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The effect of yeast extract addition on bread quality parameters

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Abstract: The effects of yeast extract addition, with varied quantities of salt and sugar, on the chemical and mineral composition, colour and sensory properties of spelt bread, in order to obtain new products were investigated. The addition of 5 % yeast extract positively influenced the mineral characteristics and increased protein content by 30.77 %. As a salt substitution, addition of yeast extract improved appearance without deteriorating texture descriptors and breadcrumb quality, while the taste became more complex, but without increasing salty taste. Addition of sugar in samples with yeast extract, improved most sensory characteristics. The developed mathematical models of bread with yeast extract quality parameters were statistically significant, indicating the satisfactory approximation of the bread quality parameters within the varied formula. Bread samples with addition of 5 % yeast extract, 1.5 % of salt and 0 % sugar were determined as the best from the aspect of overall quality. A new product was obtained with good total quality, higher level of nutritional value and reduced salt content.

Keywords: salt reduction; protein enriched product; nutritional value; mathematical models.

INTRODUCTION

In accordance with the modern nutritionist opinions, cereal products, such as bread enriched with functional components, are the most common foods in the daily diet.[1] Consumers have been increasingly interested in the health effects of food or their components.[2] Bread plays a significant role in human diet regardless of ethnic or religious orientations. It is consumed on a daily basis, in a wide

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range of types and qualities and all diets worldwide.[3,4] The average consumption is approximately 70 kg of bread per capita per year, while European people consume on average 59 kg of bread per year, although, there are remarkable differences across European countries.[4] Its nutritional value and health benefits could be improved by adding bioactive component and decreasing the salt content in bread.[3,5] These changes to bread formula are addressed at people who are not eager to modify their eating habits. On the other hand, these changes may be accompanied by the deterioration of sensory qualities that significantly affects consumer acceptance of the product.[5] During milling of wheat grain, a high proportion of minerals, vitamins and fibres are lost, resulting in a reduction in the nutritional value of the flour.[6] Whole meal spelt wheat has higher protein and mineral elements (Fe, Zn, Cu, Mg and P) contents compared to *Triticum aestivum.*[7,8] For this reason, whole meal and spelt species wheat were used for bread production.

Yeast extract, is a yeast product separated from the inner yeast cells and usually is in the forms of liquid, paste or powder. It could be a functional source of nutrients and excellent natural seasoning, widely used as an ingredient for the production of savoury foods.[9,10] Yeast extract is a natural ingredient composed of a variety of peptides, nucleotides, B-complex vitamins, minerals and high quality protein rich in essential amino acids.[9]

Comparing the composition of yeast protein and muscle protein in terms of the essential amino acids composition revealed striking similarity. Yeast protein is shown to contain all of the essential amino acids and to be a biologically complete protein.[11]

Yeast extract could also be used as an ingredient for the production of functional foods with health benefits. Functional foods are conventional food products that are taken as a part of the normal diet and demonstrate health benefits beyond their nutritional properties.[12] The effects of functional foods on the humans health are often not easily measurable but their positive impact could be seen after the end of the perennial period of consumption.[13]

Elevated dietary salt intake is an established risk factor for high blood pressure and salt reduction has consistently been shown to reduce cardiovascular events.[14] Consequently, the World Health Organization issued a public health recommendation of a maximum intake for adults of 5 g per day.[15,16] For this reason, the food industry should reduce the amount of salt added to food products to affect public health improvement.[15,17]

The aim of this study was to test the addition of yeast extract, as an active ingredient, to bread formula in an effort to reduce the amount of salt and increase the protein and mineral content to obtain a new product on the market with enhanced nutritive value and good sensory characteristics.

EXPERIMENTAL

Material

For whole meal bread production, flour from spelt, grown in the year 2018 in Serbia was used. Tested chemical composition is presented in Table I.

Salt, sugar and yeast were commercial products, taken from a local food market. Salt was produced by "So Product" d.o.o, Stara Pazova, Serbia, sugar was produced by "Crvenka", Crvenka, Serbia, and yeast and yeast extract were taken from "Altech Serbia" d.o.o, Senta, Serbia. The chemical composition of the yeast extract is presented in Table I.

TABLE I. Chemical composition of whole meal spelt flour and yeast extract

Parameter	Chemical composition, % d.m.	
	Whole meal spelt flour	Yeast extract
Moisture	10.00	6.29
Ash	3.05	8.00
Total sugar	2.35	1.52
Protein	17.02	79.68
Cellulose	2.37	0.00
Starch	65.87	–
Fat	2.38	0.17

Bread making procedure

Bread was baked according to a slightly modified AACC method.[18] The composition of bread dough was: spelt flour (in amount of 100 g), yeast extract, salt and sugar (in amount

TABLE II. Design matrix with coded values of yeast extract, salt and sugar addition as independent variables

Sample no.	Yeast extract addition	Salt addition	Sugar addition
0	–1	–1	–1
1	–1	–1	0
2	–1	0	–1
3	–1	0	+1
4	–1	+1	0
5	0	–1	–1
6	0	–1	+1
7.1[a]	0	0	0
7.2[a]	0	0	0
7.3[a]	0	0	0
7.4[a]	0	0	0
7.5[a]	0	0	0
8	0	+1	–1
9	0	+1	+1
10	+1	–1	0
11	+1	0	–1
12	+1	0	+1
13	+1	+1	0

[a]Repetitions in the central point

determined by experimental plan in Table II), instant dry yeast, ascorbic acid and water in amounts of 0.5 g, 0.6 ml (1 g ascorbic acid in 100 ml water) and 60 g, respectively.

The design matrix of the various bread formulas is given in Table II with coded values, where –1, 0 and +1, represents added quantities of yeast extract, salt and sugar in amounts of 0, 2 and 5; 1.0, 1.5 and 2; 0, 5 and 10 % d.m. on flour basis, respectively.

The measured ingredients were placed in a farinograph bowl and mixed until peak time, previously determined by the farinograph curve. The temperature of the ingredients yielded a final dough temperature of 30 °C. After mixing, the dough was rounded by hand and placed in the fermentation cabinet at 30 °C. The bulk fermentation lasted 150 min, while punching was done by hand after 60 and 120 min from the beginning of the bulk fermentation. After bulk fermentation, the dough was moulded by hand and placed in a greased pan. Proofing was performed at 32 °C, at relative humidity of 75 %, during 60 min. Baking lasted 25 min at 230 °C, at a humidity provided by the oven.

Basic chemical analysis

Basic chemical analyses (protein, starch, fat, total sugar, and cellulose) of the whole meal spelt flour and bread were determined according to the official methods of AOAC.[19]

Mineral content of bread

Mineral content of zinc, copper, magnesium, calcium and iron was determined using an Atomic Absorption Spectrophotometer, AOAC.[20]

Colour of the bread

The bread colour was measured using a tri-stimulus colour meter type CR-400 (Konica, Minolta, Tokyo, Japan) equipped with D65 illuminant. The results are expressed as per CIELab system in terms of coordinates: L^*– lightness (0, black to 100, white), a^*– redness ($-a^*$, green to $+a^*$, red), and b^*– yellowness ($-b^*$, blue to $+b^*$, yellow), and C^*– differences in chroma (+ brighter, – duller). The measurements were observed under constant lighting conditions, at 28 °C, using a colour attributes of white control plate, $L^* = 98.76$, $a^* = -0.04$ and $b^* = 2.01$.[8]

Breadcrumb quality determination

Breadcrumb quality was quantified by sensory evaluation of both texture analysis of crumb elasticity and crumb grain structure. Evaluation was performed 24 h after the baking by a panel of five trained evaluators using numeric scores that gave summary values ranging from minimum 0 to maximum 7.[21]

Sensory analysis

Sensory analysis was conducted according to SRPS ISO 4121:2002.[22] A team of six trained panellists identified descriptors, and scored sensory characteristics using a 10-point scale (1 – lowest, 10 – highest intensity of the descriptors). The following descriptors were evaluated: appearance, taste, aroma and texture. The panellists were asked to evaluate randomly coded 2 cm slice of bread and to rinse their mouth with water before and after each bread tasting. The sensory analysis was performed 24 h after baking.

Statistical analysis

Response surface methodology (RSM) and analysis of variance (ANOVA) were selected to estimate the main effects of the yeast extract, and salt and sugar addition to the formula on the bread quality parameters. The accepted experimental design was according to a Box and Behnken experimental plan,[23] which uses minimum experimental runs for every tested independent variable optimization.[24] The independent variables were quantity of yeast extract (X_1), quantity of salt (X_2) and quantity of sugar (X_3). The dependent variables were the responses of chemical composition (Y_1–Y_5); the responses of mineral composition (Y_6–Y_{10}); the responses of instrumental colour and texture analysis (Y_{11}–Y_{15}) and the responses of sensory analysis (Y_{16}–Y_{31}). A model was fitted to the response surface generated by the experiment. The model used was function of the variables:

$$Y_\mathrm{k} = f_\mathrm{k}\,(\text{quantity of yeast, quantity of salt, quantity of sugar}) \tag{1}$$

The following second order polynomial (SOP) model was fitted to the data. Thirty-two models of the following form were developed to relate thirty-one responses (Y) to three process variables (X):

$$Y_\mathrm{k} = \beta_{\mathrm{k}0} + \sum_{i=1}^{3} \beta_{\mathrm{k}i} X_i + \sum_{i=3}^{3} \beta_{\mathrm{k}ii} X_i^2 + \sum_{i=1}^{3} \sum_{j=i+1}^{3} \beta_{\mathrm{k}ij} X_i X_j\ ,\ k = 1\text{–}31 \tag{2}$$

where $\beta_{\mathrm{k}ij}$ are constant regression coefficients.

ANOVA and RSM were performed using StatSoft Statistica, for Windows, ver. 12, program (STATISTICA 2012). The model was obtained for each dependent variable (or response) where factors were rejected when their significance level was less than 95 %.

For the purpose of ANOVA Tukey HSD analysis all testing was performed in three parallel runs.

Z-Score analysis

The *Z*-score analysis used min–max normalisation of the bread quality parameters transforming them from their original unit system into a new dimensionless system, where further mathematical calculations with different types of quality parameters are applicable.[25] The maximum value of the normalised score presents the optimum value of all combined analysed parameters, indicating the optimum total quality:

$$S_{1\mathrm{i}} = \frac{\displaystyle\sum_{k=1}^{3} \frac{(x_\mathrm{ki} - x_\mathrm{kmin})}{(x_\mathrm{kmax} - x_\mathrm{kmin})} + \sum_{\mathrm{j}=1}^{2} 1 - \frac{(x_\mathrm{ji} - x_\mathrm{jmin})}{(x_\mathrm{jmax} - x_\mathrm{jmin})}}{5} \tag{3}$$

where x_k are proteins, starch and cellulose, and x_j are fat, total sugars.

$$S_{2\mathrm{i}} = \frac{\sum_{l=1}^{5} (x_{l\mathrm{i}} - x_{l\mathrm{min}}) / (x_{l\mathrm{max}} - x_{l\mathrm{min}})}{5} \tag{4}$$

where x_l are: Zn, Cu, Mg, Ca and Fe;

$$S_{3\mathrm{i}} = \frac{\sum_{m=1}^{5} (x_{m\mathrm{i}} - x_{m\mathrm{min}}) / (x_{m\mathrm{max}} - x_{m\mathrm{min}})}{5} \tag{5}$$

where x_m are: L^*, a^*, b^*, C^* and bread crumb quality;

$$S_{4\mathrm{i}} = \frac{\sum_{n=1}^{8} (x_{n\mathrm{i}} - x_{n\mathrm{min}}) / (x_{n\mathrm{max}} - x_{n\mathrm{min}}) + \sum_{o=1}^{8} 1 - (x_{o\mathrm{i}} - x_{o\mathrm{min}}) / (x_{o\mathrm{max}} - x_{o\mathrm{min}})}{16} \tag{6}$$

where x_n are: characteristic appearance, taste and aroma, crust colour intensity, colour uniformity, sweet taste, elasticity and pores uniformity, and x_o are: crumb colour intensity, sour and salty taste, sour, yeast and pungent aroma, firmness and wall thickness:

$$\mathrm{Score_i} = \frac{\sum_{p=1}^{4} S_p}{4} \tag{7}$$

where S_p are S_1, S_2, S_3 and S_4.

$$\max\,[\mathrm{Score_i}] \rightarrow \mathrm{optimum} \tag{8}$$

RESULTS AND DISCUSSION

Bread product is a complex multi component system consisting of biomacromolecules, such as proteins, carbohydrates and lipids. The Investigated breads were characterized by a low protein content in the samples without yeast extract (samples 0–4), where the addition of non-protein components (salt and sugar) reduced the protein content of the bread samples, Table III. The addition of yeast extract contributed to a statistically significant increase of the protein content in bread, since yeast extract is rich in proteins,[9,10] which can also be seen from the graphical presentation of the developed mathematical models of the dependence of the bread protein content on yeast extract, sugar and salt addition, Fig. S-1a and b of the Supplementary material to this paper. Linear terms of yeast extract and sugar statistically significantly contributed to the SOP model forming.

TABLE III. Average values of the chemical composition of the bread with yeast extract; different letters in superscript in the same column indicate statistically significant difference between the values, at a level of significance of $p < 0.05$ (based on the post hoc Tukey HSD test)

Sample No.	Content / % d.m. ± standard deviations				
	Proteins	Starch	Fat	Total sugars	Cellulose
0	17.20±0.19 ^{c}	61.20±0.60 ^{e}	2.30±0.03 ^{h}	1.99±0.01 ^{a}	2.64±0.05 ^{e}
1	16.02±0.02 ^{b}	58.17±0.41 ^{d}	2.18±0.01 ^{ef}	7.03±0.03 ^{c}	2.50±0.03 ^{c}
2	17.05±0.07 ^{c}	60.91±0.13 ^{e}	2.29±0.03 ^{gh}	2.05±0.04 ^{a}	2.66±0.04 ^{e}
3	15.17±0.15 ^{a}	55.27±0.51 ^{b}	2.06±0.04 ^{bc}	11.89±0.17 ^{e}	2.41±0.03 ^{b}
4	15.05±0.04 ^{a}	57.31±0.63 ^{cd}	2.12±0.04 ^{cd}	6.99±0.02 ^{c}	2.45±0.04 ^{b}
5	19.03±0.17 ^{e}	60.26±0.33 ^{e}	2.24±0.07 ^{fg}	1.99±0.02 ^{a}	2.62±0.20 ^{d}
6	16.14±0.15 ^{b}	52.98±0.45 ^{a}	2.02±0.03 ^{ab}	11.11±0.10 ^{d}	2.39±0.22 ^{b}
7	16.93±0.10 ^{c}	56.20±0.73 ^{bc}	2.11±0.06 ^{cd}	6.95±0.06 ^{c}	2.48±0.02 ^{c}
8	17.89±0.18 ^{d}	57.71±0.39 ^{d}	2.18±0.08 ^{ef}	1.97±0.03 ^{a}	2.47±0.02 ^{c}
9	16.11±0.17 ^{b}	52.69±0.68 ^{a}	1.97±0.03 ^{a}	10.86±0.12 ^{d}	2.32±0.02 ^{a}
10	20.95±0.07 ^{e}	55.55±0.59 ^{b}	2.07±0.03 ^{cd}	7.02±0.08 ^{c}	2.38±0.03 ^{b}
11	20.06±0.19 ^{f}	57.34±0.58 ^{cd}	2.17±0.08 ^{de}	2.04±0.03 ^{a}	2.51±0.03 ^{c}
12	18.20±0.27 ^{d}	51.84±0.62 ^{a}	1.96±0.02 ^{a}	10.99±0.12 ^{d}	2.29±0.02 ^{a}
13	19.10±0.09 ^{e}	53.17±0.24 ^{a}	2.02±0.05 ^{ab}	5.99±0.06 ^{b}	2.44±0.04 ^{b}

Starch is the dominant component in bread, where maximum value (61.20 % d.m.) was observed in sample 0 and, as expected, the minimum content of starch (51.84 % d.m.) was observed in sample 12, Table III and Fig. S-2a and b. The addition of the maximum quantity of yeast extract statistically significantly decreased the starch content in the bread (samples 10–13), due to the addition of non-starch component (yeast extract) to the bread formula. All three SOP linear terms, together with cross products of yeast extract × salt and salt × sugar were statistically significant in model forming.

The highest content of fat was in sample 0 (2.30 % d.m.), while the lowest was in sample 12 (1.96 % d.m.), Table III and Fig. S-3a and b. The addition of yeast extract in a quantity of 5 % statistically significantly decreased the fat content in the bread. The addition of salt and sugar also decreased the fat content in the bread, since all of these additions are non-fat components. All three SOP linear terms were statistically significant in model forming.

The addition of yeast extract did not statistically significantly change the total sugar content of the bread samples, Fig. S-3a and b. The addition of higher quantities of salt indirectly affected the chemical composition of the bread. The total sugar content was statistically significantly affected by the addition of the sugar to the bread formula, and the highest values were observed in samples 3, 6, 9 and 12, Table III, while the SOP linear terms for sugar and yeast extract were statistically significant.

The highest contents of cellulose were noticed in samples 0, 2 and 5 with 0 % sugar (2.64, 2.66 and 2.62 % d.m., respectively), while the lowest content of cellulose was in sample 12 (2.29 % d.m.) with 10 % sugar, Table III. From Fig. S-5a and b, it could be seen that only the linear term of sugar statistically significantly contributed to the bread with the yeast cellulose content mathematical model forming.

The daily quantities of mineral nutrients are, by nature, small, especially when compared to nutrients, such as macro minerals, but it is necessary for the functioning of the organisms.[26] The addition of yeast extract to the bread formula statistically significantly increased the contents of Zn, Mg and Ca, while it did not statistically significantly affect the contents of Cu and Fe in the bread samples, Table IV. The linear SOP terms for yeast extract and sugar were statistically significant in all cases of the models for the mineral composition of bread, which could be seen from the dependencies presented in Figs. S-5–S-10. A quadratic term for salt statistically significantly contributed to the Zn and Cu model forming, together with a statistically significant quadratic term for sugar in the case of the Cu model. The highest values of Zn, Mg and Ca (26.48, 407.84 and 123.94 mg kg^{-1}, respectively) were found in bread sample 11, which is characterized by the highest addition of yeast extract, Table IV, Figs. S-6, S-8 and S-9. Based on the recommend minimum daily intake of mineral matter for the normal functioning of metabolism,[26] the daily intake of 100 g of bread with yeast extract (in quantity of 5 %) fulfils 17.65, 29.20, 10.20, 1.24 and 25.30 % of recommended daily intake of Zn, Cu, Mg, Ca and Fe, respectively.

TABLE IV. Average values of the mineral composition of the bread with yeast extract; different letters in superscript in the same column indicate statistically significant differences between the values, at a level of significance of $p < 0.05$ (based on post hoc Tukey HSD test)

Sample No.	Content, mg kg^{-1} ± standard deviations				
	Zn	Cu	Mg	Ca	Fe
0	22.94±0.22 ^{de}	6.09±0.01 ^{g}	294.93±4.91 ^{cd}	81.17±0.51 ^{b}	44.94±0.27 ^{de}
1	21.81±0.35 ^{bc}	5.70±0.06 ^{de}	270.24±1.74 ^{ab}	78.85±1.10 ^{b}	41.55±0.22 ^{ab}
2	22.91±0.22 ^{de}	6.09±0.04 ^{fg}	290.28±2.69 ^{c}	81.71±0.70 ^{b}	44.50±0.71 ^{de}
3	20.73±0.09 ^{a}	5.44±0.05 $^{a-c}$	265.83±3.00 ^{a}	71.63±0.04 ^{a}	40.83±0.61 ^{a}
4	21.09±0.37 ^{a}	5.51±0.05 $^{b-d}$	276.61±2.77 ^{b}	78.86±0.94 ^{b}	41.49±0.91 ^{ab}
5	24.44±0.37 ^{g}	5.93±0.05 ^{fg}	351.47±3.36 ^{g}	110.55±0.93 ^{f}	45.80±0.69 ^{e}
6	22.41±0.06 ^{cd}	5.38±0.07 ^{ab}	310.83±2.84 ^{e}	99.14±0.75 ^{d}	41.01±0.50 ^{a}
7	23.42±0.02 ^{ef}	5.67±0.04 $^{c-e}$	334.53±3.11 ^{f}	99.56±0.73 ^{d}	43.14±0.34 ^{c}
8	24.01±0.39 ^{fg}	5.87±0.05 ^{ef}	340.12±4.93 ^{f}	103.74±1.12 ^{e}	44.84±0.30 ^{de}
9	21.69±0.26 ^{b}	5.25±0.05 ^{a}	300.21±3.06 ^{d}	94.80±0.73 ^{c}	40.48±0.56 ^{a}
10	25.27±0.21 ^{h}	5.51±0.04 $^{c-d}$	380.52±4.12 ^{i}	120.12±0.98 ^{h}	43.64±0.50 ^{cd}
11	26.48±0.18 ^{i}	5.84±0.04 ^{ef}	407.84±1.27 ^{j}	123.94±1.56 ^{j}	45.54±0.39 ^{e}
12	24.06±0.30 ^{fg}	5.27±0.07 ^{a}	364.27±6.41 ^{h}	114.69±1.13 ^{g}	41.31±0.34 ^{a}
13	24.65±0.18 ^{gh}	5.44±0.08 $^{a-c}$	370.04±3.77 ^{h}	120.11±0.09 ^{h}	42.80±0.35 ^{bc}

As in case of the change in the chemical composition of bread with added yeast extract, the addition of higher quantities of sugar and salt affected indirectly the mineral composition of bread.

Colour is an important organoleptic characteristic of baked products and it influences consumer choices.[27] The addition of yeast extract in quantities of 2.5 and 5 % in bread products (samples of 5–13) contributed, in most cases, to a statistically significant increase in the L^*, b^* and C^* parameters and statistically significant decrease in the a^* parameter, Table V and Figs. S-11–S-14. Only the linear SOP term for yeast extract showed statistical significance in all four models of colour characteristics. Based on the increase of parameters L^* and b^*, it is possible to see the positive effect of the yeast extract on the bread colour, since it was lighter and more yellow in colour than whole meal spelt flour. Due to the increased Fe content of the bread samples with yeast extract addition (Table IV), the positive effects of yeast extract on the characteristics of bread colour could probably be attributed to catalyzation of the oxidative reaction of ascorbic acid to dehydro-ascorbic acid,[11] thus acting as a dough improver.

Increasing levels of salt addition to the bread samples statistically insignificantly increased the L^*, b^* and C^* values. While addition of sugar statistically insignificantly decreased L^* and increased C^* values, probably related to requirements for the initiation of colour formation during bread baking.[28]

TABLE V. Average values and standard deviations of the instrumental colour and bread crumb quality analysis of the bread with yeast extract; different letters in superscript in the same column indicate a statistically significant difference between the values, at a level of significance of $p < 0.05$ (based on post hoc Tukey HSD test)

Sample no.	*L**	*a**	*b**	*C**	Bread crumb quality
0	64.37±0.75 ^{a}	5.36±0.06 ^{e}	17.79±0.18 ^{bc}	18.55±0.25 ^{ab}	1.65±0.15 ^{b}
1	64.14±0.72 ^{a}	5.35±0.02 ^{e}	17.21±0.21 ^{a}	18.61±0.13 $^{a-c}$	4.15±0.15 ^{e}
2	64.44±0.63 ^{ab}	5.74±0.05 ^{g}	17.98±0.13 ^{c}	18.87±0.23 ^{bc}	2.20±0.20 ^{c}
3	64.37±0.80 ^{a}	5.63±0.04 ^{fg}	17.32±0.07 ^{ab}	18.26±0.12 ^{a}	5.00±0.00 ^{i}
4	64.87±0.80 $^{a-c}$	5.51±0.02 ^{ef}	19.06±0.33 ^{d}	18.84±0.20 ^{bc}	3.95±0.05 ^{d}
5	65.99±0.75 $^{a-e}$	4.68±0.05 ^{d}	19.29±0.22 ^{de}	19.11±0.11 ^{cd}	1.50±0.00 ^{a}
6	65.15±0.34 $^{a-d}$	4.62±0.06 ^{d}	19.68±0.12 ^{ef}	19.51±0.27 ^{de}	4.55±0.05 ^{h}
7	66.88±0.60 $^{c-e}$	4.60±0.07 ^{d}	19.30±0.17 ^{de}	20.01±0.33 ^{ef}	4.30±0.30 ^{g}
8	66.45±1.00 $^{b-e}$	4.43±0.05 ^{c}	19.45±0.21 $^{d-f}$	19.59±0.11 ^{de}	2.25±0.25 ^{c}
9	65.74±0.36 $^{a-e}$	4.38±0.05 ^{c}	19.84±0.23 ^{f}	19.79±0.20 ^{e}	4.65±0.15 ^{h}
10	67.09±0.17 ^{de}	3.62±0.04 ^{a}	20.81±0.16 ^{g}	19.99±0.20 ^{ef}	3.85±0.15 ^{d}
11	67.79±0.69 ^{e}	3.74±0.02 ^{ab}	20.79±0.37 ^{g}	20.58±0.11 ^{g}	4.30±0.30 ^{fg}
12	65.97±0.19 $^{a-e}$	3.66±0.02 ^{a}	20.66±0.29 ^{g}	20.49±0.05 ^{fg}	4.20±0.20 ^{ef}
13	70.04±0.93 ^{f}	3.84±0.03 ^{b}	21.05±0.32 ^{g}	20.88±0.16 ^{g}	4.25±0.25 $^{e-g}$

Addition of yeast extract to the bread formulas statistically significantly improved the breadcrumb quality, comparing corresponding bread samples (2 and 11; 4 and 13), and analyzing the modelled dependence of breadcrumb quality on yeast extract addition, presented in Fig. S-15a and b. Together with the proposed mechanism of dough improvement by increased Fe content, yeast extract (containing dead yeast cells) acts as a yeast food source,[11] improving fermentation tolerance, loaf volume and overall bread crumb quality.

The salt concentration, however, is not only influential on the sensory acceptability of food in terms of taste. In case of bread, salt is an essential ingredient, being crucial for the proper development of dough structure. The interaction of salt with dough components such as gluten is very important due to inhibitory effect on proteolytic enzymes and direct interaction with flour proteins, providing better dough handling and oven spring.[11,16] The proposed effects contribute to higher bread crumb quality, as could be seen from the statistically significant increase in the bread crumb quality results for the samples with higher salt addition (compare samples 5 and 8; 10 and 13, and also from Fig. S-15a).

Analyzing the effect of yeast extract, as a salt substitute in the bread formulas, on texture characteristics by comparing bread samples 4 and 10, it could be seen that addition of yeast extract only statistically insignificantly decreased bread crumb quality (by about 2.5 %).

Bread samples with sugar added in the highest quantities to their recipes had the highest breadcrumb quality values, Fig. S-15b, indicating that sugar acted as an improver of the textural characteristics of bread with added yeast extract. The added sugar promoted vigorous yeast fermentative activity, contributing to delayed gelatinization of starch and protein denaturation, consequently improving oven spring and bread crumb and pores quality.[11] In case of bread crumb quality model, only the linear term for sugar showed statistical significance.

The results of the sensory analysis of the bread with yeast extract are presented in Table S-I, from which it could be seen that the addition of yeast extract statistically significantly affected the appearance, taste, aroma and texture descriptors. From Figs. S-16–S-31, it could be seen that the addition of yeast extract affected an increase in the descriptors for characteristic appearance, crust and crumb colour intensity, colour uniformity, sweet, sour and salty taste, sour, yeast and pungent aroma and wall thickness, while it affected a decrease in the descriptors for colour uniformity, characteristic taste and aroma, firmness, elasticity and pores uniformity.

Lysine from yeast extract could be the major source of primary amines in proteins in the Maillard reactions of condensation between reducing sugars and amino acids,[28] providing for increased crumb colour intensity of the bread samples containing yeast extract.

The linear SOP term of yeast extract for characteristic appearance, crust colour intensity, crumb colour intensity and for all taste and aroma descriptors statistically significantly contributed to the formation of the SOP model. The quadratic term of yeast extract was statistically significant for sweet taste and yeast aroma models.

Different quantities of salt addition (comparison of the sample 1 and 4; 5 and 8; 10 and 13; Figs. S-16a–S-31a) statistically significantly increased the characteristic appearance, crust and crumb colour intensity, salty taste, pungent aroma and all texture descriptors, while it decreased colour uniformity descriptors. Linear term for salt was statistically significant in cases of the characteristic appearance, salty taste and yeast and pungent aroma models. The quadratic term for salt was statistically significant in cases of sweet taste and elasticity models.

The addition of sugar statistically significantly contributed to the increase in the characteristic appearance, crust and crumb colour intensity, sweet and salty taste, pungent aroma, elasticity and pore uniformity descriptors (comparison of the samples 11 and 12, Figs. S-16b–S-31b). Sugar added to the bread with yeast extract statistically significantly decreased colour uniformity, characteristic taste and aroma, firmness and wall thickness. Sugar addition in quantities of 5 and 10 % in samples with 5 % added yeast extract (samples 10 and 12), improved most of the sensory characteristics in comparison to the bread samples with yeast extract addition but without sugar addition (sample 11).

Linear term for sugar statistically significantly contributed to the formation of characteristic taste and aroma, yeast aroma, and all texture descriptors models. Quadratic term for sugar was statistically significant only in case of the elasticity model. The crops product term of yeast extract × sugar was statistically significant in cases of characteristic and salty taste, characteristic aroma and texture descriptors of firmness, elasticity and wall thickness models.

By comparing the effectiveness on sensory characteristics of yeast extract as a salt substitution in bread samples recipes, by analysing bread samples 4 and 10; 1 and 7; 3 and 6; it could be seen that addition of yeast extract improved the appearance descriptors, without high deterioration of the texture descriptors. In Maillard reactions, the type of flavour compound formed depends on the type of sugars and amino acids involved,[28] and hence, the taste of the samples with yeast extract became more complex, but without increasing the salty taste. The aroma of the yeast extract bread samples was also changed, with statistically significantly increased descriptors of sour, yeast and pungent, which was to be expected.

The regression coefficients of thirty-one SOP models of chemical and mineral composition, instrumental colour, texture and sensory characteristics of bread with yeast extract are given in Tables S-II–S-V. The statistical significance of individual coefficients is marked and the values of the coefficient of determination (R^2) are given. The calculated critical values with critical values of independent variables are also presented in Tables S-II–S-V. The high values of R^2 in all the developed models (ranging from 0.881 to 0.999) indicate that the applied models for the responses of chemical and mineral composition, instrumental colour, breadcrumb quality and sensory characteristics of bread with yeast extract are adequately fitted to the experimental data. Using the presented data, quadratic equations describing the SOP models of bread with yeast extract quality parameters could be completed. Data obtained from these models could be used for the prediction and optimization of the quality of bread with yeast extract.

The results of the *Z*-score analysis providing information about segment and total quality of the tested bread samples are given in Table VI. The highest value

TABLE VI. Score values of the quality parameters for bread with yeast extract

Sample No.	S_1	S_2	S_3	S_4	Score
0	0.66	0.52	0.23	0.56	0.49
1	0.45	0.22	0.34	0.73	0.43
2	0.67	0.48	0.34	0.54	0.51
3	0.28	0.06	0.40	0.66	0.35
4	0.41	0.15	0.48	0.57	0.40
5	0.73	0.76	0.34	0.33	0.54
6	0.30	0.28	0.53	0.58	0.42
7	0.47	0.48	0.59	0.54	0.52
8	0.59	0.64	0.42	0.39	0.51
9	0.29	0.17	0.56	0.48	0.37
10	0.56	0.69	0.55	0.39	0.55
11	0.70	0.92	0.66	0.47	0.69
12	0.32	0.45	0.57	0.35	0.42
13	0.53	0.59	0.78	0.35	0.56

of S_1 of bread sample with addition of 2.5 % of yeast extract, 1 % of salt and 0 % sugar indicated the best chemical composition, while the highest value of S_2 of bread sample with addition of 5 % of yeast extract, 1.5 % of salt and 0 % sugar, indicated the best mineral composition. The highest value of S_3 of the bread sample with addition of 5 % of yeast extract, 2 % of salt and 5 % sugar, indicated the best colour and breadcrumb quality, while the highest value of S_4 of the bread sample with addition of 0 % of yeast extract, 1.0 % of salt and 5 % sugar, indicated the best sensory characteristics. The best total quality was determined for the bread sample containing 5 % of yeast extract, 1.5 % of salt and 0 % sugar.

CONCLUSIONS

From the presented results, the following could be concluded.

Bread samples with added yeast extract were characterized by an improved nutritional profile, due to the increased high quality protein from yeast, Zn, Mg and Ca content. The colour and breadcrumb quality of the bread samples with yeast extract were significantly improved. The addition of yeast extract statistically significantly affected sensory characteristics descriptors of all bread samples.

Analysis of yeast extract, as a salt substitution, in the bread formulas showed that the yeast extract improved the appearance without deteriorating the texture descriptors and breadcrumb quality, while the taste became more complex, but without increasing salty taste.

Although the addition of yeast extract deteriorated the overall sensory characteristics, a combination of sugar and yeast extract addition improved most sensory characteristics, enhancing the overall acceptability of the bread samples.

The developed mathematical models of thirty-two breads with yeast extract quality parameters were statistically significant. The results showed that the calculated and observed responses corresponded very well, indicating to a satisfactory approximation of bread quality parameters in dependence on addition of yeast extract, salt and sugar.

Bread samples with addition of 5 % of yeast extract, 1.5 % of salt and 0 % sugar were determined as the best from the aspect of overall quality.

SUPPLEMENTARY MATERIAL

Additional data are available electronically at the pages of journal website: http:// //www.shd.org.rs/JSCS/, or from the corresponding author on request.

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ИЗВОД

УТИЦАЈ ДОДАТКА ЕКСТРАКТА КВАСЦА НА ПАРАМЕТРЕ КВАЛИТЕТА ХЛЕБА

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Испитан је утицај додатка различите количине екстракта квасца, соли и шећера, на хемијски и минерални састав, боју и сензорна својства хлеба од органске спелте, како би се добио нови производ на тржишту. Додатак 5 % екстракта квасца на масу брашна од спелте позитивно је утицао на нутритивне карактеристике хлеба повећањем садржаја протеина у хлебу за 30,8 % и обогаћењем минералима. Додатак екстракта квасца побољшао је изглед без погоршања дескриптора текстуре и квалитета хлеба, док је укус постао комплекснији, али без повећавања сланог укуса. Додатак шећера у узорцима са екстрактом квасца, побољшао је већину сензорних и текстуралних карактеристика хлеба. Развијени математички модели параметара квалитета хлеба са екстрактом квасца били су статистички значајни, указујући на задовољавајуће предвиђање параметера квалитета хлеба у оквиру граница варираних рецептура. Додатак 5 % екстракта квасца, 1,5 % соли и 0 % шећера се показао као оптималан са аспекта укупног квалитета хлеба. Хлеб од спелте обогаћен екстрактом квасца (2,5–5 %) имао бољи хемијски и минерални састав, боју и сензорна својства, с повећаним нивоом нутритивне вредности и смањеним уделом соли.

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