The friction of root crops on different surfaces in preparation for feeding animals

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Abstract. The purpose of the research was to determine the functional dependencies of the friction parameters of root crops on various surfaces for subsequent use in energy calculations of working bodies. The research methodology provided for the experimental determination of static and kinetic friction coefficients on various surfaces and subsequent statistical processing of experimental data to obtain a regression model of indicators from the pressure of compression. Based on the research, equations were obtained that characterize the friction processes of root crops on various surfaces (steel, rubber, painted steel), which will serve for their further use in the design of machines and energy calculation. The highest friction coefficient corresponds to a pressure of 4.0-5.0 kPa, regardless of the static or dynamic loading method. At motion speeds of surfaces up to 2.0...2.6 m/s, the released juice manages to squeeze out of the contact zone. This increases the friction coefficient. At speeds from 2.000...3.095 m/s, the resulting juice does not have time to leak out of the contact zone, and therefore works as a liquid lubrication. As the speed increases, the friction coefficient decreases.

1. Introduction
Increasing the productivity of farm animals requires providing them with vitamins and sugar. For these purposes root crops are used. Root crops are used in the form of succulent milk-making feed in dairy cattle-breeding and as the main component of the feed mixture for potato-concentrate type of pig feeding. Accordingly, for cows root crops can be used raw, for pig feeding they must be steamed. The use of root crops in the diets of farm animals has a positive effect on their productivity, as it contributes to the activation of the vital functions of microorganisms living in the gastrointestinal tract and involving in the digestion process. For example, the inclusion of sugar beets in the newly-calved cows diet contributes to an increase in the average daily milk yield [1–3]. However, it is necessary to grind the root tubers before feeding the newly-calved cows.
Root crops include beets (fodder, sugar and semi-sugar), turnips, carrots, rutabaga, potatoes, girasol etc. In root crops contain a lot of water (70-90 %) and very little protein (1-2 %). The dry matter of root crops consists almost entirely of carbohydrates - starch or sugar. Before feeding animals, they must be prepared to increase their eatability and digestibility.

The use of machines for grinding feed, which can increase the productivity of animals while reducing the cost of their preparation, is a necessary condition for the effective use of equipment for mechanization of technological processes of animal husbandry. There are disk choppers, disk choppers with a vertical shaft, drum choppers and choppers with fixed knives. Root crop choppers include root cutters, root grater and various grinders, which differ from each other in the arrangement of working bodies and the degree of material grinding.

Mechanical grinding methods include: crushing by impact, splitting, grinding, as well as cutting. When choosing a grinding method, it should take into account the magnitude of the emerging voltage, as well as the energy costs. In this regard, splitting, grinding or cutting are more advantageous as splitting shear stresses are less than normal stresses. An additional limitation when choosing a method is the required fractional composition of the mass [3].

An important stage in experimental studies of the technological process of root crop grinding is the development of experimental methods, the processing of the obtained data and the manufacture of instruments for determining the physicomechanical properties of root crops [4]. C. Reginer's research has determined the effect of cassava root processing methods on digestibility and palatability when feeding to hog fattening [5]. During the experiment, the roots were crushed using a mechanical grinder or manually with a rifted tool. Three groups of animals were formed, which were fed cassava roots, respectively, as a whole, roughly chopped and chopped. As a result, the best performance was obtained using a mechanical chopper. The method of slicing root crops affects the antioxidant activity of enzymes during storage, that is, determines the organoleptic quality of the feed [6].

It is known that reducing the particle size of feed improves food consumption. In the study [7], the effect of the feed particles use ranging in size from 52 mm (normal particle size) to 7 mm (reduced particle size) in the diet of highly productive cows was determined. As a result of studying chewing activity, food consumption and digestion of nutrients in the digestive tract, it was found that cows that consumed a diet with a reduced particle size, dry matter intake improved (+1.8 kg / day), but fiber absorption was decreased (~ 3.25 kg / day.). The cows of the experimental group reduced the time of eating and chewing per kilogram of dry matter by 4.8 and 1.9 minutes, respectively.

The consumption of feed depends on the quality of grinding the feed. The use of preparing technologies for feeding involves the correction parameters of their optimal mode of their functioning. To this end, experimental studies of various grinding technologies are carried out. For example, when studying the process of grinding grain using a mill with a hammer and roller mechanisms, it was found that the roller mill is the most energy-efficient device, followed by a multi-mode device, and the hammer mill was the least efficient. It is important for feed manufacturers to combine these devices in order to ensure an effective grinding operation and to coordinate the grinding device with its specific grinding purpose (fine grinding, coarse grinding or with a certain particle size distribution) [8]. In other studies, the specific grinding energy and physical properties of the obtained feed particles were determined [9, 10], and the ratio of speed and grinding time parameters was studied [11, 12]. In the past decade in many countries more and more attention has been paid to the mechanization of agricultural production, in particular to issues of grinding during harvesting and preparation of feed for feeding animals [13-15], as well as the effect of feed dosing on productivity [16].

The purpose of the research was to determine the functional dependencies of the root crops friction parameters on various surfaces for subsequent use in energy calculations of working bodies.

2. Methods and Materials
The research methodology provided for the experimental determination of static and kinetic friction coefficients on various surfaces and subsequent statistical processing of experimental data to obtain a regression model of indicators from the pressure of compression.
To study the friction process, an experimental device was made that allows one to determine the friction coefficients of root crops on different surfaces. The scheme of the device for studying the static friction coefficients and kinetic friction coefficients of root crops used in Volga region of Russia on various materials (steel, rubber, painted steel), is shown in Figure 1.

The device operating principle is as follows: the root crops are loaded into the carriage 8, which is put on the rail 7, and the root crops come into contact with the surface of the removable disk 1 (different disks have different material of the contact surface with root crops); the root crops press to the surface due to their own weight, the weight of the pressure plate 10 and the load 9; the carriage 8 is connected through a spring 14 with a screw mechanism 13; the disc rotational speed is set using the variable speed controller 2 and is controlled by the tachometer; under the friction force, the carriage 8 moves along the rail 7 in the direction of disk rotation 1, while the spring 14 is stretched; with a screw mechanism 13, the card returns to its original position, the spring extension is fixed on a scale 11, data is recorded in the logbook.

The experiment was repeated five times for each test sample of the root crops with subsequent disk change.

Based on the numerical values of experimental data, the average values of indicators were calculated, which were then used to obtain regression equations.

The friction coefficient was determined by the formula:

\[ f = \frac{F_1}{N}, \]  

where \( F_1 \) is the friction force of root crops on surface, N; \( N \) is the normal surface reaction, N.

The friction force is balanced by the reaction force of the deformed spring:

\[ F_1 = (L_2 - L_1)C, \]  

where \( L_2 \) is the stretch of spring when balancing the friction force, m; \( L_1 \) is the spring pretension; m; \( C \) is the spring’s stiffness, N/m.

The spring stiffness was determined from the condition that the weight of the load is balanced by the reaction force of the deformed spring and calculated by the formula:

\[ F'_1 = (G_2 - G_1)g = (L_4 - L_3)C, \]  

where \( G_2, G_1 \) are the initial and final mass of the cargo, respectively, kg; \( L_4, L_3 \) are the initial and final spring length, respectively, m.

It follows thence:

\[ C = \frac{(G_2 - G_1)g}{L_4 - L_3} \]  

Substituting the expression (4) in (2), we got:

\[ F_1 = \frac{(L_2 - L_1)(G_2 - G_1)g}{(L_4 - L_3)} \]  

The normal surface reaction was determined by the formula:

\[ N = (G_r + G_p + G_i)g, \]  

where \( G_r, G_p, G_i \) are the mass of root crops in the carriage, pressure plate and load, kg, respectively, kg.
Substituting expressions (6) and (5) into formula (1), we obtained the dependence for determining the friction coefficient:

\[
f = \frac{(L_2 - L_3)(G_2 - G_1)}{(L_4 - L_3)(G_R + G_p + G_f)}.
\]  

(7)

The pressure in the contact zone of the root crops on the friction surface was determined by the expression:

\[
P = \frac{N}{S}.
\]

(8)

where \(S\) is the contact area of the root crops on the friction surface, \(m^2\).

3. Experiment and calculations

The dependences of the change in the static friction coefficient of potatoes, carrots and beets on a steel painted and unpainted surface on the pressure in the contact zone are shown in Figures 2 and 3.
The static friction coefficient increases depending on the pressure and surface type: for potatoes – from 1.08 to 1.06 times; carrots – from 1.14 to 1.23 times; beets – from 1.13 to 1.15 times, and then decreases: for potatoes – from 1.06 to 1.13 times; carrots – from 1.1 to 1.18 times; beets – from 1.03 to 1.12 times (Figures 2, 3).

The dependency of change in the friction coefficient of potatoes on the motion speed on a steel painted and unpainted surface at various loads are shown in Figures 4 and 5.
Figure 4. The dependence in the kinetic friction coefficient of potatoes on the load and speed on a painted steel surface: 1 – speed \( \vartheta = 0.258 \) m/s; 2 – speed \( \vartheta = 2.064 \) m/s; 3 – speed \( \vartheta = 2.580 \) m/s; 4 – speed \( \vartheta = 3.095 \) m/s; \( y_1, y_2, y_3, y_4 \) – the value of the kinetic friction coefficient for potatoes from the speed of movement, respectively, for 0.258. 2.064. 2.580. 3.095 m/s; \( x \) - the value of the pressure in the contact zone, kPa

The increase in the friction coefficient at the first stage is explained by an increase in the load and adhesion forces in the contact zone.

Figure 5. The dependence in the kinetic friction coefficient of potatoes on the load and speed on an unpainted steel surface: 1 – speed \( \vartheta = 0.258 \) m/s; 2 – speed \( \vartheta = 2.064 \) m/s; 3 – speed \( \vartheta = 2.580 \) m/s; 4 – speed \( \vartheta = 3.095 \) m/s; \( y_1, y_2, y_3, y_4 \) – the value of the kinetic friction coefficient for potatoes from the speed of movement, respectively, for 0.258. 2.064. 2.580. 3.095 m/s; \( x \) - the value of the pressure in the contact zone, kPa
With an increase in pressure in the contact zone from 2.0 to 4.0 kPa, the friction coefficient increases and reaches its maximum value. With increasing pressure in the contact zone from 4.0 to 6.4 kPa, the friction coefficient decreases.

The frictional drag coefficient, depending on the type of surface and speed, increases with pressure in the contact zone from 2.0 to 4.2 kPa: for potatoes – from 1.05 to 1.18 times, and with an increase in pressure from 4.2 to 6.4 kPa decreases: for potatoes – from 1.03 to 1.22 times (Figures 4, 5).

The static friction coefficient has a maximum value at a pressure of \( P = 4.2 \) kPa and interaction with a steel unpainted disk: for potatoes \( f_s = 0.637 \) (Figure 3).

For potatoes, frictional drag coefficient has a minimum value \( f_f = 0.478 \) at a pressure \( P = 1.98 \) kPa, interaction with a steel painted disk, a speed \( \vartheta_1 = 0.258 \) m/s (Figure 4), and a maximum value \( f_f = 0.610 \) at a pressure \( P = 4.14 \) kPa (Figures 4, 5).

The dependences in the friction coefficient of root crops on a steel painted surface have lower values than on unpainted steel, as the steel unpainted surface has a rougher surface.

The increase in the friction coefficient with increasing pressure from 2.0 to 4.2 kPa is due to the fact that when the pressure increases, the root crops interact more closely with the surface, increasing the adhesion forces. A further increase in pressure leads to the release of juice, which forms a liquid film that acts as a lubricant and reduces the interaction forces.

The speed of the surfaces also affects the friction coefficient. At the speed \( \vartheta = 0.258 \) m/s, the sliding friction coefficient is influenced by the generated pressure and the speed of movement interacting surfaces. For potatoes, the sliding friction coefficient with an increase in the surface velocity from 0.258 to 2.580 m/s increases on the average 1.09 times. With an increase in speed from 2.580 to 3.095 m/s, the sliding friction coefficient decreases on average by 1.1 times (Figures 4, 5). This is due to the fact that at surface speeds of up to 2.0...2.6 m/s, the released juice manages to squeeze out of the contact zone, partially reducing the effect of the juice as a liquid lubricant. At speeds from 2.000...3.095 m/s, the juice that is released does not have time to completely squeeze out of the contact zone and works like a liquid lubricant.

**Conclusion**

The friction process took place at varying pressures in the contact zone and motion speeds of the test material (carrots, potatoes, beets). Based on the research, equations were obtained that characterize the friction processes of root crops on various surfaces (steel, rubber, painted steel), which will serve for their further use in the design of machines and energy calculation. The highest friction coefficient of corresponds to a pressure of 4.0-5.0 kPa, regardless of the static or dynamic loading method. At motion speeds of surfaces up to 2.0...2.6 m/s, the released juice manages to squeeze out of the contact zone. The higher the speed – the more liquid lubricant and the lower the friction coefficient. This increases the friction coefficient. At speeds from 2.000...3.095 m/s, the resulting juice does not have time to leak out of the contact zone, and therefore works as a liquid lubricant. As a result, the friction coefficient decreases with increasing speed. The presented results are reliable, since they were obtained on certified equipment and are consistent with the data of other researchers working in a similar direction of the topic under consideration. The developed research methodology can also be used in the design of root crop choppers.

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