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Agro-ecological analysis of optimization of extruding parameters of feed additive based on rice processing products

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Abstract

Agroecology is the study of ecological processes applied to agricultural production systems. Bringing ecological principles to bear in agroecosystems can suggest novel management approaches that would not otherwise be considered. The results of agro-ecological analysis of optimization of extruding parameters of feed additive based on rice processing products with the use of methods of multiple-factor experiments planning, statistical processing of test data and search optimization were given in this article. The optimum of criterion functions was determined in Excel 2003 by the method of search optimization with the use of "Search of Decision" computer program. Trial tests of production of extruded feed additive based on rice and compound feeds processing containing rice for farm animals have confirmed the results of researches received in laboratory and experimental and bench conditions were carried out in industrial conditions.

Keywords: agro-ecological analysis, optimization, extruding, feed additive, rice screenings, rice grain waste, rice pod, methods of multiple-factor experiments planning, statistical data processing

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INTRODUCTION

Agriculture worldwide has been benefited from several decades of increasing yields and surplus production of many commodities. Present agricultural practices are pointed to as the principal area in which to begin the shift toward more sustainable food and agricultural systems. An agroecological approach simultaneously strives to improve crop yields, as well as understand the processes that permit the maintenance of those yields. The primary goal is to establish a means of determining the long-term sustainability of agricultural systems. The primary foundation of agroecology is the concept of the ecosystem, defined as a functional system of complementary relations between living organisms and their environment, delimited by arbitrarily chosen boundaries that in space and time appears to maintain a steady yet dynamic equilibrium. Important condition of forage production and livestock production development is application of all available raw material resources.

Now grain raw materials which share in their production makes 70-80% and more (Iztayev et al. 2000) are generally used for compound feeds production.

Kazakhstan takes the 7th-8th place among the largest producers of grain, both in the CIS countries, and in the world market. At the same time as the leading branch of agriculture, production of grain uses main part of land, material and manpower resource (Kulchikova 2007, Naleev and Shevchik 1999).

Such use of grain is irrational as its most part should be spent for nutrition purposes. At the same time by-products and waste of various processing industries, and nonconventional types of raw materials are used insufficiently.

When processing rice-grain for cereal, except main product, there are rice screenings, pod and grain wastes. The use of these products relates toa few difficulties.

Annually at rice plant "Otes Bio Azia" LLP when processing rice-grain for cereal there are 438 tons of rice screenings, 92 tons of grain waste which will serve as an additional raw reserve for mixed feed industry. However, rice screenings turn rancid quickly, and it is badly transported. Besides there are 62 tons of pod which serves as raw materials while production of yeast at hydrolytic plants, but because of unprofitability of transportation to hydrolytic plants, and low volume mass, high content of cellulose constrains their application as fodder means therefore they are just

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burned, thereby worsening ecological situation of the region.

The analysis of rice pod has shown that it contains a lot of ashes (about 20%), cellulose (about 30%), pentosans (about 20%) and lignin (about 20%), and insignificant amounts of protein (about 3%) and fat (about 2%). Besides, pod contains small number of vitamins. Rice screenings are rich source of vitamin E and vitamin of group B, but contain few vitamins A, C and D. Besides, it promotes decrease in level of cholesterol in organism (GRAIN AND GRAIN PRODUCTS, 2006).

In the works of Dilmagombetov (1994) it is expedient to crush rice pod and grain wastes as a part of mix in hammer-mill with a diameter of sieve openings – 3.0 mm. The ratio of rice grain wastes and pod: 13 … 20:87 … 80. The pilot batch of fodder mix containing rice pod (53%), rice screenings (38%) and grain wastes (9%) was developed. Zootechnical tests on bull-calves of meat breed have shown a possibility of use of feed mixture from waste of rice processing in number of 20% as a part of compound feeds without decrease in efficiency of animals.

Chechula (1986) recommends a new type of fodder means - extruded fodder mix received based on by-products of rice plants with the content of rice pod to 25%. For this purpose, grain waste consistently processed by screening machine for removal of organic and mineral impurity, by air qualifier for removal of light organic and mineral touch, then it was passed through a magnetic barrier and crusher; rice screenings were passed via screening machine; pod was crushed and processed by alkali (20% NAOH solution) and softened within 4 hours (for destruction of lignin connections). The prepared components were dosed, mixed and processed by KMZ-2 extruder. The use of extrudate in cattle diets in quantity to 25% instead of grain raw materials provides the set nutritional value of compound feeds and increases a gain of live mass of animals by 6%.

The researches carried out by Scherbakova and Shovgurova (2008) have shown that for effective use of rice pod in feeding of farm animals it is expedient to subject it to chemical processing by sodium hydroxide in a dosage of 45 gr/kg with the subsequent extruding in mix with bran. Fodder mix with humidity of 18-20% was extruded at the temperature of 120^0C and pressure of 10 MPa during 30 seconds. Input of rice extruded pod at the rate of 37.5% into compound feed increases consumption of main nutrients by calves, provides effective use of exchange energy on a gain of live weight, reduces costs of obtained production.

The researches carried out in this field demonstrate that at the correct application of processing methods it is possible to increase fodder value of this waste.

Development of technology of receiving highly effective feed additive from waste of rice plants and natural minerals will allow to receive the evidence-based recommendations submitted on the increase in fodder balance for livestock production, decrease in cost of production of rice grain due to introduction of waste-free technology and release of grain and other valuable types of raw materials by the production of compound feeds.

MATERIALS AND METHODS

The main objective of the research is optimization of parameters of feed additive extruding: x_1 – humidity of feed additive (W, %); x_2 – extruding temperatures (T, °C); x_3 – softening duration (τ, h), at which the content of cellulose S (%) and specific power consumption Y(kW·h/t) have the best (minimum) values.

The solution of the objective was received by the methods of multiple-factor experiments planning, statistical processing of test data and search optimization.

Optimum (minimum) of criterion functions: Y1 indicators – content of cellulose (S, %) and Y2 – specific power consumption (Y, kW·h/t) were determined in Excel 2003 by the method of search optimization with the use of "Search of Decision" computer program. After that the found solution was corrected considering the results received by the methods of experiments planning.

RESULTS AND DISCUSSION

For the preparation of feed additive 6 recipes differing with a ratio of rice screenings, pod and grain wastes were made, and the content of cake rape, shungite, chalk and salt remains constant.

Input of pod in the recipes increases from 10 to 35%, and the content of rice screenings decreases from 65 to 15%, input of cake rape in all versions of recipes makes 10%, shungite - 4%, chalk - 5%, salt - 1%.

The researches of pilot batches of feed additive, according to the developed recipes have shown that input of rice pod in a native state more than 30% is undesirable as there is a decrease in protein and fat content and increase of cellulose and ashes. In feed additives where the content of pod reaches up to 50% deterioration in organoleptic indicators, decrease in technological properties is observed. Input of rice screenings less than 40% does not provide optimum nutritional value of feed additive.

The structure of feed additive including rice pod from 20 to 25%, grain waste from 15 to 20% was offered, the rest - rice screenings, rape cake, shungite, salt and chalk.

It is possible to solve the problem of increase in digestibility and comprehensibility of the feed additive containing indigestible pod component by processing in extruders.

In scientific practice, research of difficult processes such as extruding feed additive, it is not possible to

Table 1. The studied parameters of feed additive extruding and their levels of variation in laboratory conditions

Adjustable parameters: coded (natural)	Coded levels			Variability interval
	–1	0	+1	
x_1 – temperature of feed additive extruding, °C	20	40	60	20
x_2 – humidity of feed additive, %	14	17	20	3
x_3 – duration of feed additive softening, hours	2	4	6	2

receive authentic, and at the same time simple, mathematical description. However, as shown from the experience of scientific developments of the last years, such processes can be researched by experimental and statistical methods. It allows to receive reliable mathematical models adequate to the put experiment on the basis of which it is possible to solve the formulated problems with a certain accuracy and simplicity (Grachev 1979, Ostapchuk 1991).

For designation of the considered process of feed additive extruding which mechanism of functioning is difficult and unknown, we use "black box" concept. Our process influenced by casual influences ξ, has certain "entrance" for input of information on adjustable parameters of extruding and "exit" for control of the results characterized by optimization criteria. The condition of exits Y presumably functionally depends on a condition of entrances X: Y=*f*(X). However, the type of results dependence on entrance data is unknown.

The main objective of the research is optimization of feed additive extruding parameters: x_1 – humidity of feed additive (*W*, %); x_2 – extruding temperatures (*T*, °C); x_3 – softening duration (*τ*, h), at which content of cellulose S (%) and specific power consumption *Y*(kW·h/t) have the best (minimum) values.

The solution of objective is received by the methods of planning of multiple-factor experiments, statistical processing of test data and search optimization. The parameters of optimization and the most significant factors influencing process of feed additive extruding have been selected for this purpose; the plan of carrying out pilot studies was defined, and based on the obtained test data the mathematical model was developed on which influence of adjustable factors for the output process parameters in stationary area of factorial space was investigated.

Parameters of feed additive extruding and the chosen levels of their variation were specified in **Table 1**.

Laboratory research of feed additive extruding process for cattle was carried out according to the scheme of full three-factorial planning of experiments.

In cases when the type of response dependence on the studied parameters is unknown, the equation of regression is presented in the form of polynom of the second degree. The central points together with other points of the plan allow to estimate coefficients of full square model of regression from *k* =3 coded variables x_1, x_2, x_3 in the field of factorial space:

$$Y = f(x_1, \ldots, x_k) = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k} b_i x_i^2 + \sum_{i<j}^{k} b_{ij} x_i \, x_j \quad (1)$$

At the equation of square regression (1) there are linear (main) effects x_1, …, x_k. Members of the second order $x_i x_j$ at $i \neq j$ consider effects of interaction, i.e. effects of joint action x_i and x_j on value *Y*, and members $x_i x_j$ at *i=j* (т.е.x_i^2 – squares of arguments) – non-linearity of change of response function *Y*at the change of *I* argument. At the same time the effect of *i* factor influence on the studied indicator of feed additive extruding is estimated by the regression equation coefficients (3.5.)

As criterion functions Y_i, *i* = 1, 2, 3 we have accepted indicators Y_1 – content of cellulose (S, %) and Y_2 – specific power consumption (*Y*, kW·h/t). Using for them the equation of regression (5.2), we will formulate mathematical statement of the general problem of justification of parameters of feed additive extruding as follows:

to find an optimum of criterion functions:

$$\begin{cases} Y_1 = f_1(\theta_{11}, \ldots, \theta_{1m}; x_1, \ldots, x_k) \Rightarrow max, \\ Y_2 = f_2(\theta_{21}, \ldots, \theta_{2m}; x_1, \ldots, x_k) \Rightarrow min, \end{cases} \quad (2)$$

in the field of factorial space

$$x_{jmin} \leq x_j \leq x_{jmax}, j = 1, \ldots, k \quad (3)$$

Here Y_1, Y_2 – dependences constructed on experimental data;

θ_1, θ_2 – estimates of response functions coefficients Y_1 and Y_2;

x_{jmin}, x_{jmax} – bilateral restrictions for key parameters of feed additive extruding.

Thus, the model of key parameters optimization of feed additive extruding (2) – (3) which belongs to the class of multi-purpose problems of non-linear mathematical programming was received. In a task, it is required to define such values of W, T, τparameters from the field of factorial space at which responses have the minimum value. At the same time the received optimum parameters of feed additive extruding at the solution of one-target tasks should not differ strongly from each other that it was possible to give the compromise solution of task on their basis.

Optimum (minimum) of criterion functions: Y1 indicators – contents of cellulose (S, %) and Y2 – specific power consumption (Y, kW·h/t) was determined in Excel 2003 by the method of search optimization with the use of "Search of Decision" computer program. After

Table 2. Statistical characteristics of indicators of feed additive extruding for cattle

Statistical characteristics	Reference character	Parameter			Y_1	Y_2
		W	T	τ		
Volume of observations	*N*	27	27	27	27	27
Arithmetic average	*M*	40	17	4	369.074	85.341
Standard mistake	*m*	3.203	0.480	0.320	5.175	1.384
Standard mistake, %	*m*, %	8.006	2.826	8.006	1.402	1.621
Median	*med*	40	17	4	365	86.6
Mode	*mod*	20	14	2	350	88.3
Standard deviation	*s*	16.641	2.496	1.664	26.891	7.190
Selection dispersion	s^2	276.92	6.231	2.769	723.15	51.701
Excess	*E*	-1.560	-1.560	-1.560	-0.573	-0.392
Asymmetry	*A*	0.000	0.000	0.000	0.278	-0.611
Range	*R*	40	6	4	100	24.2
Minimum	*min*	20	14	2	320	72.2
Maximum	*max*	60	20	6	420	96.4
Coefficient of variation, %	*V*	41.6	14.7	41.6	7.3	8.4

that the found solution was corrected considering the results received by the methods of experiments planning.

Previously we will characterize the received set of experimental data, having calculated statistical characteristics of the main indicators of feed additive extruding process (**Table 2**).

According to the experiment, for each indicator in **Table 2** there were estimated: average *M* and error of average *m*, median (*med*) and mode (*mod*), standard (mean square) deviation *s*and dispersion s^2, minimum (*min* – minimum) and maximum (*max* – and maximum) values, range *R*, asymmetry indicators *A*and excess*E*, variation factor *V*.

Statistical characteristics of Table 3.14 give a quantitative idea of empirical data (provision of average, his dispersion – dispersion, asymmetry) and as the first approximation check the assumptions which are the cornerstone of the regression analysis. Standard errors of resultant indicators are small and make less than 3% of the corresponding average values. Approximate equality of average and median is observed. The mode for the content of cellulose S and specific power consumption Y is absent, and values of excess and asymmetry are negative; minimum and maximum values are approximately equidistanted from an average, coefficients of variation make less than 12%. It demonstrates proximity empirical and normal or generally - normal distributions.

Creation of Non-linear Regression of Feed Additive Extruding Process for Cattle

In our research, type of response function $Y_i = f(x_1, x_2, x_3)$, *i* = 1, 2, from adjustable parameters of extruding is unknown. At the nonlinearity of process of feed additive extruding noted earlier as it is accepted when using multiple-factor planning of experiment, regression equation is presented in the form of polynom of the second degree at enough experimental points. The chosen plan of Boks-Benkin has 15 experimental points and allows to calculate mathematical model of feed additive extruding process in the form of full square function of three studied parameters:

$$Y_i = b_0 + b_1x_1 + b_{11}x_1^2 + b_2x_2 + b_{22}x_2^2 + b_3x_3 + b_{33}x_3^2 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 \quad (4)$$

Approximation (approach) of optimality criteria Y*i* by polynom of the second degree allows to gain a good impression about response surface form. As a result of implementation of computing procedures realized in *Statistica* 7.0 computer program, calculated ten *b*-coefficients of non-linear regression at the coded variables x_1, x_2 and x_3, their standard mistakes, *t*-Student's criteria for check of the importance of regression components, probability levels *p*, top and lower 95% confidential borders.

Thus, using estimates *b*-coefficients, it is possible to write down the following equations of square regression of three parameters of feed additive extruding for cattle:

extruder output, kg/h

$$Y_1 = -316.08 + 8.681x_1 - 0.093x_1^2 + 55.062x_2 - 1.451x_2^2 + 8.958x_3 - 0.764x_3^2 - 0.014x_1x_2 - 0.083x_1x_3 + 0.069x_2x_3 \quad (5)$$

specific power consumption, kW-h/t

$$Y_2 = 311.77 - 2.824x_1 + 0.0275x_1^2 - 18.7883x_2 + 0.4809x_2^2 - 3.9847x_3 + 0.2819x_3^2 + 0.0268x_1x_2 + 0.0202x_1x_3 + 0.0292x_2x_3 \quad (6)$$

The analysis of the received values of *t*-criterion of Student and appropriate levels of the value *p*confirms significant effect on resultant indicators of feed additive extruding of parameters: x_1– humidity of feed additive *W*, %; x_2 – extruding temperatures *T*, °C. So, there was significant influence of squares x_1^2, x_2^2 parameters, and also linear components$x_1$andx_2, with$p < 0,05$.Softening duration x_3(h) not significantly influences resultant criteria Y_1 and Y_2.

Thus, based on the data obtained in experiments, the method of the smallest squares has calculated the equations of square regression (5) and (6) for the content of cellulose S and specific power consumption of Y, depending on three studied parameters x_1, $x_2$andx_3, presented in the standardized scale.

Table 3. Check of adequacy and reliability of regression models for justification of extruding parameters of feed additive

Statistics of quality and criteria of adequacy	Response	
	Y_1	Y_2
Multiplecorrelation R … … … … … … … …... …	0.968	0.948
Coefficientofdetermination R2 … … … … … … …	0.936	0.898
Rated R-square … … … … … … … … … … …	0.903	0.844
Standardmistake … … … … … … … … … … … … …	8.391	2.839
Number of freedom degrees *df* :k_1; k_2…………………	9;17	9;17
Fisher'sratiotest*F* ……………………………………	27.781	16.640
Value*F* ……………………………………………	1.9E-08	9.2E-07
Darbin-Watson'scriterion*d* ………………………..	2.253	2.378
Serialcorrelationcoefficient*r*………………	-0.133	-0.231
Note: k_1иk_2 – number of freedom degrees for numerator and denominator, respectively		

Table 4. Coordinates of special points and productivity value of extruder Y1 and specific expense of electric power Y2

Response	Coordinates of stationary points			Value of response
	x_1 – temperature of feed additive processing, °C	x_2 – humidity of feed additive, %	x_3 – duration of feed additive processing, hours	
Y_1, kg/h ($Y_1 \to$ max)	43.280	18.876	4.361	410.972
Y_2, kW-h/t				73.818
Y_2, kW-h/t($Y_2 \to$ min)	40.755	18.259	4.662	73.413
Y_1, kg/h				409.786

For quality check of the received equations of regression (3) and (4) or (5) and (6) the coefficient of multiple correlation *R*, determination coefficient has been calculated R^2, Fisher's ratio test F and Darbin-Watson's criterion *d* (**Table 3**).

3 values of statistical criteria given in the table demonstrate that the received regression equations with 95% confidential probability authentically and adequately describe influence of the studied extruding parameters on the content of cellulose and specific power consumption.

Rather high values of coefficient of multiple correlation (R= 0.982 – 0.993) demonstrate very close interrelation of resultant indicators $Y_1$and$Y_2$and adjustable parameters of feed additive extruding for cattle included in the research. Coefficient of determination (R^2 = 0.965 – 0.987) characterizes 96.5% and 98.7% of variation of the corresponding response in experimental data.

The values of Fischer criterion *F* equal 15.357 and 41.243 respectively for the content of cellulose S and specific power consumption *Y*, and the calculated significance values p <0.001 testify to rather high approximating ability of the received equations.

For the regression remains of equations (3) both (4) coefficients of serial correlation are weak and insignificant. As values of criterion of Darbin-Watson *d* testify, it is possible to consider that serial correlation is absent.

Thus, the reliable and adequate equations of regression (3) and (4) controlled parameters which are rather fully characterizing the studied technological process of extruding of feed additive were received.

For definition of optimum Y1 and Y2 values, the received equations of regression (3) and (4) have been used as criterion functions, and lower and top levels of variation of independent variables are taken for bilateral restrictions for the studied parameters. Two optimizing tasks were solved:

to find extruder productivity maximum Y_1 (kg/h)

$$\begin{cases} Y_1 = f_1(x_1, x_2, x_3) \Rightarrow max; \\ minx_i \le x_i \le maxx_i, i = 1,2,3; \end{cases} \quad (7)$$

and minimum of specific power consumption Y_2 (kW-h/t)

$$\begin{cases} Y_2 = f_2(x_1, x_2, x_3) \Rightarrow min; \\ minx_i \le x_i \le maxx_i, i = 1,2,3. \end{cases} \quad (8)$$

Results of set above tasks solution (coordinates of special points and the corresponding values of the studied functions of responses Y1 and Y2) are given in **Table 4**.

Compromise solution is a point with the coordinates equal to average values of optimum parameters which are received by search of extremum for each autonomous problem of optimization:

$$x_1^* = \frac{x_1^{*(1)} + x_1^{*(2)}}{2} = 420;$$
$$x_2^* = \frac{x_2^{*(1)} + x_2^{*(2)}}{2} = 185;$$
$$x_3^* = \frac{x_3^{*(1)} + x_3^{*(2)}}{2} = 4.5$$

At such recommended values of parameters of feed additive extruding for cattle:

– temperature of feed additive processing
x_1= 42°C;
– humidity of feed additive
x_2 = 18.5 %;
– duration of feed additive softening
x_3 = 4.5 hour
criteria of optimality will have the following values:
– extruder productivity
Y_1 = 410.6 kg/h;
– specific expense of electric power
Y_2 = 735 kW-h/t.

Based on the carried out researches, the technology of extruded feed additive based of rice processing products was developed.

CONCLUSION

In the conditions of experimental formula-feed plant "OtesBioAziya" LLP trial tests of extruded feed additive development were carried out based on the processing of rice and compound feeds containing it for farm animals which have confirmed the results of researches received in laboratory and experimental and bench conditions.

As a result of carrying out three-months sagination of buck lambs it was revealed that when replacing in number of 25% of grain components of compound feed with extruded feed additive in test group of buck lambs, additional weights have made 14.98 kg that 2.27 kg (17.8%) is higher in comparison with the first group with set basic compound feed – OK-81-2 concentrate.

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