obtained (Fig. 13). Studies have shown that seedlings in clay capsules appeared faster than unprocessed seeds, carrots, tomatoes by 20%, and peppers by 32%. This is due primarily to the fact that the clay shell has hygroscopic properties, the ability to absorb soil moisture and provide reliable aeration, and as a result, to provide better seed germination.

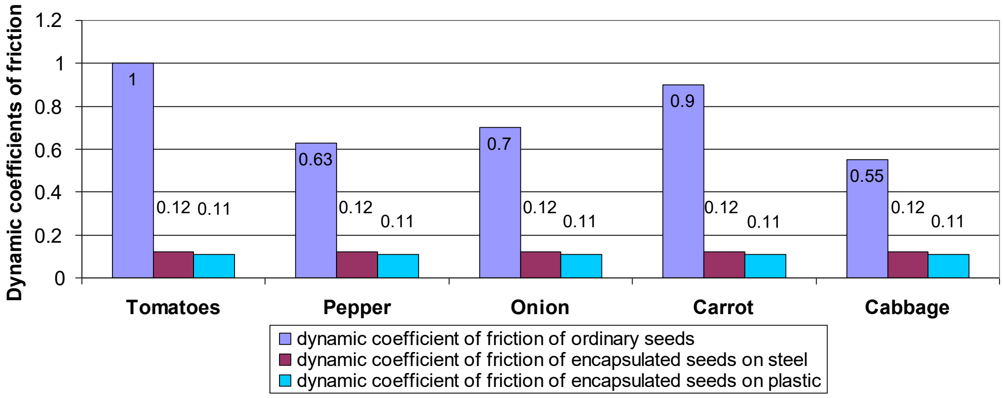


Fig. 12 - Dynamic coefficients of friction of conventional and encapsulated vegetable seeds

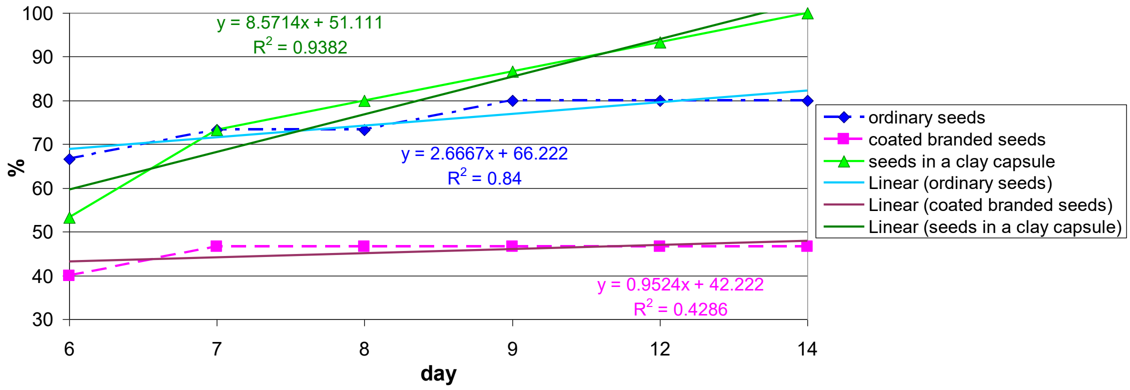


Fig. 13 - Dynamics of carrot seedlings

a – behaviour of spring shank response to the external impacts; b – autocorrelation function; c – density of distribution; d – spectral analysis.

CONCLUSIONS

1. As a result of the simulation application, the requirements for encapsulated seeds were formulated for accurate sowing by the mesh-disk seeding apparatus: the coefficient of friction should be no more than 0.6, and the coefficient of variation of capsule sizes no more than 5…8 %.

2. The optimum parameters of the experimental setup are substantiated: dynamic mode of the seed coating machine k=0.85, angle of installation of the seed coating machine drum - 190 degrees to the horizontal and angle of installation of the slope board - 140 degrees to the horizontal.

3. Physical-mechanical properties of the encapsulated seeds were investigated. The static coefficient of friction in comparison with untreated seeds decreased 2 - 3.8 times (depending on the culture) and is 0.32, the dynamic coefficient of friction decreased 4.5 - 8 times (depending on the culture) and is 0.12.

4. As a result of studies of encapsulated seeds quality, the seedling emergence dynamics of encapsulated seeds of tomatoes and carrots was 20% higher than of untreated seeds and pepper by 32%.

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