RESULTS OF EXPERIMENTAL STUDIES OF PROCESS OF PREPARATION OF FEED MIXTURES WITH THEIR MOISTENING

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Abstract. The technologies for preparation of compacted feed mixtures involve moistening of feed materials in order to increase the strength of the pellets, as well as to reduce the specific energy consumption of pressing.We investigated the process of mixing with moistening of a model two-component feed mixture consisting of the most common grain and stem components – ground barley and alfalfa hay. The initial hay moisture was 17.5 %, barley initial moisture – 11.4 %, average length of hay particles – 7.6 mm, barley grinding degree – 1.2 mm. The studies were conducted using a multifactorial experiment planning technique. In the course of the investigations the influence on the coefficients of the mixing and moistening heterogeneity of the following factors were determined: mixing time (60-180 s), hay content (20-60 %), set humidity of the feed mixture (20-40 %), moistening time (20-60 s). When conducting the studies, the start time of moistening was the start time of mixing. The experiments were conducted on a vertical laboratory mixer with a spiral type working body. The mixer shaft rotating frequency was one turnover per 1 s. After processing the experimental results, the heterogeneity of mixing (in the range 7.56-48.57) and moisture (in the range 8.61-53.27) were obtained as second-degree polynomial functions. The greatest impact on both mixing and moistening heterogeneity indices of the feed mixture has the factor of the mixing time, the least – the moistening time. With increasing the mixing time, the heterogeneity of mixing and moisture decrease. Increasing the content of hay in the feed mixture, increases both the heterogeneity of mixing and moisture, and the effect of this factor on the quality of the feed mixture decreases with increasing the mixing time.

Keywords: feed mixture; heterogeneity; mixing; moistening; multifactorial experiment.

Introduction

One of the valuable sources of protein in the rations of feeding animals is the hay of legumes. For example, the dry matter of alfalfa contains 14 % of crude protein, and when mowing in the budding phase, its content can reach 21-22 % in terms of dry matter [1; 2]. The content of digestive protein of legume hay is not inferior to cereals, and their content of vitamins and minerals is much higher than in the grain feeds [3].

The addition of a significant proportion of stem feed in the composition of feed mixtures, in particular in the processes of production of pelleted feed [4], increases the requirements for the quality of their mixing. Mixing and moistening of feed mixtures are some of the main operations in the technological process of preparation of pelleted compound feeds [5]. The studies [6] have established that both the mixing process and the process of production of feed pellets are significantly influenced by the moisture content of the source components. The moisture of feed mixtures is one of the main factors that also determine the accuracy of their dosing [7; 8].

Therefore, the use of moist grain-stem feed mixtures in the processes of feed preparation requires the study of the effects of the moisture content and moistening on their production effectiveness. The purpose of the research was to find the regularity of the influence of the parameters of the process of mixing and moistening of the feed mixture of grain and stem components on the homogeneity of mixing and moistening.

Materials and methods

Barley is the main grain component of the rations for farm animals in Ukraine, while the main stem component is the legume hay [3]. Therefore, in the studies, a two-component grain-stem feed mixture of ground barley and alfalfa hay was used as feedstock.

The following devices and equipment were used for this purpose: scales RN 50ShVP-1; scales VLK-500-M; drying cabinet 2B-151; volume for determining the bulk mass; classifier with a set of sieves with holes of different diameters and so on. Primary data processing was reduced to calculating the arithmetic mean, finding the standard error and checking the homogeneity of the variances by Cochran's C test [9]. As a control component in finding the homogeneity of mixing components of the mixture coloured oat grains were used.

A laboratory feed mixer with a spiral working body and a vertical axis of rotation was used for the experimental studies (Fig. 1). This design and technological scheme of mixers has become most widespread in the processes of feed preparation [10]. The rotation speed of the mixer shaft was 1 s^{-1}.

Fig. 1.**Working chamber of laboratory feed mixer:** 1 – shaft; 2 – working chamber bottom; 3 – tape of the helix working body

The laboratory mixer had the following design parameters: height of the working chamber (working body) – 570 mm, diameter of the working chamber – 490 mm, pitch of the helix working body – 500 mm, width of the tape of the working body – 50 mm, outer diameter – 450 mm.

Water supply during mixing and moistening of the feed mixture was carried out by its free-flowing through a hole of a certain diameter (according to the required amount of liquid and time of moistening). The place of water supply was above the working body at a distance that corresponded to half the radius of the working chamber of the mixer from the axis of rotation of its shaft.

As the experiment criteria the coefficients of mixing and moistening heterogeneity v_m, v_w were used

$$v_m = \frac{100}{\overline{m}} \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} \left(x_i - \overline{m}\right)^2}, \quad v_w = \frac{100}{\overline{w}} \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} \left(x_i - \overline{w}\right)^2}, \tag{1}$$

where x_i – value of the random variable in each experiment;
$\bar{m}$ – arithmetic mean of the content of the control components in the sample, pieces;
$\bar{w}$ – arithmetic mean of the moisture of the sample, %;
n – total number of samples, pieces.

The coefficients of mixing and moistening heterogeneity were determined for each experiment. Five samples were taken for each experiment, for each of which the moisture and content of the control components were determined (Fig. 2).

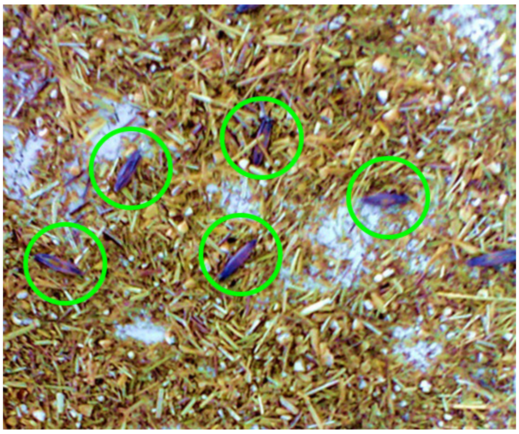

Fig. 2. **Mixed feed with control components (control components are highlighted in green circles)**

The experiments have been conducted using the design methodology of multivariate experiments, using factor variation at three levels [11].

For the experimental studies, the factors that have the greatest influence on the feed preparation process were selected: mixing time (t, s or x_1) [12], hay content (s, % or x_2), moisture (w, % or x_3), moistening time (τ, s or x_4). Wherex_1, x_2, x_3, $x_4 \in [-1;1]$ – respectively, the coded values of the factors (Table 1).

Table 1

Experimental factors and their levels of variation

Levels of variation of factors	Experimental factors			
	Mixing time, t (x_1)	Hay content, s (x_2)	Moisture content,w (x_3)	Moistening time, τ (x_4)
Upper level (1)	180	60	40	60
Basic level (0)	120	40	30	40
Lower level (-1)	60	20	20	20
Variation interval	60	20	10	20

During the experiments, the start time of moistening corresponded to the start time of mixing.

To analyse the results of the experimental studies, software products were used that implement known methods of the correlation and regression analysis [13]. According to the results of the experiment, mathematical models were constructed – the regression equation in the form of second-order polynomials.

The initial materials had the following characteristics: moisture content of alfalfa hay – 17.5 %; moisture content of barley – 11.4 %; average length of hay particles – 7.6 mm; barley grinding module – 1.2 mm.The mass of one portion of the feed mixture for each replication was 2 kg. The number of control components per replication was 49 g, which corresponded to 1500 pieces of oat grains with a mass of 1000 grains – 32.67 g.

Results and discussion

The matrix of experiments and the results of the experiments of the influence of the studied factors on the criteria are given in Table 2.

Table 2

Influence of the experimental factors on the heterogeneity of mixing and moistening of feed mix

Exp. num.	Experimental factors				Criteria		Exp. num.	Experimental factors				Criteria	
	x_1 (t)	x_2 (s)	x_3 (w)	x_4 (τ)	v_m, %	v_w, %		x_1 (t)	x_2 (s)	x_3 (w)	x_4 (τ)	v_m, %	v_w, %
1	1	1	1	-1	14.959	13.112	14	-1	-1	1	1	26.342	41.359
2	1	1	1	1	10.883	20.357	15	-1	-1	-1	-1	24.422	30.663
3	1	1	-1	-1	10.239	11.245	16	-1	-1	-1	1	24.435	33.839
4	1	1	-1	1	10.607	13.437	17	1	0	0	0	7.660	10.885
5	1	-1	1	-1	8.365	9.825	18	-1	0	0	0	27.733	29.769
6	1	-1	1	1	7.756	14.548	19	0	1	0	0	16.538	19.949
7	1	-1	-1	-1	7.806	8.609	20	0	-1	0	0	11.978	13.808
8	1	-1	-1	1	7.557	10.364	21	0	0	1	0	17.988	16.470
9	-1	1	1	-1	48.573	44.121	22	0	0	-1	0	13.403	15.522
10	-1	1	1	1	39.628	53.271	23	0	0	0	-1	14.433	12.317
11	-1	1	-1	-1	34.143	34.384	24	0	0	0	1	12.096	15.726
12	-1	1	-1	1	35.954	37.068	25	0	0	0	0	13.004	14.760
13	-1	-1	1	-1	36.328	32.915							

After processing the experimental results, the dependencies of the experimental factors on the investigated criteria were obtained in the form of second-order regression equations. For the coefficient of heterogeneity of mixing, the resulting model had the form:

$$\nu_m = 13.2704 - 11.7627x_1 + 5.11952x_1^2 + 3.69024x_2 - 1.95912x_1x_2 + 1.90212x_2^2 + \\ + 2.37989x_3 - 1.70801x_1x_3 + 1.37087x_3^2 - 1.46888x_4 + 1.08755x_1x_4 - 1.21466x_3x_4, \quad (2)$$

and in decoded view:

$$\nu_m = 44.6154 - 0.422893t + 0.00142209t^2 - 0.0016326ts - 0.00284668tw + \\ + 0.000906288t\tau + 0.0047553s^2 + 0.0137087w^2 - 0.00607329w\tau. \quad (3)$$

For dependences (2)-(3), which is adequate at 95 % confidence level, the multiple determination factor D = 0.986501, the multiple correlation coefficient R = 0.993227. All given model coefficients are significant at a confidence level of at least 95 %.

For the moistening heterogeneity coefficient, the resulting model had the form:

$$\nu_w = 14.4325 - 12.5004x_1 + 7.21062x_1^2 + 2.83411x_2 - 0.953938x_1x_2 + 3.76213x_2^2 + \\ + 2.68958x_3 - 1.04101x_1x_3 + 1.52649x_2x_3 + 2.57794x_4 + 0.859314x_3x_4, \quad (4)$$

and in decoded view:

$$\nu_w = 68.6845 - 0.6052t - 0.7443s + 0.00200295t^2 - 0.000794948ts - \\ - 0.00173502tw + 0.00940532s^2 + 0.00763245sw + 0.00429657w\tau. \quad (5)$$

For dependences (4)-(5), which is adequate at 92 % confidence level, the coefficient of multiple determination $D = 0.981838$, the coefficient of multiple correlation $R = 0.990877$. All given model coefficients are significant at a confidence level of at least 92 % (in the model, most of the coefficients are significant at a confidence level of at least 99 %, except for the coefficient characterizing the interaction of the mixing time factors t, x_1 with the hay content s, x_2 that is significant at a confidence level of 92 %). The obtained empirical dependences (3), (5) allow to determine the rational parameters of the process of preparation of feed mixture for granulation at a given content of stem feed (hay) and humidity of the feed mixture.

When analysing the coefficients of the regression equations (3), (5), we can conclude that the greatest influence on the heterogeneity indices of both mixing and moistening of the feed mixture has a factor of the duration of mixing, the smallest – the duration of moistening. With increasing the mixing time, the heterogeneity of mixing and the heterogeneity of moistening decrease. To analyse the influence of other factors and their interaction on the response function, we presented the obtained models in graphical form (Fig. 3). When charting, the factors that were not affected were recorded at baseline levels. Fig. 3 shows that increasing the content of hay in the feed mix increases both the heterogeneity of mixing and moistening and the effect of this factor on the quality of feed mix decreases with increasing the mixing time. The effect of moistening on the quality of the feed mix is also reduced with increasing the mixing time.

Increasing the moisture time leads to some increase in the heterogeneity of moistening and reduces the mixing heterogeneity. The effect of this parameter also decreases with increasing the feed mix time. It is also possible to note the combined negative influence of factors of the hay content and moisture of feed mixture on the quality of its preparation. However, increasing the moistening time has a negative effect on the homogeneity of moistening, but it improves the homogeneity of mixing the feed mixture. Moreover, the effect of the moistening time on the quality of moistening increases with increasing the hay content in the mixture.

The effect of the moistening time on the homogeneity of mixing and moistening decreases with the amount of moisture added. This is explained by the fact that with a large amount of added moisture, which is introduced into the mixture by free-flowing from one hole, there is a formation of unevenly moistened balls of feed (with a moistened surface layer and a dry core), which accumulate in the upper layer of the mixer material. This impairs the mixing quality of the mixture, as it eliminates the ingress of control components into the contents of these balls during the mixing process.

Accordingly, with the duration of mixing at the level of 60 s (x_1 = -1) with an increased moisture content of the mixture from 20 % to 40 %, there is an increase in the influence of the duration of moistening of the feed mixture on the quality of its mixing.

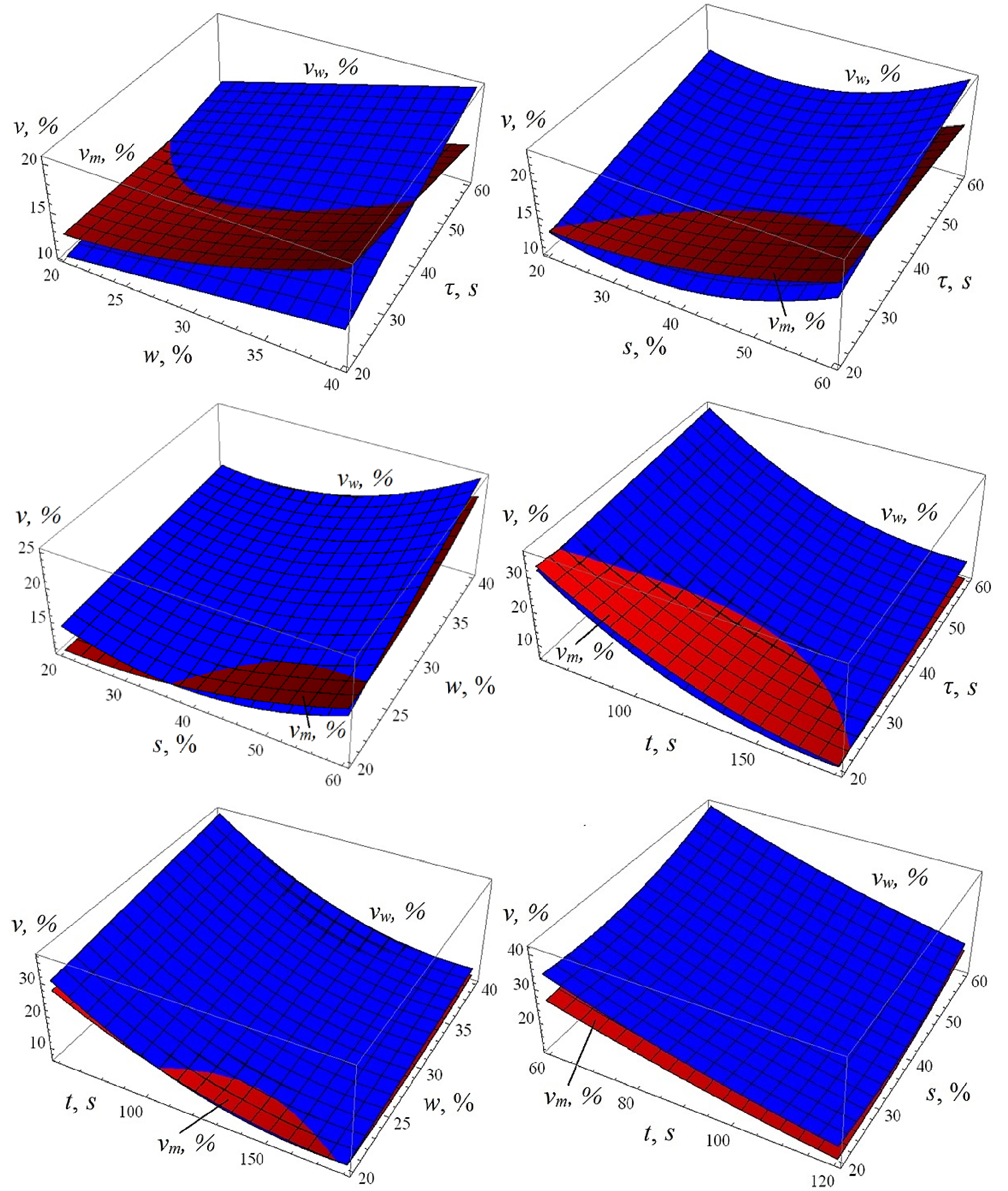

Fig. 3. **Dependence of the heterogeneity coefficients of mixing v_m and moistening v_w on mixing time (t, factor x_1), hay content (s, factor x_2), moisture content (w, factor x_3) and moistening time (τ, factor x_4)**

The authors of [14], estimating by the coefficient of heterogeneity the quality of mixing, divide the latter into the following groups: $v < 5$ % – excellent quality of mixing; 5 % $\leq v < 10$ % – good mixing quality; 10 % $\leq v < 20$ % – satisfactory mixing quality.

The data of Table 2 and Fig. 3 show, for example, that during the mixing time of 60 s it is not possible to achieve a satisfactory quality of mixing. However, subject to the application of the set values of the moisture content and the content of stem feed in the feed mixture of dependencies (3), (5) allows determining the minimum value of the mixing time to ensure the desired quality of feed. This, in the end, will reduce the specific energy consumption and increase the productivity of the process of preparation of feed mixtures with the content of stem feed. As it also can be seen from

Table 2, the rational ranges of factors providing 90 % mixing homogeneity are the content of hay below 20 % in combination with a mixing time of more than 180 s. Other parameter combinations practically do not allow satisfactory mixing quality while simultaneously moistening the mixture.

Conclusions

As a result of the experimental studies, empirical dependencies of mixing heterogeneity (in the range 7.56-48.57) and moistening heterogeneity (in the range 8.61-53.27) were obtained as second-order polynomials. The greatest influence on the heterogeneity indices of both mixing and moistening of feed mixture has the factor of the duration of mixing, the least – the duration of moistening. Increasing the content of hay in the feed mix increases both the heterogeneity of mixing and moistening, and the effect of this factor on the quality of the feed mix decreases with increasing the mixing time.The rational ranges of the factors providing 90 % mixing homogeneity are the content of hay below 20 % in combination with a mixing time of more than 180 s.

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