VALIDAÇÃO DO PROJETO E DOS PARÂMETROS PADRÕES DO MOEDOR DE GRÃOS ÚMIDOS DE PLANTAS LEGUMINOSAS (COMO EXEMPLO, O GRÃO DE SOJA)

SUBSTANTIATION OF DESIGN AND STANDARD PARAMETERS OF CHOPPER OF SOAKED GRAIN OF LEGUMINOUS PLANTS (AS AN EXAMPLE OF THE SOYA GRAIN)

ОБОСНОВАНИЕ КОНСТРУКТИВНО-РЕЖИМНЫХ ПАРАМЕТРОВ ИЗМЕЛЬЧИТЕЛЯ ЗАМОЧЕННОГО ЗЕРНА ЗЕРНОБОБОВЫХ КУЛЬТУР (НА ПРИМЕРЕ ЗЕРНА СОИ)

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RESUMO

A maneira mais eficiente de preparar as sementes das leguminosas para a ração animal é a produção da emulsão proteica. Existem diversas maneiras para se obter a emulsão de proteína. No entanto, o processo de operações é fornecido para o uso de máquinas de grande escala, com alto consumo de energia e caras, que muitas vezes não podem ser oferecidas pelas pequenas empresas que produzem hoje mais de 50% de produtos de animais e aves. Desta forma, é necessário desenvolver uma tecnologia universal para fazer a emulsão proteica aplicada em pequenas propriedades. O objetivo da pesquisa é o desenvolvimento de uma tecnologia livre de resíduos para fabricar a emulsão proteica para a ração animal. Partindo da busca de patentes por tecnologias e projetos para fazer uma emulsão proteína, oferecemos uma tecnologia livre de resíduos, que permite unir um grande número de operações tecnológicas (corte, extração, divisão de suspensão em frações) em uma única operação, usando um novo equipamento, a Patente RF No. 2614777. Pesquisas teóricas e experimentais de processos de corte dos grãos e extração de proteína de soja em emulsão foram descritas. O desenho principal e os parâmetros padrão do dispositivo desenvolvido foram comprovados teórica e experimentalmente.

Palavras-chave: Moedor de grão encharcado, proteína de soja, emulsão proteica.

ABSTRACT

The most efficient way to prepare the leguminous plants' seeds for the livestock animal food is making of the protein emulsion. There are a lot of ways of obtaining the protein emulsion. However, process operations provide for the use of large-scale, energy-intensive and expensive machines, which often cannot be afforded by the small enterprises producing more than 50% of animal and poultry products today. This way, it is necessary to develop a universal technology of making the protein emulsion applied in small holdings. The research objective is the development of a waste-free technology of making the protein emulsion for animal food. Proceeding from the patent search for technologies and designs to make a protein emulsion we offered a waste-free technology, which makes it possible to unite a whole number of technological operations (chopping, extraction, a division of suspension into fractions) into one operation through using a new facility, the RF Patent No. 2614777. Theoretical and experimental research of processes of the grain chopping and the soy protein extraction into emulsion was described. The main design and standard parameters of the device developed were substantiated theoretically and experimentally.

Keywords: chopper of the soaked grain, soy protein, protein emulsion.

АННОТАЦИЯ

Наиболее эффективный путь подготовки семян бобовых культур на корм сельскохозяйственным животным – приготовление белковой эмульсии. Существует множество способов получения белковой эмульсии. Однако осуществление технологических операций предусматривает применение крупногабаритных, энергоемких и дорогостоящих машин, которые зачастую не по силам предприятиям малых форм хозяйственности, производящим на сегодняшний день более 50 % продукции животноводства и птицеводства. Таким образом, возникает потребность в разработке универсальной технологии приготовления белковой эмульсии, применимой в условиях ведения личного подсобного хозяйства. Целью исследования является разработка безотходной технологии приготовления белковой эмульсии на корм животным, реализуемой с помощью одного технического средства. На основании патентного поиска технологий и конструкций для приготовления белковой эмульсии нами предложена безотходная технология, позволяющая объединить целый ряд технологических операций (измельчение, экстракция, разделение суспензии на фракции) в одну, за счет использования нового технического средства (патент РФ № 2614777). Приведены теоретические и экспериментальные исследования процессов измельчения зерна и экстракции соевого белка в эмульсию. Теоретически и экспериментально обоснованы основные конструктивно-режимные параметры разрабатываемого устройства.

Ключевые слова: измельчитель замоченного зерна, соевый белок, белковая эмульсия, абразивный диск

INTRODUCTION

The soya is one of the most nutritious agricultural crops. The protein meal, oilcake, full-fatsoy flour, soya milk, fodder phosphatides, stock feed, straw, chaff, and herbage are used for the animal food. Its seeds contain up to 26% of fat, and about 40% of protein, 34.9% of carbohydrates, and its fodder value are 1.45 fodder units in 1 kg of the grain (Bartashevich, 2006). In addition, the soy protein is rich in amino acids favoring the protein digestion (Burobkin and Kazarinov, 2005). When such substances are fed to animals, they significantly increase the rations' biological value and assure the productivity increase.

Although the soya beans have high nutritive value, they cannot be fed when they are raw because they contain the anti-nutritional biologically active substances, which can give rise to allergic, endocrine and rachitic disorders (Begeulov, 2006; Dotsenko and Bibik, 1997). Those anti-nutritional substances content can be reduced to safe concentration by means of processing the grain into the high-protein fodders

with the thermal treatment.

The most efficient way of using the soy seeds for the livestock animal food is to make the soya milk, which is close to the cow milk in terms of its features (Akaeva and Petrova, 2007; Bazanova *et al.*, 1967). The milk is used to feed calves and piglets (Ryadchikov, 2008), which makes it possible to save much-unskimmed milk.

The soya milk is also used to feed the milk cattle. In this case, high-carbohydrate additives may not be used. The soya milk application makes it possible to increase the milk yields and fat content, especially in early lactation. The fat content increases by 1–2 % (McCance and Widdowson, 2006), the additional production of 1.5-3 liters are stimulated in the first three months of lactation (Vysotski, 2001). Treacle is often added to the soya milk to improve the digestion and nutrient availability and, therefore, to make the lactogenesis more intense (Alyoshkin, 1995; Baranov, 2001; Konakov, 2001; Furtsev and Sayapina, 1991).

There are a lot of ways and facilities making it possible to obtain the soya milk. In this case, the main operations of making the soya

milk are as follows: chopping, extraction, division into liquid and solid fractions, thermal treatment, cooling, and storage. All of that makes it necessary to acquire the whole complex of large-scale, energy-intensive and expensive machines, which often cannot be afforded by the small enterprises producing more than 50% of animal and poultry products today (Burobkin and Kazarinov, 2005).

Scientific research of the facilities' operational process to chop different crops, which was performed by A. A. Artyushin, V. R. Alyoshkin (1993, 1995), R. V. Solntsev (2000), I. Z. Barfakov, V. G. Gopka, B. I. Vagin, G. M. Kukta, L. M. Kytsyn, S. M. Dotsenko *et al.* (2002, 2004), V. Ju. Frolov *et al.* (1996), A. V. Burmaga, and other authors, became determinative when developing and improving the existing machinery. It is noted that there is no universal equipment to prepare for the protein food feeding in medium and small livestock businesses (Pilipenko and Timapovsky, 1989).

This way, it is necessary to develop a universal facility, which would be able to combine such technological operations as chopping, protein extraction and division of suspension into fractions.

MATERIALS AND METHODS

Analysis of production lines to produce the soya milk showed (Baikin *et al.*, 2007; Begeulov, 2006; Dotsenko and Bibik, 1997; Frolov and Sysoev, 2016) that the most intense protein yield during extraction takes place during the use of the chopped dry finer soya grain (the 0.35-0.5 mm flour). However, the process of energy consumption is quite high. So, it is unacceptable to use the technologies based on chopping off the dry soya grain into the flour in small farms because of high energy consumption and metal consumption of the equipment with rather low consumption of the fodder product. In view of the above, the most rational production line schemes in the farm businesses are the schemes, in which the soaked soya grain is chopped, which makes it possible to lower the power inputs because the latter becomes less firm.

As a result of the exploratory research, we offer a waste-free technology of making the high-quality fodders on the basis of the soya grain, which includes a fundamentally new chopper of

the soaked soya grain, which makes it possible to obtain the soya milk and high-protein fodder base – okara as a processing product (Figure 1).

The technology of producing the soy protein is as follows (Frolov *et al.*, 1998; Frolov and Sysoev, 2013). The soya grain is preliminarily soaked for 8 hours, and then it is fed simultaneously with water at the ratio of 1:10 to the processing chamber, in which the latter is chopped with simultaneous division into the insoluble soya residue and suspension.

The suspension is accumulated to the inactivator vessel, where it is treated thermally with the steam generator. The inactivated suspension is coagulated with the CaCl_2 solution, and it is divided into the whey and the soy protein.

Apart from that, in prospect it is possible to obtain, according to the technology developed, the soy processing products (dry soya milk, soy protein, "tofu" soya curd) to use them in the food manufacturing industry and as food additives (Dotsenko *et al.*, 2012, 2014).

The main element of the developed technology is the chopper of the soaked grain (Figure 2), whose technical result is the improvement of chopping quality and enhancement of functional capabilities through obtaining the fine milling of the products, reduction of energy consumption of the operating process by means of chopping of the soaked grain.

The technical novelty of the offered device is confirmed by the RF patents for invention No. 2614777 dated 29.03.2017 "Device for chopping the soaked leguminous plants grain", No. 2621274 dated 01.06.2017 "Device for obtainment of the protein suspension out of the leguminous plants grain".

As a result of the analysis of the operating process of similar facilities, the main analytical dependences were obtained (Klasner *et al.*, 2014) on substantiation of the design and standard parameters of the chopper developed.

The chopper's productivity or throughput capacity can be determined from the formula of B. P. Goryachkin (2001) with a preliminary determination of the whole quantity of the product, which simultaneously covers the whole surface of the chopping disk (G) and the soaking time (T):

$$Q_w = g_0 \frac{\pi R^2 (k^2 - 1) v_r}{k^3 S_r}, \quad (\text{Eq. 1})$$

with account taken of the Equations 2 and 3, we obtain:

where g_0 – the grain load, kg/m²;

v_r – velocity of the particle movement along the furrow, m/s;

R – rotating disk radius, m;

k – disk constant, $k=R/r$;

S_r – the length of the arc along which the chopped particle moves, m.

The velocity of rotation of the lower disk v_r is determined from the formula:

$$v_r = \sqrt{r^2 \omega^2 - 2f \left(g + \frac{G}{m} \right) S_r}, \quad (\text{Eq. 2})$$

where r – distance from the disk center to the grain, m;

ω – rotational velocity of the grain, rad/s;

m – grain mass, kg;

G – the force of the upper disk pressure on the grain;

g – acceleration of gravity, m/s².

The expression describing the length of arc S_r is as follows:

$$S_r = \frac{r}{a} \sqrt{1 + a^2} + C_2, \quad (\text{Eq. 3})$$

where $a = r/r_0 = \text{const}$;

C_2 – arbitrary constant.

The capacity required to chop the soaked soya grain is determined as:

$$N_u = g_0 \frac{\pi R^2 (k^2 - 1) v_r}{k^3 S_r} r, \quad (\text{Eq. 4})$$

$$N_w = g_0 \frac{\pi R^2 (K^2 - 1) \sqrt{r^2 \omega^2 - 2f \left(g + \frac{G}{m} \right) \frac{r}{a} \sqrt{1 + a^2} + C_2}}{k^3 \frac{r}{a} \sqrt{1 + a^2} + C_2}. \quad (\text{Eq. 5})$$

When analyzing Eq. 5 one can conclude that the power inputs for the chopping process of the soaked soya grain depend on its design and standard parameters, the determining influence is exerted by the velocity of rotation of disk v_r and time of chopping of the soya grain, which depends on the path length.

The analytical dependences, which were obtained as a result of the theoretical research, express the functional connection between the design and standard indexes influencing the grain chopping process. Those dependencies make it possible to reveal the qualitative and quantitative sides of the influence of the said factors with some prerequisites and assumptions. So, the theoretical conclusions about the significance of the influence of some factors upon the soya grain chopping process with subsequent extraction of the protein require the experimental verification.

In the experiments on researching the soya grain chopping process with subsequent extraction of the protein, it is necessary to verify the theoretical prerequisites and to specify the initial data required to select the optimal design and standard parameters of the chopper of the soaked soya grain.

RESULTS AND DISCUSSION

The experimental research was conducted on the Barra soya variety. 6 experimental samples with 10 grains in each sample were selected out of the whole batch of the soya grain. The grain's average length made up 6 mm. The mass of 10 grains was 1.767, the volume of 10 grains made up 1.4 ml when the grain's absolute humidity was 10%. The experiment was carried out with the room temperature (20–22 °C). According to the obtained values the graph of the dependence of increase in mass (m), volume (v) and length (L) of the grain on the soaking time was constructed (Figure 3) (Valge, 2002; Melnikov *et al.*, 1980).

Analysis of the graph (Figure 3) showed that the optimal time (T) of the soya grain soaking makes up 6–7 hours (the knock point on Figure 3). During the 6-hour soaking the grain's length, mass and volume make up $L = 13$ mm, $m = 0.36$ g, $V = 0.34 \cdot 10^{-6}$ m³. Further increase in time of the soya grain soaking is inefficient since when the grain is soaked for 24 hours, $m = 0.434$ g, $V = 0.38 \cdot 10^{-6}$ m³, and no change of the geometrical dimensions of soya is changed.

When knowing the change of the grain's mass and volume depending on the soaking time, we can calculate the change of the grain density (Figure 4) (Aret *et al.*, 2009). As the soaking time increases up to 7 hours, the grain density is lowered and makes up $\rho = 1.088$ g/ml. It is not reasonable to continue increasing the soaking time since later on the density reduction becomes somewhat stable.

While optimizing the operating process of the chopper of the soaked grain (Frolov *et al.*, 2014, 2015), the quality of the finished product, as well as the technological parameters of the process of obtaining the soya milk and curd, were studied.

While processing the experiment results the dependences of the suspense water duty with the extracting agent temperature of 55–60° C were constructed (Figure 5).

Dependence of the protein yield into the extract is based on physical and chemical properties of solving the high-molecular organic compounds in the offered technology, and the extracting agent is potable water.

Analysis of the graph (Figure 5) makes it possible to conclude that the extracting agent is actively saturated to the water duty value of 1:10, and when the water duty continuous to increase, the saturation becomes somewhat stable.

The rotation frequency of the moving disk (Figure 7) and the clearance between it and the fixed disk (Figure 8) influences the protein yield significantly.

The analysis of dependence in Figure 7 makes it clear that the lower limit of the rotation frequency of the moving disk of the chopper, should be not less than $2.4 \cdot 10^3$ min⁻¹. Otherwise, because of the low frequency of the disk rotation, the soaked grain is not chopped sufficiently finely, which leads to incomplete protein extraction.

However, as the rotation frequency of the moving disk grows, the power inputs increase too. When the rotation frequency is $2 \cdot 10^3$ min⁻¹, the power inputs are 0.016 kW h/kg, and when the rotation frequency is $2.6 \cdot 10^3$ min⁻¹ the power inputs are 0.0168 kW h/kg. The foregoing shows that as the rotation frequency of the moving disk grows, the specific power inputs increase but just insignificantly, so $2.5 \cdot 10^3 - 2.6 \cdot 10^3$ min⁻¹ should be considered as the rational rotation frequency of the moving disk.

As a result of the experimental research, one can see the strong influence of the value of the clearance between the moving disk and fixed disk of the chopper upon the protein extraction (Figure 8). So, as the clearance increases from 3 to 5 mm, the protein yield is reduced dramatically from $23.3 \cdot 10^{-3}$ to $18.2 \cdot 10^{-3}$ kg. At the same time, as the clearance grows, the power inputs are reduced.

This is due to decrease in the fineness degree of the soaked grain, which, in its turn, leads to decrease in the power inputs and reduction of the square of contact of the milling particle with the extracting agent. However, with the 3 mm clearance the process energy consumption makes up 0.0165 kW h/kg, and with the 5 mm clearance – 0.0186 kW h/kg. So, the 3 mm clearance should be considered rational.

Analysis of dependence (Figure 9) shows that as the rotation frequency of the moving disk of the chopper increases, the productivity increases from 0.1 kg/s, when $n = 1800$ min⁻¹, to 0.25 kg/s with 2600 min⁻¹. The dependence built on the basis of the theoretical research is well coordinated with the experiment. The divergence of results does not exceed 4.5–6%.

The analytical dependences are obtained to determine the productivity and the capacity, which make it possible to optimize the rotation frequency of the lower disk 2.6×10^3 min and the 3 mm clearance between the moving disk and fixed disk.

The obtained experimental dependences made it possible to select the rational values of the water duty $\eta = 1:10$; the extracting agent temperature $t = 55-60$ °C. With those values, the process energy consumption is $N = 0.0165$ kW·H/kg, and the productivity is $Q = 0.24$ kg/s.

Application of the fodder soya milk as a protein additive to the fodders for various groups of animals enables (Aret *et al.*, 2006):

a) full or partial replacement of the unskimmed milk, the skim milk in milking the young cattle and pigs;

b) to optimize the time of fattening the animals to the market weight. The neat cattle to 16 months, pigs to 135–140 days, poultry to 35–38 days;

c) to increase the cows' yield of milk to 2-3 liters through the addition of 3–4 liters of the fodder soya milk to the rations. The cost price of 1 liter of the soya milk, according to the technology offered, is 2.3 rubles, with the average purchase price of the unskimmed milk of 17 rubles, under the circumstances, the profitability makes up 369.6 %.

CONCLUSIONS:

The performed analysis of the ways, technologies, and facilities to make the high-quality fodders with the use of the soya grain, made it possible to conclude that they are inefficient in the small holdings, small farms since they are metal-intensive and energy-intensive. The analysis also made it possible to reveal a promising area of improving the technologies and the mechanical means of making the high-protein fodders.

There was offered a rational waste-free technology of making the high-quality and high-protein fodders on the basis of the soya grain, which includes a fundamentally new chopper of the soaked grain, whose main elements are as follows: the loading neck, two abrasive disks (one disk is fixed, and the other one is marked with curved furrows), the sieve making it possible to obtain the soya milk and the high-protein base (okara) as a product.

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Figure 1. Technology of making the soya milk and protein base for concentrated fodders

Figure 2. General view of the chopper of the soaked soya grain

Figure 3. Dependence of increase in mass (m), volume (v) and length (L) of grain on soaking time

Figure 4. Graph of dependence of density change on the soaking time

Figure 5. Dependence of protein yield into the G extracting agent on water duty η

Figure 6. Dependence of protein yield into the G extracting agent on temperature t

Figure 7. Dependence of the protein yield into the extracting agent G and the energy consumption N on the rotation frequency of the moving disk of the chopper n

Figure 8. Dependence of the protein yield into the extracting agent G and the energy consumption N on the clearance between the moving and fixed disk h of the chopper

Figure 9. Influence of the rotation frequency of the moving disk n upon the chopper's productivity. 1 — experimental; 2 — — theoretical.

Table 1. Change of the grain density resulting from time of keeping it in water

Index	Time of the soya grain soaking in water, h								
	0	1	2	3	4	5	6	7	24
m, g	0.18	0.28	0.317	0.32	0.34	0.34	0.36	0.37	0.43
V, ml	0.14	0.24	0.26	0.3	0.3	0.32	0.34	0.34	0.38
ρ , g/ml	1.26	1.14	1.22	1.07	1.12	1.08	1.06	1.08	1.14