Criteria for assessing the grain stream immersion in an aqueous salt solution

Viktor Saitov¹,², Rustam Kurbanov², Aleksey Saitov²

¹ Federal Agrarian Scientific Center of the North-East, 166 A, Lenin str., Kirov, 610007, Russia
² Vyatka State Agricultural Academy, 133, October ave., Kirov, 610017, Russia

E-mail: vicsait-valita@e-kirov.ru

Abstract. One of the most important foodstuffs for human is grain. In the grain heap delivered from combine harvesters to the post-harvest processing points, in addition to the grain of the main crop, various impurities, including poisonous ones, are also contained. Poisonous impurities include ergot sclerotia. The use of modern grain cleaning machines does not give positive results when cleaning grain material from ergot due to the proximity of its properties and the properties of the crop being cleaned. Cleaning of seeds from ergot sclerotia having a density lower than grain density is possible in aqueous solutions of inorganic salts. In order to develop a device for cleaning grain material by density using a wet method, practical experiments were carried out on immersion of Falenskaya 4 varieties of winter rye grain in a solution of sodium chloride (NaCl) with a density of \( \rho = 1030 \) and \( 1060 \) kg/m\(^3\) and water (\( \rho = 1000 \) kg/m\(^3\)) at a specific grain load \( g_{sp} = 97.975 \) kg/(s·m\(^2\)). One of the criteria for assessing the effective height of the loading hopper location relative to the surface of an aqueous salt solution in the tank of a device for separating harmful impurities from a grain material by a wet method is the proportion \( R_g \) of grains that did not drown and floated to the solution surface with air bubbles. It was found that the minimum values of \( R_g \) are at a grain supply height \( h = 40...60 \times 10^{-3} \) m. Moreover, the proportion of non-drowned grains \( P_g \), even with forced exposure to them, is the loss of grain to waste.

1. Introduction

One of the most important foodstuffs for human is grain. Nowadays, small, puny, and crushed grain is used as fodder for farm animals [1, 2].

Crops are harvested using self-propelled combine harvesters. The grain heap delivered from these combines to the post-harvest processing points contains full, small, and puny grain of the main culture, grains and seeds of foreign crops, weeds, including harmful ones [3, 4].

Harmful impurities include poisonous weed seeds, as well as grains of cultivated plants with fungal diseases - Sclerotium clavus. The use of air and screen indented surface separator, pneumatic sorting tables, photo separators and other devices does not give positive results when cleaning grain material from ergot due to the closeness of its properties and the properties of the culture being cleaned [5, 6, 7, 8].

Ergot sclerotia, which are poisonous impurities in the grain material, have a lower density (\( \rho_s = 0.9 ... 1.15 \times 10^3 \) kg/m\(^3\)) than the grain of cultivated plants (\( \rho_g = 1.2 ... 1.5 \times 10^3 \) kg/m\(^3\)). Therefore, to isolate
ergot sclerotia from rye seeds, one can use aqueous solutions of inorganic salts, for example, solutions of sodium chloride or potassium salt [9].

To mechanize the allocation of ergot sclerotia from rye seeds using the wet method, the development of a device for cleaning grain material is an urgent issue. When developing a device for cleaning grain material by density using the wet method, it is necessary to determine the effective height of the loading hopper location relative to the surface of the salt solution in the device tank. For this, it is necessary to determine the criteria for assessing the effective height of grain stream immersion in an aqueous salt solution.

2. Materials and methods

To achieve this goal, practical experiments were carried out on the stream of winter rye grain Falenskaya 4 with a moisture content of 14% [10] into an aqueous solution of sodium chloride (NaCl) with a density $\rho_1 = 1030$ and $1060$ kg/m$^3$, and water ($\rho_1 = 1000$ kg/m$^3$) at a temperature of 20$^\circ$C. For this, an experimental setup was made, which is shown in Figure 1.

![Figure 1. General view (a) and scheme (b) of an experimental setup for studying the grain stream immersion in an aqueous salt solution: 1 - laboratory tripod; 2 - holder; 3 - hopper; 4 - control gate; 5 - inclined plane; 6 - tank; 7 - sieve; 8 - mesh; 9 – counterweight.](image-url)

The experimental setup for studying the grain stream immersion in an aqueous salt solution consisted of a laboratory tripod 1, hopper 3, tank 6, mesh 8 for removing grains floating on the surface of the solution, and sieve 7 to separate the grains from the salt solution. The laboratory tripod consists of a stand and a vertical rack. It is additionally equipped with a counterbalance 9 for stability. The holder 2 is mounted on a vertical rack using a coupling with clamping screws, on which the hopper 3 is suspended.

The hopper 3 consists of vertical side, back and end walls, and inclined bottom. The end wall at the level of the shoulder of the vertical back wall and the inclined bottom is mated with an additional inclined bottom equipped with an outlet opening and a control gate. The inclined bottom from the outlet opening is made in the form of an inclined plane 5. The hopper 3 is made with side dimensions of 0.1 m and a height of 0.23 m. The angle of inclination of the bottom and the additional bottom equipped with the outlet opening was 60$^\circ$. The capacity of the hopper 3, under which the tank 6 is set, allowed holding 1.5 kg of grain [11].

The tank 6 made of transparent glass, the side walls and the bottom of which are glued together with a silicone-based sealant, is a glass vessel with a length of 0.35 m, a width of 0.20 m, and a height of 0.15 m. The volume of the water or salt solution poured in this vessel was 9 liters.

To remove grains floating on the surface of the solution, a metal mesh 8 was used with mesh openings of $1.2 \cdot 10^{-3}$ m, which was made square in shape with a side size of 0.15 m.
The sieve 7 for separating grains from the salt solution is a colander made of a metal mesh with mesh openings of $1.2 \times 10^{-3}$ m. The external dimensions of the sieve 7 corresponded to the internal dimensions of the tank 6. The walls of the sieve 7 are equipped with small “ears” that fix this device on top of the tank 6.

3. Results and Discussion

The process of grain stream immersion in an aqueous salt solution is as follows. From above, the stream of grain material is loaded into the storage part of the hopper 3, from which it is uniformly distributed along the width of the outlet opening into the tank 6 with an aqueous salt solution in which the sieve 7 is preliminarily placed. When the grain material enters the aqueous salt solution, grains having a high density in comparison with the density of the solution drown sink to the bottom of the tank 6, and other grains with a lower density float to the surface of the salt solution. When visually observing the process of grain stream immersion in an aqueous salt solution, it was noticed that part of the drowned grain floats to the surface of the salt solution with trapped air bubbles. With increasing fall height, the number of such grains becomes larger. In case of forced influence on these grains, air bubbles are removed from them, and these grains again fall to the bottom of the tank 6. As a result, grains that remained on the surface of the salt solution, which did not drown even when they were forced, will be removed to waste by the machine. They are puny, have external and internal micro-damages, and therefore have least valuable biological properties. These grains will have poor germination and do not represent value as a seed material and as a grain for germination when obtaining high-quality malt. However, these grains can be attributed to the forage crop, and they represent a valuable foodstuff for farm animals.

Thus, the determination of the effective height of grain stream immersion in an aqueous solution salt can be estimated by the proportion $R_g$ of grains that did not drown and floated to the surface of the salt solution, and by the proportion $P_g$ of grains that did not drown, even when they were forced, which constitute grain loss to waste.

The proportion of grains that did not drown and floated to the surface of the salt solution with air bubbles is determined by the formula (%):

$$R_g = \frac{n_1}{n_1} \cdot 100,$$

where $n_1$ - the number of grains supplied to the aqueous salt solution, $n_1 = 10,000$ pcs; $n_2$ - the number of grains trapped on the surface of the aqueous salt solution, pcs.

The proportion of non-drowned grains, even with forced exposure to them, which constitute the loss of grain to waste, is determined by the formula (%):

$$P_g = \frac{n_4}{n_1} \cdot 100,$$

$n_4$ – the number of grains on the surface of an aqueous salt solution, which did not drown even with forced exposure to them, pcs.

To obtain information on determining the effective height $h$ of grain stream immersion in an aqueous salt solution using the proposed evaluation criteria represented by expressions (1) and (2), triple experiments were carried out at a specific grain load of $g_{sp} = 97.975$ kg/(s·m²), which corresponded to the opening of the outlet opening of the hopper of the experimental setup at $15 \times 10^{-3}$ m.

The results of experiments on the stream immersion of winter rye grains of the Falenskaya 4 variety in an aqueous solution of sodium chloride (NaCl) with a density $\rho_l = 1030$ and 1060 kg/m³ and water ($\rho_l = 1000$ kg/m³) are shown in Figure 2.
Figure 2. Dependences of the proportion $R_g$ of grain that did not drown and floated with air bubbles (a) and the losses $P_g$ of grain to waste (b) during grain stream immersion of winter rye of the Falenskaya 4 variety on the height $h$ of supply to water (---) and an aqueous solution of sodium chloride (NaCl) with a density $\rho_l = 1030$ kg/m$^3$ (-----) and 1060 kg/m$^3$ (----).

The dependences of the proportion $R_g$ of grain, which did not drown and floated to the surface of water and the aqueous salt solution with air bubbles, on the supply height $h$ are described by the equations (%):

$$
R_{1000} = 6.0857 - 0.1615h + 0.0017h^2 - 6.0 \times 10^{-6}h^3, \quad R^2 = 0.989 
$$

$$
R_{1030} = 3.4429 - 0.0901h + 0.001h^2 - 3.0 \times 10^{-6}h^3, \quad R^2 = 0.987 
$$

$$
R_{1060} = 0.4 - 0.0085h + 8.0 \times 10^{-5}h^2, \quad R^2 = 0.957 
$$

The reliability coefficients $R^2$ for approximating the dependences (3), (4) and (5) are close to 1.0, which indicates the compliance of the trend model with experimental data. This characterizes the approximation as a mathematical model of good quality.

From the obtained dependencies it follows that when a grain stream immerses in water ($\rho_l = 1000$ kg/m$^3$), the lowest value of $R_g = 0.2\%$ is obtained at a supply height $h = 40 \times 10^{-3}$ m, and when immerses in an aqueous salt solution with a density $\rho_l = 1030$ and 1060 kg/m$^3$ - $R_g = 0.9$ and 1.4\%, respectively, with a supply height $h = 60 \times 10^{-3}$ m.

When the grain supply height $h = 20 \times 10^{-3}$ m, it was revealed that a significant amount of grains from this height cannot overcome the surface tension of water or an aqueous salt solution, and therefore the values of $R_g$ are higher than at heights $h = 40...60 \times 10^{-3}$ m. An increase in the height $h$ of the grain supply from 40...60 $\times 10^{-3}$ m causes an increase in the $R_g$ value, which is caused by the grabbing of air bubbles by the grains and their floating to the surface of water or an aqueous salt solution. Moreover, it was visually revealed that at heights $h$ of grain supply of 100...140 $\times 10^{-3}$ m, an increase in the size of air bubbles occurs, and grains with these air bubbles are grouped into lumps that actively float to the surface of water or an aqueous salt solution.

The loss $P_g$ of grain to waste when it is immersed in water and an aqueous salt solution is almost independent of the supply height $h$. When grain is immersed in water ($\rho_l = 1000$ kg/m$^3$), the highest value of $P_{g\text{max}} = 0.26\%$, and the smallest - $P_{g\text{min}} = 0.24\%$. When supplying grain into an aqueous salt solution with a density $\rho_l = 1030$ kg/m$^3$, the corresponding values are: $P_{g\text{max}} = 0.68\%$ and $P_{g\text{min}} = 0.65\%$, and in an aqueous salt solution with a density $\rho_l = 1060$ kg/m$^3$, these values increase: $P_{g\text{max}} = 0.86\%$ and $P_{g\text{min}} = 0.84\%$.

As the value of the loss of grain to waste $P_g$, we will consider the corresponding average values. Then, when the grain stream immerses in water ($\rho_l = 1000$ kg/m$^3$), an average of 0.25% of the least valuable grain can be removed to waste, and when the grain is immersed in an aqueous salt solution...
with a density \( \rho_l = 1030 \) and \( 1060\ \text{kg/m}^3 \)- an average of 0.66% and 0.85%, respectively. An increase in the density \( \rho_l \) of the solution increases the loss of the grain to waste.

4. Conclusion

Thus, based on the studies of grain stream immersion of winter rye of Falenskaya 4 variety with a moisture content of 14% at a temperature of 20\( ^\circ \)C in a solution of sodium chloride (NaCl) with a density \( \rho_l = 1030 \) and \( 1060\ \text{kg/m}^3 \) and water \( (\rho_l = 1000\ \text{kg/m}^3) \) at a specific grain load \( g_{sp} = 97.974\ \text{kg/(s} \cdot \text{m}^2) \), it follows that one of the criteria for determining the effective height \( h \) of the loading hopper location relative to the surface of an aqueous salt solution in the tank of the device for separating harmful impurities from the grain material using the wet method is the proportion \( R_g \) of grain that did not drown and floated to the surface of the solution with air bubbles. As a result of univariate search experiments, it was revealed that the minimum values of \( R_g \) were obtained at a grain supply height \( h = 40...60\ \times 10^{-3}\ \text{m} \). Moreover, the proportion \( P_g \) of non-drowned grains, even with forced exposure to them, is loss of grain to waste. Their values almost do not change when the grain supply height \( h \) varies, and they increase with an increase in the density of the liquid \( \rho_l \) [10, 12, 13].

Acknowledgments

The study was carried out according to the scientific theme “Creating a machine for the exclusion of poisonous impurities (ergot sclerotia) from winter rye grain by specific mass using aqueous solutions of inorganic salts” according to research work No. 0767-2019-0094 “Creating innovative technologies and new generation technologies for mechanization of crop production and animal husbandry, adapted to the climatic conditions of the North-East of the European part of Russia” under section 10.9, subsection 162 of the Program of fundamental scientific research of State Academies of Sciences for 2013-2020.

References

[1] Ocnin B, Gorbachev I, Terekhin A, Soloviev V 1987 Machines for post-harvest processing of grain (Moscow: Agropromizdat Publ.) p 238
[2] Sysuev V, Kedrova L, Lapteva N, Utkina E, Vaananen M, Nikulina T 2010 Rye energy for human health (Kirov, Agricultural Research Institute of the North-East Publ.) p 103
[3] Afanasova M, Sheshegova T, Kedrova L 2002 Agrarnaya nauka Evro-Severo-Vostoka 3 pp 67-70
[4] Schekleina L, Sheshegova T 2013 Teoreticheskaia i prikladnaya ehkologiya 1 pp 5-12
[5] Furuno Y, Matsui M, Inoue E 2008 Journal of the Japanese Society of Agricultural Machinery 3 70 pp 58-64
[6] Drincha V, Borisenko I 2008 Nauchno-agronomicheskii zhurnal 3 83 pp 33-36
[7] Saitov A 2016 Methods and technologies in plant breeding and crop production (Kirov: Agricultural Research Institute of the North-East Publ.) pp 352-355
[8] Schultz T 1993 Plant Dis. 77 pp 685-687
[9] Pavlovsky G, Pitsyn S 1972 Cleaning, drying and active ventilation of grain (Moscow: High school Publ.) p 256
[10] Sysuev V, Saitov V, Farafonov V, Saitov A 2017 Uspekhi sovremennogo yestestvoznaniya 10 pp 48-53
[11] Saitov V, Farafonov V, Suvorov A, Saitov A 2017 Bunker for bulk materials Patent RF no. 2631556
[12] Sysuev V, Saitov V, Farafonov V, Suvorov A, Saitov A 2017 Russian Agricultural Sciences 43 3 pp 273-276
[13] Saitov V, Farafonov V, Saitov A 2016 Mosolovskie reading: International materials scientific-practical conf. (Yoshkar-Ola: Mari State University Publ.) 18 pp 241-244