Reduction of mechanical damage to buckwheat seeds during mechanized treatment

V V Trotsenko, I V Trotsenko, N V Komendantova, A A Babariko and I P Ivanova

Omsk State Agrarian University, 1, Institutskaya square, Omsk, 644008, Russian Federation

E-mail: vv.trotsenko@omgau.org

Abstract. This article is devoted to the issues of the efficiency increasing for buckwheat seed production by reducing mechanical damage during mechanized processing. It is indicated that one of the possible ways to reduce grain damage by machines' details on a mechanized line is to assess the degree of damage adequately. Due to the fact that the samples analysis for mechanical damages taken from a grain batch that has passed according to any technological processing scheme is a labor-intensive and time-consuming procedure, the reliability of the results of which is largely dependent on the human factor, it is proposed to increase accuracy measurements on the basis of reliable experimental data, reveal the patterns of injury depending on the state of the grain material and its physical and mechanical properties, and in accordance with this, in the future, predict the quantitative increase in mechanical damage in general and by the types of injuries inflicted on the grain by a particular machine by using mathematical relationships. There are the theoretical dependence for the mechanical damages indicators on the number of passes through the machine and experimental dependence on humidity in this article established by using Markov chains. It was revealed that with mechanized processing there is a process of successive transition from less dangerous injuries to more dangerous injuries. The indicators of mechanical damage prediction will permit to compare the efficiency of individual machines of the production line in terms of their damaging ability and purposely design the technological process with minimal damage of the grain material.

1. Introduction

With the mechanization of grain crops seed production there is a decrease in their viability and durability (Ng,1998), (Shevchenko,2018), (Koval,2019). It happens due to the fact that when interacting with the machines details the stresses appears in individual grains, which are exceeded the value of the ultimate strength and, as a consequence, micro injury occurs initially, in other words, the damage to the fruit membranes, endosperm and embryo, then we can observe the macro injury that means the grinding or grain crushing (Resende,2013), (Tarasenko,2015), (Henry,2000). The crushed grains after post-harvest processing machines end up in waste and have no affect the quality of the grain batch in the future. The micro injured grains remain in the batch and affect the stability of the seed batch during storage and further processing, also reduce the germination of grain material. Since it is impossible to completely exclude the grain damage during mechanized processing, the search for ways to reduce the amount of mechanical damages by improving the technological scheme of processing and technical means of its implementation is relevant and has an important national economic importance.
2. Problem Statement

One of the ways to reduce the grain damage by machines parts of a mechanized line is to adequately assess the degree of damage. This assessment is carried out on the relevant methods (Altuntas, 2007), (Corrêa, 2007), (Kakade, 2019). However, most of these techniques are based on a labor-consuming visual inspection of the taken samples for mechanical damage. At the same time, the obtained results after each such analysis of the sample vary significantly from the qualifications of the researcher (the coefficient of variation is 20 percent or more), which raises certain doubts about the reliability of the experiments. It is possible to increase the measurement accuracy by attracting highly qualified laboratory personnel to each experiment, which is very costly. In our opinion, it is possible to improve the process of assessing the damaging ability of machines as follows: on the basis of reliable experimental data, to reveal the patterns of injury depending on the state of the grain material and its physical and mechanical properties, and in accordance with this, in the future, predict the quantitative increase in mechanical damage in general and by the types of injuries inflicted on grain by a particular machine, using mathematical relationships.

3. Research Questions

In the process of processing and transportation from the field to the consumer, the grain goes through the stages of harvesting, preliminary cleaning, drying, primary cleaning, split into seed and food, etc. At each such stage, when the grain material interacts with the working details of the machines, its state and physical and mechanical properties are changing (Corrêa, 2019), (Maryam, 2007), (Shahbazi, 2017). The condition of the grain material is defined as the degree of its damage by the previous machines mechanized line. It should also be noted that in order to achieve a certain quality the grain material can be repeatedly passed through the same machine (parameter n is the number of grain passes through the machine). Physical and mechanical properties are grain moisture $W$, trash content (contamination), temperature.

In this article, we will consider how grain damage occurs using the example of such an important agricultural crop as buckwheat. During the process of mechanized processing the buckwheat grain receives mechanical damage, which can be divided into three types: grains with a cracked shell, crushed and splitted grains. A grain batch that has passed any technological scheme is characterized by the content of grains in it: with a cracked shell $\delta_{\text{crack}}$ ($i=1$), crushed grains $\delta_{\text{crush}}$ ($i=2$), splitted grains $\delta_{\text{split}}$ ($i=3$) and non-damaged grains $\delta_{\text{non-damage}}$ ($i=0$). The values of $\delta$ are defined as the ratio of the mass of the appropriating fraction to the total mass of the batch minus the mass of impurities.

The ratio of the shares $\delta$ will change depending on the number of passes of a batch of grain $n$ through the machine at a constant condition

$$\delta_{0n} + \delta_{n} + \delta_{m} + \delta_{s} = 1 \quad (1)$$

Each of these parameters will change depending on the number of passes of grain through the machine $n$, while the effect assessment of $n$ on $\delta$ is possible using a theoretical and experimental approach. In addition, we will experimentally evaluate the effect of the moisture content of grain material $W$ on $\delta$. As part of this article we will resolve the theoretical and experimental issues.

3.1. Theoretical study of the increasing damage process during mechanized processing

The dependency $\delta_{n}=f(n)$ will be determined by using the Markov’s chains (Trotenko, 2019) (Korn, 2000) by the following expression

$$\delta_{in} = \delta_{i0} \cdot A^n, \quad (2)$$

where $\delta_{in}$ – the vector of probabilities of the final state after $n$-passes $\delta_{n}=(\delta_{0n} \quad \delta_{1n} \quad \delta_{2n} \quad \delta_{3n})$; $\delta_{i0}$ – the vector of probabilities of the primary state $\delta_{0}=(\delta_{00} \quad \delta_{10} \quad \delta_{20} \quad \delta_{30})$; $A$ – the transition matrix.

Experimentally we determined $\delta_{n}$ and $\delta_{0}$ to solve the equation (2) for unknown $A$ with known $n$. 
3.2. Experimental study of the effect of grain moisture and the number of grain passes through the machine
Since the values of $\delta_n$ will be different like the different values of $W$, we determine the value of $A$ with the different humidity $W$.

4. Purpose of the Study
The purpose of study is to establish the regularity of influence of the grain passes number through the machine and its humidity on quantitative indexes of the mechanical damages.

5. Research Methods
During the experiment weighed portions of the buckwheat grains without admixture (each portion weight was 50g) were brought to a specific humidity and passed certain $n$-number times through the special installation (Trotsenko, Trotsenko, 2019). After this each portion was visually analyzed for the quantitative content of the $i$-th types of injuries. The experiment was repeated five times.

The percent of the crushed and splitted grains in the weight of portion was determined by the following expression

$$m_p = \frac{m_{\text{crush}}}{m_p} \cdot 100, \tag{3}$$

$$m_p = \frac{m_{\text{split}}}{m_p} \cdot 100. \tag{4}$$

$m_p$ – the weight of grain portion, g;
$m_{\text{crush}}, m_{\text{split}}$ – the weight of crushed and splitted grains, g.

The quantitative index of grains with cracked shell was determined by the following method. We selected four hundred grains randomly from the sum of non-damaged grains and grains with a cracked shell, looked through the magnifying glass and determined the number of micro-damaged grains in pieces from each hundred $\delta_{\text{crack}}^m$. If the difference between the $i$-th values did not exceed 10%, then the average value of the required parameter was found by

$$\delta_{\text{crack}} = \left(100 - \delta_{\text{crush}} - \delta_{\text{split}}\right) \frac{\delta_{\text{crack}}^m}{100}. \tag{5}$$

6. Findings
The transition matrix $A$ looks like

$$A = \begin{pmatrix}
a_{11} & a_{12} & a_{13} & a_{14} \\
a_{21} & a_{22} & a_{23} & a_{24} \\
a_{31} & a_{32} & a_{33} & a_{34} \\
a_{41} & a_{42} & a_{43} & a_{44}
\end{pmatrix}. \tag{6}$$

The elements of this matrix $a_{21}, a_{31}, a_{32}, a_{41}, a_{42}, a_{43}$ are equal to zero, because this is the probabilities of transition from more damaged to less damaged state. Due to the fact that the splitted grain will be splitted at any value of $n$, the probability $a_{44} = 1$. Following this we received

$$A = \begin{pmatrix}
a_{11} & a_{12} & a_{13} & a_{14} \\
0 & a_{22} & a_{23} & a_{24} \\
0 & 0 & a_{33} & a_{34} \\
0 & 0 & 0 & 1
\end{pmatrix}. \tag{7}$$

Substituting the matrix (7) in (2), we received such equation

$$\delta_{in} = \delta_{i0} \cdot \begin{pmatrix}
a_{11} & a_{12} & a_{13} & a_{14} \\
0 & a_{22} & a_{23} & a_{24} \\
0 & 0 & a_{33} & a_{34} \\
0 & 0 & 0 & 1
\end{pmatrix}^n. \tag{8}$$

This matrix equation with the known only $\delta_{in}$ and $\delta_{i0}$ has no solutions for unknown $a_{jk}$, because the quantity of the unknown parameters exceeds the quantity of equations.
However, there is the process of sequential transition from state $i_0 = 0$ to state $i_1 = 1$, then to state $i_2 = 2$ and (in the end) to state $i_3 = 3$ in the most cases during the grain processing. In this case the elements $a_{13}$, $a_{14}$, $a_{24}$ also will be equal to zero. To simplify this entry we consider that $a_{11} = a$, $a_{22} = b$, $a_{33} = c$. Since the probability sum by strings is equal to one, then

$$a_{12} = 1 - a, \ a_{23} = 1 - b, \ a_{34} = 1 - c.$$  

(9)

Based on it the expression (8) will be

$$\delta_{in} = \delta_{i0} \cdot \begin{pmatrix} a & 1 - a & 0 & 0 \\ 0 & b & 1 - b & 0 \\ 0 & 0 & c & 1 - c \\ 0 & 0 & 0 & 1 \end{pmatrix}^n$$

(10)

The matrix elements $(\delta_{in}, \delta_{1n}, \delta_{2n}, \delta_{3n})$, which were determined by experiment with the number of passes $n=4$ and humidity of the grain material $W=9.01\%$, were $\delta_i=(0.7555 \ 0.2006 \ 0.0274 \ 0.0165)$ and with $W=17.81\%$ were $\delta_i=(0.9003 \ 0.0815 \ 0.0020 \ 0.0004)$. Also, experimentally we found the values of elements of the original matrix $\delta_{i0}=(0.9685 \ 0.0315 \ 0 \ 0)$

After the substitution of experimental results $\delta_{i0}$ and $\delta_{i4}$ in the equation (10) and multiplication of these matrices this equation looks like

$$\begin{pmatrix} 0.9685 \cdot a^4 & 0.9685 \cdot (1 - a) \cdot (a^3 + b \cdot a^2 + b^2 \cdot a + b^3) + 0.0315 \cdot b^4 (1 - b) \cdot (0.9685 \cdot (1 - a) \cdot (a^2 + b \cdot a + b^2 + c \cdot (a + b + c)) + 0.0315 \cdot b^3 + c \cdot (b^2 + b \cdot c + c^2)) \end{pmatrix} \cdot (1 - b) \cdot (1 - c) \cdot (0.9685 \cdot (1 - a) \cdot (a + b + c + 1) + 0.0315 \cdot (b^2 + b \cdot c + c^2 + b + c + 1)) = \delta_{i4}$$

(11)

Equating the appropriate elements of the left and right parts we received two systems of four equations.

For $W=9.01\%$

\[
\begin{cases}
0.9685 \cdot a^4 = 0.7555 \\
0.9685 \cdot (1 - a) \cdot a^3 + b \cdot a^2 + b^2 \cdot a + b^3 = 0.2006 \\
(1 - b) \cdot (0.9685 \cdot (1 - a) \cdot a^2 + b \cdot a + b^2 + c \cdot (a + b + c)) = 0.0274 \\
(1 - b) \cdot (1 - c) \cdot 0.9685 \cdot (1 - a) \cdot (a + b + c + 1) = 0.0165
\end{cases}
\]

(12)

For $W=17.81\%$

\[
\begin{cases}
0.9685 \cdot a^4 = 0.9161 \\
0.9685 \cdot (1 - a) \cdot a^3 + b \cdot a^2 + b^2 \cdot a + b^3 = 0.0815 \\
(1 - b) \cdot (0.9685 \cdot (1 - a) \cdot a^2 + b \cdot a + b^2 + c \cdot (a + b + c)) = 0.002 \\
(1 - b) \cdot (1 - c) \cdot 0.9685 \cdot (1 - a) \cdot (a + b + c + 1) = 0.0004
\end{cases}
\]

(13)

The real roots of the equations

For $W=9.01\%$ \(a = 0.9448\), \(b = 0.8956\), for $W=17.81\%$ \(a = 0.9862\), \(b = 0.9883\), \(c = 0.8568\)

The equation (6) for the two humidity values will look like

$$\delta_{i4}^{W=9.01\%} = \delta_{i0} \cdot \begin{pmatrix} 0.9448 & 0.0552 & 0 & 0 \\ 0 & 0.8956 & 0.1044 & 0 \\ 0 & 0 & 0.5024 & 0.4976 \\ 0 & 0 & 0 & 1 \end{pmatrix}^n$$

(14)

$$\delta_{i4}^{W=17.81\%} = \delta_{i0} \cdot \begin{pmatrix} 0.9862 & 0.0138 & 0 & 0 \\ 0 & 0.9883 & 0.0117 & 0 \\ 0 & 0 & 0.8568 & 0.1432 \\ 0 & 0 & 0 & 1 \end{pmatrix}^n$$

(15)
The analysis of the experimental data (with \( n = 4, 10, 15, 25 \)) showed that formulas (10), (12), (13), (14), (15) are acceptable: approximation confidence factor \( R^2 \geq 0.85 \).

During the seed grain cleaning from impurities, sorting and drying it is sometimes necessary to pass the grain material several times through the appropriate machines. As the result we can see the transition of less dangerous damages to more dangerous damages.

As example, as the result of using a ventilated hopper the quantitative increase of the mechanical damages is about 1% per one pass through the noria with the humidity 23.25%. If buckwheat seeds of such parameters are dried using active ventilation for 12-14 days at the temperature of 200 °C with one or two daily re-emptying of the hopper, then the quantitative increase in mechanical damage will exceed 30%, which will significantly reduce the quality of the seed. If the drying of buckwheat seeds is carried out in ventilated bunkers with a mixing element (the noria is needed only for a one-time loading and unloading), then the indicator of mechanical damage does not exceed 5% (Trotsenko, Zabudsky, 2019).

7. Conclusion

The using of the proposed method at a known initial seeds batch state \( \delta_{i0} \) enables to analytically determine the content of the mechanical damages by types \( \delta_{in} \) for any crop and assess the quality of the seed after \( n \)-number passes through the machine.

The prediction of indicators of mechanical damage will let compare the efficiency of every machine of the production line in terms of their damaging ability and design the technological process with minimal damage to the grain material in advance.

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