Experimental studies of the transport speed of immersion of pea grains in liquid

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Abstract. The basis of leguminous crops is peas, which have a food value for human nutrition. Peas are also used as concentrated and green feed, silage, hay, and hay flour. Pea seeds are susceptible to various diseases. One of the main reserves for increasing the production of pea grain is the use of seeds that are cleared of various impurities for sowing and pre-treatment with chemical preparations against pathogens. An effective method of protecting pea seeds from various diseases is wet treatment with bactericidal preparations with the simultaneous use of biologically active substances. To develop a device for processing seeds by wet method, research was conducted on the transport speed of immersion of spherical grains in liquid. When conducting practical experiments, we considered the movement in a liquid with a density of $\rho_{zh} = 1000, 1090$ and $1150 \text{ kg/m}^3$ of individual pea grains of the Vita variety (spherical shape) with a moisture content of 14%. Sodium chloride salt (NaCl) was used to change the density $\rho_{zh}$ of the liquid. To obtain more reliable information, the experiments were performed three times over. The temperature of the surrounding air and liquids of different densities was 20 °C. The data obtained were processed using one of the methods of variation statistics. It was found that in water ($\rho_{zh} = 1000 \text{ kg/m}^3$) the confidence interval of the transport speed of immersion of single grains with a reliability of $0.10-0.28 \text{ m/s}$ and in an aqueous solution of sodium chloride (NaCl) with a density of $\rho_{zh} = 1090$ and $1150 \text{ kg/m}^3$, respectively, $0.09-0.23 \text{ m/s}$. This approach to determining the transport speed of grain immersion in liquid can be used in the development of a machine for etching pea seeds using a wet method.

1. Introduction
Ensuring food security of the country is one of the main goals of the agro-industrial complex of the Russian Federation. The solution to this problem is largely determined by the increase in grain production of cereals and legumes.

The basis of leguminous crops is peas. In comparison with cereals, the value of peas is determined by a high balance of amino acid composition. Green peas contain 25-30% of sugars, vitamins A, B¹, B² and C, and minerals. Pea seeds contain 23-30% protein. In quantitative content, peas are also a high-stemmed crop. Therefore, peas are a valuable food crop. Its seeds are distinguished by their digestibility and high taste qualities. Mature, unripe seeds (green peas) and green beans (vegetable varieties) are used in the canning industry. Peas are used as concentrated and green feed, silage, hay, grain haylage and hay flour. The introduction of peas in the diet of animals can significantly reduce feed consumption and increase the yield of livestock products.
However, despite the value of this crop, pea seeds are susceptible to various diseases. At the same time, one of the main reserves for increasing the production of pea grain is the use of seeds purified from various impurities for sowing and pre-treatment with chemical preparations against pathogens [1, 2].

Sowing infected seeds leads to the transmission of diseases to vegetating plants and thus creates and maintains foci of infection in the field. Therefore, treatment of pea seeds with protective and stimulating preparations is a mandatory event in crop production [3, 4, 5].

One of the ways to protect the seed material of peas from root rot, seed mold, ascochytosis, anthracnose is treatment with preparations of bactericidal action. At the same time, the simultaneous use of biologically active substances contributes to an increase in yield and protein content [6-9].

An effective way to treat pea seeds before sowing is to etch by watering or soaking the seed material with dilute aqueous solutions of chemicals or suspensions of wetting powders. This method provides a deeper and complete penetration of the mordant solution into the pea seeds and a more complete disinfection of them from infection. At the same time, there is no air pollution [8, 9].

However, even in a well-cleaned seed material of peas, after repeated transportation, grain fines are formed again [10]. Therefore, at the end of the transport route, in order to exclude the ingress of dusty pea grain into the mordant, it is necessary to additionally clean the seed material with an air-sieve grain cleaning machine [11-19].

Therefore, the development of a machine that is not complex in design for etching pea seeds in a wet way, which has a low energy consumption of the technological process in comparison with existing machines for etching grain, and also includes the function of removing grain fines, is an urgent task.

When developing such a device, research is required to substantiate the structural and technological parameters of its main working bodies, one of which is the rate of immersion of grains in the liquid [20, 21].

Therefore, the purpose of research is to determine the rate of immersion of pea grains in liquids of different densities to justify the design and technological parameters of the machine for etching grain wet and performing it with proper efficiency of the technological process.

2. Materials and methods

When conducting practical experiments, we considered the movement in a liquid with a density of $\rho_{\text{zh}} = 1000, 1090$ and $1150 \text{ kg/m}^3$ of individual pea grains of the Vita variety (spherical shape) with a humidity of 14%. Sodium chloride salt (NaCl) was used to change the density $\rho_{\text{zh}, \text{liquid}}$.

A glass vessel with a length of 0.35 m, width of 0.20 m and height of 0.15 m was used to estimate the rate of immersion of pea grains in the liquid. Determination of the time $t_{\pi 1}$ of immersion of grains in water or an aqueous solution of salt was carried out between two marks, which were located at a distance of 0.01 m from the upper edge of the liquid and from the bottom of the vessel. The height of the liquid column $h_{\pi 1}$ between these labels was 0.135 m (Figure 1).

Pea seeds were placed on a metal plate and dumped into water or an aqueous solution of sodium chloride (NaCl) from a height of $h = 0.010$ m.

Measurement of the dimensions of the made transparent glass vessel, the height $h_{\pi 1}$ of the column of water or an aqueous solution of salt between the marks, as well as the height $h$ of dropping grains into water or into an aqueous solution of salt was performed using a metal ruler with millimeter divisions.

The time $t_i$ of movement of a spherical grain in water or an aqueous solution of salt between two marks was determined using a computer stopwatch. The process of movement of the grain in the liquid and the stopwatch was recorded by video shooting with a One Plus 3T phone at a frequency of 120 frames per second and then viewed frame-by-frame. Taking into account the fixation of two frames corresponding to the touch of the upper and lower marks by the grain, the time $t_{i,z}$ of the i-th grain movement between these marks of the liquid column was determined with an accuracy of $2/120 \text{ s} \approx 0.02 \text{ s}$. 
Figure 1. Experimental setup and computer stopwatch for studying the rate of immersion in liquid pea grains of Vita variety.

The arithmetic mean value of the time of movement of grains in the liquid was determined by the expression:

\[ t_{\text{mid},z} = \frac{1}{N} \sum_{i=1}^{N} t_{i,z} \]  

(1)

where \( N \) – the number of measurements of the movement time of pea grains in the liquid, \( N = 20 \) pc.

The average square deviations of the values of the time of movement of grains in the liquid were determined by the formula [22]:

\[ S_x(t) = \left( (N-1) \sum_{i=1}^{N} (t_{i,z} - t_{\text{mid},z})^2 \right)^{1/2} \]  

(2)

Absolute errors in the values of the time of movement of grains in the liquid were determined by the expression [22]:

\[ \Delta t_x = t_{p,N} S_x \sqrt{N} \]  

(3)

\( t_{p,N} \) – student’s table coefficient, determined by the confidence probability \( p = 0.95 \) and the number of measurements \( N = 20 \), \( t_{0.95; 20} = 2.09 \).

The total error of the movement time of Vita pea grains in the liquid is equal to [22]:

\[ \Delta t_{\text{total},z} = \left( \Delta t_x^2 + \Delta t_{\text{inst}}^2 \right)^{1/2} \]  

(4)

where \( \Delta t_{\text{inst}} \) – the instrumental error of measuring the time of movement of grains in the liquid, \( \Delta t_{\text{inst}} = 0.02 \) s.

The relative error in determining the speed of movement of a pea seed in a liquid was determined by the formula [22]:

\[ \epsilon_{v_z} = \left( \frac{\Delta t_{\text{total},z}}{t_{\text{mid},z}} \right)^2 + \left( \frac{\Delta h_{\text{h1}}}{h_{\text{h1}}} \right)^2 \]  

(5)

where \( \Delta h_{\text{h1}} \) – absolute error in determining the height of the column of liquid (half the price of dividing the ruler), \( \Delta h_{\text{h1}} = 0.5 \cdot 10^{-3} \) m;

\( h_{\text{h1}} \) – height of the liquid column between the marks on the wall of the glass vessel, \( h_{\text{h1}} = 0.135 \) m.

Then the absolute error of indirect determination of the speed of grain movement in the liquid is expressed by the formula [22]:

\[ \Delta v_z = \epsilon_{v_z} \cdot v_{\text{mid},z} \]  

(6)

where \( v_{\text{mid},z} \) – the arithmetic mean value of the speed of movement of grains in the liquid.

The average arithmetic value of the speed of movement of grains in the liquid between the marks on the vessel wall was calculated using the formula:

\[ v_{\text{mid},z} = \frac{1}{N} \sum_{i=1}^{N} v_{i,z} \]  

(7)
where \( v_{i,z} \) — the speed of the \( i \)-th grain when it is immersed in a liquid, m/s.

As a result, confidence intervals for evaluating the reliability of the average speed values of Vita pea grains in liquids of different density \( \rho_{zh} \) obtained experimentally were determined by the formula [22]:

\[
v_z = v_{\text{mid},z} \pm \Delta v_z
\]

To obtain more reliable information, the experiments were carried out in three-fold repetition. The temperature of the surrounding air and liquids of different densities \( \rho_{zh} \) was 20 °C. The obtained theoretical and experimental data were processed on a personal computer using the Microsoft Excel 2013 office documentation package for statistical information processing.

3. Results and Discussion

The speed of \( v_z \) and the duration of \( t_z \) of grain immersion in the liquid are among the main parameters taken into account when developing a machine for cleaning and etching grain material in a wet way. The values of these values determine the design and technological parameters of the developed machine.

The results of the conducted practical experiments on the fall of the grains in the liquid is given in dependence of the time \( t_z \) and speed \( v_z \) dip grain pea varieties Vita to a depth of \( h_z = 0.135 \text{ m} \) between labels in water (\( \rho_{zh} = 1000 \text{ kg/m}^3 \)) and aqueous solutions of salts (\( \rho_{zh} = 1090 \) and 1150 kg/m\(^3\)) of the number \( x_{No} \) of conducted experiences, which are presented in Figure 2.

Dependence of the time \( t_z \) of immersion of Vita pea grains in water (\( \rho_{zh} = 1000 \text{ kg/m}^3 \)) from the number \( x_{No} \) of the conducted experiment shows that the limits of variation of the time \( t_{z,1000} \) in experiments are 0.40...0.67 s. The average value of the time \( t_{\text{mid},1000} \) immersion of grains is 0.505 s. The mean square deviation of \( S_{z,1000} \) measurements of the time of movement of grains in water is 0.517 s, and the absolute error \( t_{z,1000} \) is 0.242 s. The total error of \( \Delta t_{\text{total},1000} \) measurements of grain movement time is 0.242 s.

At the same time, the minimum speed \( v_{\text{min},1000} \) of grain immersion to a depth of 0.135 m is equal to 0.201 m/s, and the maximum \( v_{\text{max},1000} = 0.338 \) m/s. The average arithmetic value of the grain speed \( v_{\text{mid},1000} \) from the experimental data according to expression (7) is 0.28 m/s.

Then, in accordance with expression (5), the relative error \( \varepsilon_{v_{1000}} \) in determining the speed of grain movement is 0.48. As a result, the absolute error \( \Delta v_{1000} \) of indirect determination of the speed of grain movement in water according to the expression (6) is 0.13 m/s. The confidence interval \( v_{\text{mid},1000} \pm \Delta v_{1000} \) of the sinking speed of grains with a reliability of \( p = 0.95 \) is 0.15-0.41 m/s.

The limits of variation of the time \( t_z \) in experiments with the movement of grains in an aqueous salt solution with a density of \( \rho_{zh} = 1090 \text{ kg/m}^3 \) are 0.40...0.67 s. The average value of the time \( t_{\text{mid},1090} \) immersion of grains is 0.721 s. The mean square deviation of \( S_{z,1090} \) measurements of the time of movement of the grain is 0.727 s, and the absolute error \( \Delta t_{z,1090} \) is 0.242 s. The total error of \( \Delta t_{\text{total},z,1090} \) measurement of grain movement time is 0.340 s.

At the same time, the minimum speed \( v_{\text{min},1090} \) of grain immersion is equal to 0.142 m/s, and the maximum \( v_{\text{max},1090} = 0.245 \) m/s. The average arithmetic value of the speed \( v_{\text{mid},1090} \) of the grain at this density \( \rho_{zh} \) liquid is 0.19 m/s. Then, in accordance with expression (5), the relative error \( \varepsilon_{v_{1090}} \) in determining the speed of the grain is 0.476. As a result, the absolute error \( \Delta v_{1090} \) of indirect determination of the speed of grain movement in water according to the expression (6) is 0.09 m/s. The confidence interval \( v_{\text{mid},1090} \pm \Delta v_{1090} \) of the sinking speed of grains with a reliability of \( p = 0.95 \) is 0.10...0.28 m/s.

In practical experiments, when grains are immersed in an aqueous salt solution with a density of \( \rho_{zh} = 1150 \text{ kg/m}^3 \), the time \( t_z \) of their movement is 0.701...1.050 s. The average value of the time \( t_{\text{mid},z,1150} \) of the grain is 0.868 s. The average square deviation of the \( S_{z,1150} \) measurement of grain movement time is 0.872 s, and the absolute error of the \( \Delta t_{z,1150} \) is 0.408 s. The total error \( \Delta t_{\text{total},z,1150} \) measurement of grain movement time is 0.408 s.
- water with a density of $\rho_{zh} = 1000 \text{ kg/m}^3$;
- aqueous solution of sodium chloride (NaCl) with a density of $\rho_{zh} = 1090 \text{ kg/m}^3$;
- aqueous solution of sodium chloride (NaCl) with a density of $\rho_{zh} = 1150 \text{ kg/m}^3$.

**Figure 2.** Dependences of time $t_z$ (a) and speed $v_z$ (b) of immersion of pea grains of Vita variety in liquid from the number $x_{No.}$ of the conducted experiment.

At the same time, the minimum speed $v_{\text{min},z1150}$ in grain immersion is equal to 0.129 m/s, and the maximum $v_{\text{max},z1150} = 0.193$ m/s. The average arithmetic value of the grain speed $v_{\text{mid},z1150}$ from the experimental data is 0.16 m/s. Then, in accordance with expression (5), the relative error $\varepsilon_{v_{z1150}}$ in determining the speed of the grain is 0.47. As a result, the absolute error $\Delta v_{z1150}$ of the indirect determination of the speed of grain movement in water according to the expression (6) is 0.07 m/s. The confidence interval $v_{\text{mid},z1150} \pm \Delta v_{z1150}$ of the sinking speed of grains with reliability $p = 0.95$ is 0.09...0.23 m/s.

**4. Conclusion**

Thus, the conducted practical experiments to determine the speed $v_z$ of immersion in a liquid of various densities $\rho_{zh}$ grains of spherical shapes can be used in the development of a machine for cleaning and etching grain material by density in a wet way to justify its design and technological parameters in order to perform it with proper efficiency of the technological process.

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