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Systemic Analysis of the Stabilization of the Biotechnological Properties of Liquid Rye Leaven with the Introduction of Nutritious Plant Material

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***Abstract*—This paper considers the possibility of intensification of biochemical processes, stabilization of biotechnological properties of semi-finished bakery products, in particular, liquid rye leaven and reduction of the production cycle by the introduction of biogenic plant raw materials, composition of herbal extracts (CELT), proposed formulations and modes of preparation of liquid rye leaven in the production cycle.**

A systematic analysis of changes in physical-chemical and microbiological parameters, as well as the processes occurring during the maturation of liquid rye leaven is carried out. It is established that the introduction of CELT into liquid leaven at a dose of 4% of the water mass intensifies the processes occurring during the fermentation of leaven.

Keywords—system analysis, liquid rye starter, yeast colonies, lactic acid bacteria, physicochemical indicators, biogenic plant materials, herbal extracts compositions

I. INTRODUCTION

Various methods of cultivation of yeast colonies and lactic acid bacteria are used in the production of bread on thick and liquid semi-finished products (yeasts). Their growth and activity provide loosening of semi-finished products, formation of organic acids, alcohol and "lifting" of the finished product. Technological schemes of rye and rye-wheat bread production suggest symbiotic development of microorganisms [1, 2].

The interest in the process of microorganism cultivation has only increased with the expansion of technological capabilities of baking and food industries, and the idea of deep processing of raw materials used in the production of by-products, industrial residues, non-traditional types of raw materials has expanded the possibilities of producers [3, 4].

II. EXPERIMENTAL

Performance of experimental research was solved at the level of realization of the following tasks: research of physical and chemical parameters of liquid rye leaven with application of biogenic plant raw materials; system analysis of influence of dosage of biogenic plant raw materials on parameters of quality of semi-finished products, activity of lactic acid bacteria and yeast colonies.

The aim of the work is to study the possibility of intensification of biochemical processes, stabilization of biotechnological properties of liquid rye leaven, reduction of the production cycle by application of biogenic plant raw materials, in particular, composition of herbal extracts (CELT), as well as system analysis of the processes occurring in the process of maturation of liquid rye leaven [5, 6].

For the preparation of liquid rye leaven with the introduction of nutritious vegetable raw materials in the production cycle, it was refreshed when the acidity of 9-13 degrees is reached in 5 hours of fermentation by selecting 50% of the finished leaven and adding to the remaining mass of leaven nutrient mixture of flour, water and CELT. Recipe and mode of preparation of liquid leaven in the production cycle is given in Table I.

TABLE I. RECIPE AND MODE OF LIQUID LEAVEN PREPARATION IN THE PRODUCTION CYCLE

Name of raw materials, semi-finished products and process indicators	**Control**	**CELT dosage, %**		
		2	***4***	***6***
Ferment, kg	100,0	100,0	100,0	100,0
Rye rye flour, kg	34,7	34,7	34,7	34,7
Water, kg	65,3	63,3	61,3	59,3
CELT, kg	-	2,0	4,0	6,0
Humidity, %.	69-75			
Initial temperature, ^{O}C	28-30			

In the process of fermentation, leaven determined changes in physical and chemical parameters: titratable acidity (Table II) and lifting power (Table III).

TABLE II. CHANGES IN TITRATABLE ACIDITY DURING FERMENTATION OF STARTER

Fermentation duration, mines	Control	Dosage of composition of herbal extracts to the mass of water in leaven, %					
		1	*2*	*3*	*4*	*5*	*6*
0	6,0	6,0	6,5	7,0	7,8	8,0	8,5
30	7,0	7,5	8,0	8,0	8,8	8,8	9,0
60	8,0	8,3	8,9	8,9	9,5	9,2	9,0
90	8,5	8,8	9,5	9,6	9,8	9,5	9,5
120	8,8	9,4	10,2	9,8	10	9,8	9,5
150	9,5	9,8	11,0	10,5	10,8	10	9,8

TABLE III. CHANGES IN LIFTING FORCE DURING THE FERMENTATION PROCESS

Fermentation duration, mines	Control	Dosage of composition of herbal extracts to the mass of water in leaven, %					
		1	*2*	*3*	*4*	*5*	*6*
0	50	45	45	60	70	75	90
30	45	40	38	48	55	65	75
60	40	38	35	40	45	57	65
90	35	30	30	35	38	46	50
120	32	28	25	30	32	38	40
150	25	23	21	25	25	32	35

Microbiological parameters were also determined: activity of yeast colonies (Table IV), lactic acid bacteria (Table V).

To formalize and check the adequacy of the model of multiple regression of the titratable acidity change in the fermentation process we denote the i-th change of the output variable y_i, and the output variables X_i1, X_i2. Then the multiple regression model will be presented in the form of the model:

$$Y_i = ß_0 + ß_1 x_1 + ß_2 x_2 + ß_3 x^2_{i1} + ß_4 x^2_{i2} + ß_5 x_{i1} x_{i2} + E_i, \quad (1)$$

where i=1,2,..., n=49 is the number of measurements, Ei- is a random variable characterizing the deviation of the output variable from the model regression function. Let's consider the following prerequisites to be true: perturbation Ei is a random value, mathematical expectation $M(E_i)=F$, perturbation dispersion E_i is constant for Ɏi: $E(E_i)=\sigma_\varepsilon^2$, perturbations E_i and E_j are independent, perturbation E_i is a normally distributed random value. Let's denote by $Y=(y_1,y_1\ldots y_n)^t$ - vector of output variable values in experiments, n=49. In our case:

Y^T=6, 6, 6,5 ,7, 7,8, 8, 8,5, 7, 7,5, 8, 8, 8,8, 8,8, 9, 8, 8,3, 8,9, 8,9, 9,5, 9,2, 9, 8,5, 8,8, 9,5, 9,6, 9,8, 9,5, 9,5, 8,8, 9,4, 10,2, 9,8, 10, 9,8, 9,5, 9,5, 9,8, 11, 10,5, 10,8, 10, 9,8, 10, 10,8, 11,9, 11,2, 12,1, 10,5, 10,3

Let's denote through X the matrix of the plan of the dimensional experiment (n·6).

$$\tilde{O} = \begin{matrix} 1 & X_{11} & X_{12} & X_{11}^2 & X_{12}^2 & X_{11} & X_{12} \\ 1 & X_{21} & X_{22}^2 & X_{21}^2 & X_{22} & X_{21} & X_{22} \\ 1 & X_{n1} & X_{n2} & X_{n1}^2 & X_{n2}^2 & X_{n1} & X_{n2} \end{matrix}$$

TABLE IV. CHANGES IN THE NUMBER OF YEAST COLONIES DURING FERMENTATION

Fermentation duration, mines	Number of yeast colonies, CFU/G	
	Control	*Dosage of composition of herbal extracts to the mass of water in leaven 4 %*
30	$65,4\cdot10^6$	$76,8\cdot10^6$
60	$87,4\cdot10^6$	$98,8\cdot10^6$
90	$116,7\cdot10^6$	$127,1\cdot10^6$

TABLE V. CHANGES IN THE AMOUNT OF LACTIC ACID BACTERIA DURING THE FERMENTATION PROCESS

Fermentation duration, mines	Amount of lactic acid bacteria, CFU/G	
	Control	*Dosage of composition of herbal extracts to the mass of water in leaven 4 %*
0	$337,5\cdot10^6$	$403,0\cdot10^6$
30	$439,2\cdot10^6$	$530,3\cdot10^6$
60	$599,0\cdot10^6$	$715,2\cdot10^6$
90	$804,0\cdot10^6$	$905,0\cdot10^6$

In matrix X in the first column, all experiments are equal to 1, because it is assumed that in the first model, the free term $ß_0$ is multiplied by the dummy variable $X_{iф}$, taking the value of 1 for all i= (1,2,..., n).

Let's denote by $ß=(ß_0, ß_1, ß_2, ß_3, ß_4, ß_5)^T$ - vector of parameters of dimension p=6, p- number of model parameters.

Then the first model will appear in the matrix record:

$$Y = Xß+ε \quad (2)$$

Estimation of the second model in the experiment sample is the equation:

$$Y = X_в+e \quad (3)$$

where $в=(в_0,в_1, в_2,в_3,в_4,в_5)^T$, $e=(e_1, e_{2,\ldots} e_n)$, n= 49.

The least squares method is used to estimate the vector of independent parameters ß. According to this method, the condition of minimizing the residual sum of the squares will be recorded in the form of a minimum:

$$S=\sum_{i=1}^{n=49}(y_i^p - y_i)^2 = \sum_{i=1}^{n=49} e_i^2 \to \min, \quad (4)$$

where y^p_i – estimated value of the output variable.

You can write it down in matrix form:

$$\sum_{i=1}^{n=49} e_i^2 = e^T \cdot e = (Y - Xb)^T (Y - Xb) \to \min. \quad (5)$$

Expanding the brackets, we will get the minimization condition in the following form:

$$S= Y^TY - 2b^T X^TY + b^TX^T X b \to \min \quad (6)$$

Differentiating by b, we equalize the vector of partial derivatives to zero:

$$\frac{\partial S}{\partial b} = -2X^{O}Y + 2X^{O}Xb = 0$$

From here we get a system of normal equations in matrix form:

$$X^T X\, b = X^T Y \qquad (7)$$

In our case, the matrices included in the equation:

$$X^T X = \begin{pmatrix} 49 & 4410 & 147 & 573300 & 637 & 13230 \\ 4410 & 573300 & 13230 & 83349000 & 57330 & 1719900 \\ 147 & 13230 & 637 & 1719900 & 3087 & 57330 \\ 573300 & 83349000 & 1719900 & 1.29E+10 & 7452900 & 2.5E+0.8 \\ 637 & 57330 & 3087 & 7452900 & 15925 & 277830 \\ 13230 & 1719900 & 57330 & 2.5E+0.8 & 277830 & 7452900 \end{pmatrix},$$

$$X^T Y = \begin{pmatrix} 449.6 \\ 43923 \\ 1385.4 \\ 5868810 \\ 6017 \\ 133377 \end{pmatrix},$$

Matrix identifier $\left|X^T X\right| = 3.35 \cdot 10^{26}$. Since this determinant is not equal to zero, the matrix $\left|X^T X\right|$ - is not separate and there is an inverse matrix $(X^T X)^{-1}$. In our case:

$$X^T X = \begin{pmatrix} 0{,}300595 & -0{,}003359 & -0{,}100765 & 9{,}45Å-0{,}6 & 0{,}008503 & 0{,}000383 \\ -0{,}003359 & 8{,}65Å-0{,}5 & 0{,}000383 & -3{,}78Å-0{,}7 & -9{,}57Å-19 & -4{,}25Å-06 \\ -0{,}100765 & 0{,}000383 & 0{,}0077806 & 1{,}93Å-20 & -0{,}010204 & -0{,}000128 \\ 9{,}45Å-0{,}6 & -3{,}78Å-0{,}7 & -1{,}36Å-20 & 2{,}1Å-0{,}9 & 3{,}67Å-21 & -1{,}01Å-22 \\ 0{,}008503 & 9{,}33Å-19 & -0{,}010204 & 1{,}84Å-21 & 0{,}001701 & -1{,}92Å-19 \\ 0{,}000383 & -4{,}25-0{,}6 & -0{,}000128 & -8{,}3Å-20 & 5{,}31Å-20 & 1{,}42Å-06 \end{pmatrix},$$

We get the ratio for determining vector b:

$$b = (X^T X)^{-1} X^T Y \qquad (8)$$

In our case:
$$b = \begin{pmatrix} b_0 \\ b_1 \\ b_2 \\ b_3 \\ b_4 \\ b_5 \end{pmatrix} = \begin{pmatrix} 5.668793 \\ 0.032117 \\ 0.885459 \\ -2.97E-05 \\ -0.080612 \\ -0.002389 \end{pmatrix},$$

Estimates of the ß vector based on the least-squares method are unbiased, valid and effective. Thus, the multiple regression equation in our case has the following form:

$$y_i = 5.668793 + 0{,}032117x_{i1} + 0{,}885459x_{i2} - 2.97 \cdot 10^{-5}x^2_{i2} - 0.080612x^2_{i2} - 0{,}002389x_{i1}\,x_{i2} \qquad (9)$$

The significance of the obtained regression equation was estimated. The estimation of the significance was carried out on the basis of the dispersion analysis. The sum of the squares of deviations of the output variable from the average ỹ:

$$Q = Q_R + Q_e, \qquad (10)$$

where Q_R is the sum of the squares of deviations caused by the regression;

Qe- residual sum of squares characterizing the influence of unaccounted factors.

At the same time:

$$Q_R \sum_{i=1}^{n=49} (y_i^2 - \bar{y})^2,\ Q_e = \sum_{i=1}^{n=49} (y_i^p - y_i)^2,\ Q = \sum_{i=1}^{n=49} (y_i - \bar{y})^2,\ \bar{y} = \frac{\sum_{i=1}^{n=49} y_i}{n}.$$

In our case: $\bar{y} = 9.17551$, Q_R=82.9303,

Q_e =5,90029, Q=88,8306.

The significance of the equation is checked by Fisher's criterion (F- criterion). The equation is considered significant if:

$$F = \frac{Q_R (n-p)}{Q_e (p-1)} \rangle F_{tabl}, \qquad (11)$$

where F_{table} is a table value of Fisher's F-criterion at the significance level $\alpha = f_1 f_5$ at the number of degrees of freedom f_2 =n-p and f_1 =p-1,

p - number of model parameters, p=6, n=49. In our case, F=120.876, F_{table}=2.25. The obtained regression equation (9) is significant.

The significance of the individual regression coefficients was checked.

The dispersion of the regression coefficient bj is determined by the formula:

$$S^2_{bj} = S^2_e (X^T X)^{-1}_{jj}, \qquad (12)$$

where $(X^T X)^{-1}_{jj}$- the element lying on the main diagonal of the inverse matrix$(X^T X)^{-1}$. Standard error of the coefficient b_j:

$$S_{bj} = S_e \sqrt{(X^T X)^{-1}_{jj}}$$

The significance of the regression coefficient can be checked if we take into account that the statistics $\frac{b_j - \beta_j}{S_{bj}}$ has a t-distribution of the Student with (n-p) degrees of freedom. Therefore, b_j is significantly different from zero, if

$$t_j = \left| \frac{b_j}{S_e \sqrt{(X^T X)^{-1}_{jj}}} \right| \rangle t_{tabl}, \qquad (13)$$

where $t_{tabl.}$- tabular value of the Student's criterion at significance level α=0,05 and number of degrees of freedom (49-6=43). In our case $t_{tabl.}$=2,02; t_0=27,91; t_1=9,33; t_2=8,57; t_3=1,75; t_4=5,28; t_5=5,42.

Thus, for the coefficient b_3 the value of the Student's criterion $t_3 \langle t_{tabl}$, so the coefficient b_3 is insignificant. In formula (12) S_e^2-sampling estimate of residual dispersion:

$$S^2_e = \frac{Q_e}{n-p} = 0.13722.$$

The other coefficients of the obtained regression equation are significant. Similarly, we perform the calculation for other data as well.

III. RESULTS AND DISCUSSION

For the analysis of the change of the lifting force in the process of fermentation of yeast, we denote through $Y = (y_1, y_1 \ldots y_n)^T$ - vector of output variable values in experiments, n= 49. In our case: Y^T=50, 45, 45, 60, 70, 75,

90, 45, 40, 38, 48, 55, 65, 75, 40, 38, 35, 40, 45, 57, 65, 35, 30, 30, 35, 38, 46, 50, 32, 28, 25, 30, 32, 38, 40, 25, 25, 23, 21, 25, 25, 25, 32, 35, 25, 20, 20, 23, 23, 28, 30.

Received a matrix of the experimental dimensional plan (n·6). The multiple regression equation in our case has the following form:

$$y_i=47,53019-0,22360x_{i+}-0,16964x_{i2}+0,00062x^2_{i2}$$
$$+1,07993x^2_{i2}-0,03380x_{i1}\,x_{i2} \quad (14)$$

In our case F=322,81, $F_{tabl.}$=2,25. Consequently, condition (11) is fulfilled, so the obtained regression equation (14) is significant.

The equation of multiple regression of the change in the number of yeast colonies in the process of fermentation of control leaven has the following form:

$$y_i=50,03500+0,39283x_{i1}+0,00386x^2_{i2} \quad (15)$$

In our case, F=51320,88, $F_{tabl.}$=199,48. Consequently, condition (11) is fulfilled, so the obtained regression equation (15) is significant.

The equation of multiple regression of changes in the number of yeast colonies in the process of yeast fermentation with the introduction of CELT has the following form:

$$y_i=58,44000+0,51633x_{i1}+0,00272x^2_{i2} \quad (16)$$

In our case, F=3357,57 Ft_{able} =199,48. Consequently, condition (11) is fulfilled, so the obtained regression equation (16) is significant.

The equation of multiple regression of the change in the number of lactic acid bacteria in the process of fermentation of control starter has the following form:

$$y_i=336,85500+2,61517x_{i1}+0,02869x^2_{i2} \quad (17)$$

In our case, F=7465,81 F_{table} =199,48. Consequently, condition (11) is fulfilled, so the obtained regression equation (17) is significant.

The equation of multiple regression of the change in the quantity of lactic acid bacteria in the process of fermentation of leaven with the application of CELT has the following form:

$$y_i=400,32000+4,06733x_{i1}+0,01744x^2_{i2} \quad (18)$$

In our case, F=501,20, F_{tabl}=199,48. Consequently, condition (11) is fulfilled, so the obtained regression equation (18) is significant.

IV. CONCLUSION

Increasing the acidity of rye leaven and the duration of its fermentation is of great practical importance. The higher acidity of the rye dough is necessary not only to achieve sufficient protein peptization, but also to inhibit the action of the α-amylase present in the rye flour. The final acidity is judged by its readiness. It has been established that the introduction of CELT into liquid rye leaven at a dose of 4% of the water mass intensifies the processes occurring during the fermentation of leaven. Faster acid accumulation occurs, fermentation activity increases, accumulation of lactic acid bacteria and yeast colonies is more active.

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