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Influence of black chokeberry (*Aronia melanocarpa* L.) addition on the main characteristics of bread

Toncho Kolev[1*], Rosen Chochkov[2] and Zlatin Zlatev[1]

[1] *Trakia University, Faculty of Technics and Technologies, 8600Yambol, Bulgaria*
[2] *University of Food Technologies, Technology of Cereals, Feed, Bakery and Confectionery Products Department, Faculty of Technology, 4000 Plovdiv, Bulgaria*
[*]*Corresponding author:* sevenfist@abv.bg

Abstract

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The article describes the results of a study of bread produced with the use of raw materials of berries origin. By using appropriate computer-based statistical methods, the appropriate amount of black chokeberry flour in bread was determined. An analysis of a total of 43 features describing the change in the physicochemical, geometric, organoleptic and optical properties of bread with the addition of black chokeberry was found. It was found that only 18 of them are informative. It has been proven that the shape stability, dry matter content, active and titratable acids, general appearance and aroma, as well as 9 color and 3 spectral indices, sufficiently reflect the changes in bread, depending on the amount of added chokeberry flour. The specific relationship between the reduced data to two principal components of the created vector of 18 features was studied. It has been found that this relationship can be described with an accuracy of up to 83%. It was found that the addition of 8.62% raw material from black chokeberry flour improves the physico-chemical and organoleptic and optical characteristics of bread. In further studies, whole black chokeberry flour, due to its specific chemical composition and significant content of biologically active substances and macronutrients, can be used to obtain bread with functional properties

*Keywords***:** fruit powder; color; spectra; sensory characteristics; wheat flour; feature selection; PCA; regression model

Introduction

The fruits obtained from black chokeberry (*Aronia melanocarpa*) are used in food production. They can also be consumed fresh by humans. The fruits are processed into juices, fruit wines and as an additive in fruit-sugar preserves, enriching them with pectin and various biologically active substances. Fruits can also be processed into fruit flours obtained by drying whole fruits or fruit presses and their subsequent grinding (Šnebergrová et al., 2014). The resulting flour can be used in various types of bread, bakery and confectionery products.

Black chokeberry fruits are rich in a wide range of biologically active substances important for the human body. According to Kokotkiewicz et al. (2010), the following groups of important nutritional and biologically active substances are mainly contained: sugars (10-18%), pectin (0.6–0.7%), sorbitol, parasorbide and small amounts of fat, up to 0.14% by mass of the fresh raw material. The qualitative composition of these fats mainly includes linolenic acid and its glycerides and phosphatidylinositol. Macronutrients are mainly represented by K, Zn, Na, Ca, Mg, Fe, as well as group vitamins and vitamin C and vitamin A are also contained in significant amounts in the fresh product. The chemical composition of black chokeberry also includes carotenoids, tannins, triterpenoids, amygdalin, and volatile components.

Recently, a widespread trend is the inclusion of polyphenols of vegetable origin in the dough for the preparation of bread, bakery and confectionery products. The purpose of this operation is to increase the functional properties of these products and potentially reduce the content of a number of harmful substances in bakery products obtained as a result of the thermal impact on the already formed products during their baking (García-Flores et al., 2018).

As a component in the recipe composition for preparing wheat bread with black chokeberry flour, significant amounts of dietary fiber - soluble and insoluble – are introduced. Due to their specific physicochemical and chemical properties, they have a significant impact on the rheological properties of wheat dough (Alba et al., 2018).

Catana et al. (2018), investigated the influence of black chokeberry addition (1–5%) in bread and pasta products. In their research on bread, the authors found that the bread was softer, compared to the other products studied, due to the high water content (41.69±0.30%). Also, the darker color of the additive leads to a decrease in the values of the L (Lab) component (L = 40.18).

Petković et al. (2019), found that the drying regimes of black chokeberry fruits had a significant effect on the main characteristics of bread to which they were added. The authors added 10% flour from whole aronia fruit obtained in three different fruit drying regimes. The best characteristics – organoleptic, color and with the smallest changes in the composition of the raw material, shows when drying at 50°C. The coloring substances from the composition of the plant are preserved and the color is pleasant and acceptable. The antioxidant properties of aronia are also preserved. At higher temperatures, especially at 70°C, the characteristics of the raw material deteriorate.

Petković et al. (2020), made a further study comparing different amount of added black chokeberry fruit flour (1%, 2.5%, 5% and 10%) obtained at different drying regimes (50, 60 and 70°C). through regression models, the authors found that over 90%, the different amount of chokeberry flour and the temperature regimes of obtaining the flour from the plant affect the bread and its: dry matter content, active acidity, titratable acidity, the content of phenolic compounds, flavonoids, antioxidant activity, color components from the Lab model. to demonstrate these influences, the authors used the representation of the data by the principal component analysis (PCA) method.

In the next stage of their research, Filipović et al. (2021), again conducted a study on black chokeberry flour addition (1%, 2.5%, 5% and 10%) obtained at different drying regimes (50, 60 and 70°C). In this case, the research is related to the nutritional qualities of the resulting bread. The authors propose a technology for the production of bread with added black chokeberry flour. They prove that chokeberry bread provides bioactive components (Mg and Ca) and unsaturated fatty acids that have a beneficial effect on human health. The resulting bread is characterized by a reduced content of starch and proteins and an increased content of sugars, Mg and Ca. The authors indicated that the optimum amount of black chokeberry flour was 10% obtained by drying at 60°C.

From the review of the available literature sources, it can be seen that research on the application of black chokeberry flour as an additive in bread shows that the permissible content levels of this additive are also reported in a wide range of 0-10%. It is not clear how higher levels of this additive affect the basic characteristics of bread.

Computer-based statistical analysis methods with data reduction were applied to bread supplemented with black chokeberry flour. These analyzes are related to the correlation between different characteristics of bread, bakery and confectionery products, as well as a representation of these characteristics after their reduction with the Principal Component Analysis method (Yadav et al., 2022).

The aim of the present work is to determine the influence of the addition of black chokeberry flour in bread. To determine the appropriate amount of this supplement, using computer-based statistical methods.

Material and Methods

In the present work, flour from ground whole black chokeberry fruit, originating in Bulgaria, was used. It is obtained as a result of the processing of aronia fruits for food production, the so-called fruit presses. Black chokeberry flour is packaged in Bulgaria (New S Net, Ltd., Sofia, Bulgaria).

Table 1 shows data on the chemical composition of black chokeberry flour. Of the vitamins, the largest amount are vi-

Table 1. Chemical composition of black chokeberry flour (whole fruit)

Name	Quantity	Name	Quantity
Vitamin, mg/kg	137–237	Vitamin K, μg/kg	242
Vitamin B1, μg/kg	200	Sodium, mg/kg	26
Vitamin B2, μg/kg	180	Potassium, mg/kg	1.80
Vitamin B6, μg/kg	200	Calcium, mg/kg	322
Pantothenic acid, μg/kg	280	Magnesium, mg/kg	162
Folic acid, μg/kg	3000	Zinc, mg/kg	1.47
Niacin, μg/kg	2.79	Iron, mg/kg	9.3
Tocopherols, μg/kg	17.1	–	–

Table 2. Energy value of black chokeberry flour (whole fruit)

Parameter	Value	Parameter	Value
Fat, g	2.7	Proteins, g	28
– of which unsaturated fatty acids, g	0.63	Sodium chloride, g	0.02
Carbohydrates, g	51	Energy value, kJ	1317
– of which sugars, g	49	–	–

tamins B1, B6 and K. The product is characterized by a relatively high content of folic acid, calcium and magnesium.

Table 2 shows data on the energy value of black chokeberry flour. Carbohydrates and proteins are in the largest quantities. Accordingly, sugars.

Table 3. Recipe composition of wheat bread samples with black chokeberry flour

Raw material \ Black chokeberry flour, %	0	2,5	5	7,5	10	15
Wheat flour type „1850“, g	500	487,5	475	462,5	450	425
Black chokeberry flour, g	-	12,5	25	37,5	50	75
Pressed bread yeast, g	10	10	10	10	10	10
Cooking salt, g	6	6	6	6	6	6
Drinking water, cm^3	349	350,1	351	352	352,5	353

Black chokeberry flour was added in amounts of 2.5%, 5%, 7.5%, 10% and 15% to the basic recipe of whole wheat flour type 1850 bread. Table 3 presents the recipe and composition of the bread samples with added black chokeberry flour. The amount of wheat flour and black chokeberry flour are changed, while the amounts of the other raw materials are preserved. Whole grain wheat flour type 1850 was used. It waxs used pressed bread yeast, purchased commercially.

The salt used is table iodized, according to the Bulgarian Regulation on the requirements for the composition and characteristics of salt for food purposes (adopted by PMS No. 23 of 2001; promulgated, SG No. 11 of February 6, 2001). The water is potable, according to Bulgarian Ordinance No. 9/2001 on the quality of water intended for domestic drinking purposes of the Ministry of Health, the Ministry of Regional Development and Public Works and the Ministry of the Environment and Water, (promulgated, SG No. 30, 2001). According to their manufacturers, the raw materials used do not contain substances that can cause allergic reactions or other intolerance in humans. The amount of water for preparing the dough was determined analytically based on the humidity of the resulting mixtures between the two types of flour. The aim is to introduce the same amount of dry matter in the prepared tests. The amount of water required to obtain the dough varies in a small interval, as the humidity of the individual mixtures also varies within small limits.

Table 4 shows the technology for making bread with the addition of black chokeberry flour. It consists of 10 stages. Part of the technological operations are carried out at room temperature, and those where there are fermentation processes are at 25–30°C. The total time for making the bread according to the technology presented in this way is 5–5.5 h.

Determination of pH, EC, TDS, ORP. The preparation of the samples for measurement was done according to the methodology according to AACC 02-52.01 02-52.01 Hydrogen-Ion Activity (pH)-Electrometric Method. According to the methodology, distilled water is heated to 70°C. The bread

Table 4. Description of the technological process

Stage	Time, min	T, °C	Name	Description
1	–	20–22	Preliminary preparation of raw materials	Sifting the flour, tempering the drinking water and pressed bread yeast
2	–	20–22	Dosage of raw materials	According to the working recipe
3	10–15	18–20	Preparation of bread dough by a single-phase method of kneading the dough	Mixing the wheat flour, the enrichment component, the common salt solution and the suspension of water and pressed baker's yeast
4	35–50	30–32	Maturation of the main dough	Fermentation of the prepared main dough under a certain technological mode - maturing temperature of the main dough – 32°C for a certain time – between 35–50 min
5	–	20–25	Dividing the main dough	The dough is divided into pieces with a certain mass:
6	–	20–25	Forming the short dough	230 g for a loaf of bread
7	–	20–25	Arrange in baking trays and molds	440 g for loaf bread
8	40–45	35	Final fermentation	End round shape for floor bread
9	20–25	180	Baking the pieces of dough	Baguette mold for loaf bread
10	180	20	Cooling	Pre-prepared baking trays for floor bread

sample was dissolved in distilled water in a ratio of 1/10 (5 g of raw material in 50 ml of distilled water). It is periodically stirred until a homogeneous solution is obtained. After the mixture is cooled to ambient (room) temperature. Three consecutive measurements of each characteristic were made and their mean value and standard deviation were determined.

- Temperature T, °C, digital thermometer, V&A VA6502 (Shanghai Vihua V&A Instrument Co, Ltd., Shanghai, PR China).
- The amount of raw materials was determined with a Pocket Scale MH-200 (ZheZhong Weighing Apparatus Factory, Yongkang City, Zhejiang Province, PR China), maximum determined mass 200 g, with a resolution of 0.02 g.
- Active acidity (pH), pH meter PH-108 (Hangzhou Lohand Biological Co., Ltd. Jiubao Town, Jianggan Dist, PR China).
- Electrical conductivity (EC, µS/cm), Conductivity Meter AP-2 (HM Digital, Inc., Culver City, CA).
- Total dissolved solids (TDS, ppm), TDS-3 measuring instrument (HM Digital, Inc., Culver City, CA).
- Oxidation-reduction potential (ORP, mV) determined with Measuring device ORP-2069 (Shanghai Longway Optical Instruments Co., Ltd., Shanghai, PR China).

Determination of moisture content. Moisture content (MC, %) was determined with a Kern DBS 60-3 moisture analyzer balance (KERN & SOHN GmbH, Balingen, Germany). The prepared sample of 5 g was dried to a constant mass. The preparation of the sample is carried out on the basis of a previously prepared laboratory sample for analysis obtained from a certain number of products. The required amount of the analyzed product is crushed and the required laboratory sample is weighed for analysis.

Dimension stability. Measure the average diameter (D, mm) of the bread sample, as the arithmetic mean of two measurements of the diameter in opposite directions, as well as its height (H, mm) in the highest part. The indicator is determined by the ratio of the height to the diameter of the floor bread (H/D). An electronic digital caliper SEB-DC-023 was used, with an accuracy of 0.05 mm and a maximum measured length of 150 mm (Shanghai Shangerbo Import & Export Co., Ltd., Shanghai, PR China).

Determination of titratable acidity. Titratable acidity, in °N (Neumann's degree). An aqueous extract of the bread sample is prepared and filtered. Pipette 50 cm^3 of the filtrate and titrate with 0.1 N NaOH with phenolphthalein indicator, according to BDS 3412:79 (Bread and bakery products. Rules for sampling and test methods).

Organoleptic evaluation of bread. This assessment was made in accordance with the method of organoleptic analysis of foods and BDS EN ISO 13299:2016 (Sensory analysis. Methodology. General guide for establishing a sensory profile), according to the specified methods, organoleptic evaluation of bread is carried out in terms of: appearance, volume, rind and core color, chewiness, airiness, flavor and aroma. 9 teachers and students from the "Food Technologies" department of Faculty of Technics and Technologies – Yambol, Bulgaria participated in the organoleptic analysis. They have prior training in performing this type of food analysis. The requirements for the ethical code of the university community have been met (http://uni-sz.bg/truni5, accesses 25 June 2022, in Bulgarian). Informed consent was obtained from all participants in the consumer evaluation of the bread. Respondents were randomly selected, regardless of their educational level, age and gender. Respondents rate the products independently of each other. A 5-point Likert scale was used in the evaluation of bread (1-completely does not correspond to the indicator; 5-completely corresponds to the indicator), as shown in Table 5. Finally, an overall average evaluation of the organoleptic characteristics of bread with the addition of black chokeberry was calculated.

Table 5. Organoleptic evaluation scale

Value	5	4	3	2	1
Decision	Strongly agree	Agree	No decision	Disagree	Strongly disagree

Obtaining color digital images. Bread images were acquired with a Huawei P10 mobile phone video sensor (Huawei Technologies Co., Ltd., Shenzhen, PR China). CPU ARM Cortex A53. The characteristics of the video sensor are: Focal length 28 mm; Maximum resolution 20 MP, 3840×2160 pixels; Aperture size F1.8. Homogeneous illumination of the captured scene is provided by a light source, which consists of a dome-shaped part in which white LEDs with cold white light (6400K), model VT-3528-60 (V-TAC Europe Ltd., Plovdiv, Bulgaria) are installed), with maximum emitted light intensity at 450 nm. Color adjustment was performed with a 24-field color scale Danes Picta Color chart BST11 (Danes-Picta, Praha, Czech Republic).

Color components. Color digital images were obtained in RGB color model, which were converted to Lab and LCh color models. Color component conversion functions were used at observer 2° and illuminance D65 (average daylight with UV component, 6500K). Color components from RGB (RGB [0 255]) model, converted to Lab (L [0 100], a [-86.18 98.23], b [-107.86 94.47]). When converting Lab to LCh, L(Lab)=L(LCh). The remaining color components (C and h) are converted according to the following formulas:

$$C = \sqrt{a + b} \qquad h^{o} = \operatorname{atan}(a/b) \tag{1}$$

Color difference. The color difference ΔE was determined. It varies in the range 0-100, with the closer to 0, the closer the colors of the supplemented bread are to those of the control sample, and the closer to 100, the more different they are.

$$\Delta E = \sqrt{(L_c - L_a)^2 + (a_c - a_a)^2 + (b_c - b_a)^2}, \quad (2)$$

where Lc, ac, bc are color components of the control sample; La, aa, ba – color components of the sample with additive.

Color indexes. The obtained values from Lab and LCh color models were used in the calculation of color indices. The indices are determined according to the formulas summarized by Pathare and colleagues (Pathare et al., 2013). These indices reflect the changes in the brown, yellow, white color of the studied samples. They also present relationships between the color components of the specified patterns. The color indices used have the form:

$$ci_1 = L \quad (3)$$

$$ci_2 = a \quad (4)$$

$$ci_3 = b \quad (5)$$

$$ci_4 = C \quad (6)$$

$$ci_5 = h \quad (7)$$

$$ci_6 = \frac{142,86b}{L} \quad (8)$$

$$ci_7 = 100 - \sqrt{(100 - L)^2 + a^2 + b^2} \quad (9)$$

$$ci_8 = \frac{x - 0.31}{0.17} \qquad x = \frac{a + 1.75L}{5.645L + a - 0.012b} \quad (10)$$

$$ci_9 = \sqrt{a^2 + b^2} \quad (11)$$

$$ci_{10} = \frac{180 - h}{L + C} \quad (12)$$

$$ci_{11} = \frac{2000a}{LC} \quad (13)$$

$$ci_{12} = \frac{a}{b} \quad (14)$$

$$ci_{13} = \frac{a}{b} + \frac{a}{L} \quad (15)$$

$$ci_{14} = L - b \quad (16)$$

$$ci_{15} = \frac{L}{b} \quad (17)$$

$$ci_{16} = \frac{1000a}{L + h} \quad (18)$$

Spectral characteristics. The conversion of the values from XYZ and LMS models into reflectance spectra in the VIS region, in the range 390–730 nm was done according to mathematical formulas presented by Vilaseca et al. (2004). These formulas are for observer 2° and illuminance D65 (average daylight with UV component (6500K)). The conversion to spectral characteristics in the VIS area (Rvis) is based on the presented dependencies:

$$XYZ = RGB.M_{XYZ} \quad (19)$$

$$LMS = XYZ.M_{LMS} \quad (20)$$

$$L = \int_{380}^{780} A(\lambda)\bar{L}(\lambda)d\lambda; \quad (21)$$

$$M = \int_{380}^{780} A(\lambda)\bar{M}(\lambda)d\lambda;$$

$$S = \int_{380}^{780} A(\lambda)\bar{S}(\lambda)d\lambda$$

$$R_{VIS} = \sqrt{\Delta L^2 + \Delta M^2 + \Delta S^2}, \quad (22)$$

where MXYZ and MLMS are the conversion matrices between the color models for the above observer and illuminance. The conversion from XYZ to LMS color model is according to [CIE_2006]. A(λ) is a conversion matrix to reflectance spectra in the visible region, for the above observer and illuminance. The matrices are available in (Mather, 2010).The reflection range (RR) in the spectral characteristics is calculated by the formula:

$$R_R = R_{max} - R_{min}, \quad (23)$$

where R_{max} is the maximum reflectance of the spectral characteristics; R_{min} is the minimum reflectance value of the spectral characteristics.***Spectral indices***. Calculated according to Atanassova et al. (2019). These indices reflect changes in the red, green, blue and orange colors of the sample. Also photochemical processes, as well as statistical dependences between them, which is determined by excess, normalization, average value. These indices are calculated from the reflectance values in the VIS range of the spectrum (380–780 nm). They have the form:

A method for reducing the volume of data in a feature vector. Principal component analysis (PCA) (Mladenov, 2020) creates an orthogonal coordinate system, where depending on the variance in the original data, the axes are ordered according to the corresponding principal component and variances in the original data. If the covariance matrix is diagonal, the variables are independent and in this case

$$SI_1 = \frac{R_{740}}{R_{720}} \tag{24}$$

$$SI_2 = \frac{R_{530} - R_{570}}{R_{530} + R_{570}} \tag{25}$$

$$SI_3 = \frac{1}{R_{510}} - \frac{1}{R_{550}} \tag{26}$$

$$SI_4 = 0.5(120(R_{750} - R_{550}) - 200(R_{670} - R_{550})) \tag{27}$$

$$SI_5 = \frac{R_{550}}{R_{680}} \tag{28}$$

$$SI_6 = \frac{2R_{520} - R_{620} - R_{420}}{R_{520} + R_{620} + R_{420}} \tag{29}$$

$$SI_7 = \frac{R_{520} - R_{620}}{R_{520} + R_{620}} \tag{30}$$

$$SI_8 = \frac{{R_{520}}^2 - R_{620}R_{420}}{{R_{520}}^2 + R_{620}R_{420}} \tag{31}$$

$$SI_9 = \frac{2R_{520} - R_{620} - R_{420}}{2R_{520} + R_{620} + R_{420}} \tag{32}$$

$$SI_{10} = \frac{R_{520} - R_{620}}{R_{520} + R_{620} - R_{420}} \tag{33}$$

$$SI_{11} = 2R_{520} - R_{620} - R_{420} \tag{34}$$

the data can be visualized by their root mean square error by selecting those with the largest variance. If it is not diagonal, the matrix can be transformed to one containing its own vectors as the main diagonal. The PCA method was used to determine which bread characteristics were affected by the addition of black chokeberry flour. Table 6 presents the trait-quantity combinations of black chokeberry. Before processing with the PCA method, the data in the table were normalized to the interval [0;1].

Table 6. Feature (F)/ Black chokeberry (BC) combinations table

Feature / Black chokeberry, %	F1	F2	…	Fm
BC0	BC0F1	BC0F2	…	BC0Fm
BC2.5	BC2.5F1	BC2.5F2	…	BC2.5Fm
…	…	…	…	…
BC15	BC15F1	BC15F2	…	BC15Fm

A method for selection of informative features. A regression feature selection method by neighbor component analysis, FSRNCA [FSRNCA, 2022], was used. Through this method, the number of features describing the studied object is significantly reduced. Consistently improving scores are used to determine appropriate features. The weight coefficients of all compared features are determined by a basic algorithm that uses a diagonal adaptation of the neighbor component analysis (NCA) method. Important features are those with weight coefficient above 0.6. The method is suitable for distance-based models. More commonly used for feature selection for regression analysis.

Regression model. A regression model applied to the analysis of food products was used (Georgieva et al., 2020). It describes the relationship between and independent and dependent variables and has the form:

$$z = b_0 + b_1x + b_2y + b_3x^2 + b_{4x}y + b_5y^2, \tag{35}$$

where z is the dependent variable. The independent variables are x and y; the coefficients of the model are denoted b. The evaluation of the model is done, depending on the coefficient of determination (R2), the coefficients of the model, their standard error (SE), t-statistic (tStat), p-value, Fisher's criterion (F). An analysis of the residuals was performed. Each of the model coefficients was analyzed depending on the value of the p-level compared to the significance level α. Those coefficients where $p > \alpha$. The significance of the coefficients was determined according to the Student's test, and the adequacy – according to the Fisher test.***Determining the appropriate amount of additive***. A linear programming algorithm implemented by function linprog in Matlab environment was used to determine the appropriate amount of additive. In linear programming, one solves a problem related to finding a vector x such that the linear function fTx, with linear constraints:

$$\min f^T x \tag{36}$$

One of the conditions must be fulfilled:

$$Ax \le b \quad A_{eq}x = B_{eq} \quad l \le x \le u \tag{37}$$

An "interior-point-legacy algorithm" was used. The algorithm reaches a suitable solution by traversing the interior of the data region. The Matlab software system (The Mathworks Inc., Natick, MA, USA.) was used in the processing of the obtained data. All data were processed at a level of significance $\alpha = 0.05$.

Results and Discussion

Figure 1 shows the general appearance of the bread crust and the crumb of the control sample and those with the addition of black chokeberry fruit flour. When increasing the amount of black chokeberry flour, it is evident that both the color characteristics and the surface structure of the crumb of the bread change. Low levels (up to 2.5%) of the additive do not significantly affect changes in the appearance of the product. On the other hand, added above 5%, black chokeberry flour changes both the color of the crumb of the bread to a darker one, as well as a densification of the structure and a reduction in the size of the cavities. The porosity present is thick-walled and uneven.

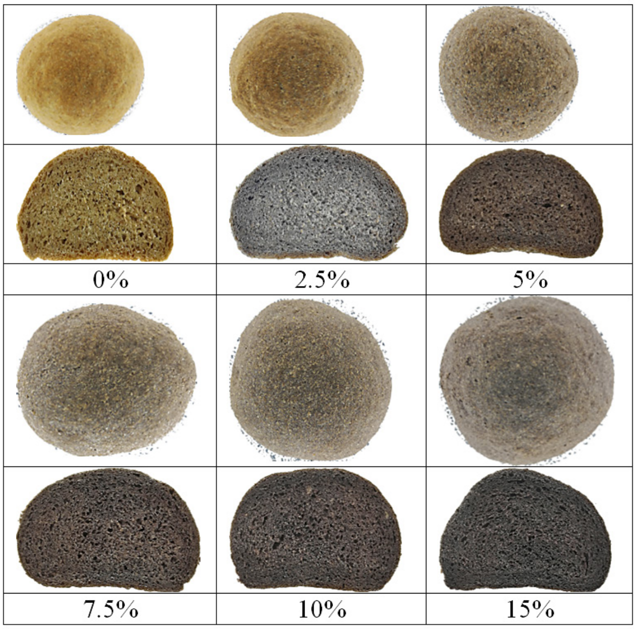

Fig. 1. Bread with addition of black chokeberry

Table 7 shows the measured values of the main characteristics of bread with the addition of black chokeberry. The increased value of the stretch coefficient, as well as the decrease in the bread volume values, is due to changes in the rheological properties of the unbaked and baked product. This is most likely due to the weakening influence of the insoluble dietary fiber introduced with black chokeberry flour on the rheological properties of the dough. A tendency to decrease the moisture content in the bread is clearly observed when the amount of black chokeberry is increased. The moisture content of the bread decreases because the higher amount of black chokeberry affects the moisture content of the total mixture of wheat flour and black chokeberry flour, which also affects the moisture content of the final baked product. As the amount of black chokeberry added increases, the pH and ORP values decrease. On the other hand EC and TDS are increasing their levels. According to the obtained results for oxidation-reduction potential, it can be considered that significant amounts of substances with reduction potential, introduced with the enriching raw material or obtained during the heat treatment, accumulate in the obtained product.

Table 8 shows the results of an organoleptic evaluation of bread with the addition of black chokeberry. The general appearance of the samples is preserved regardless of the amount of additive. In all other cases related to the evaluation of structure, chewiness, aroma and taste, a deterioration of the organoleptic characteristics was observed in the samples with 10 and 15% addition of black chokeberry.

Figure 2 shows the overall organoleptic evaluation (OA) of bread with the addition of black chokeberry. This assessment confirms the results of the organoleptic analysis. When increasing the quantity of the additive above 7.5%, the organoleptic characteristics of the bread begin to deteriorate significantly compared to the previous samples.

Table 7. Main characteristics of bread with addition of black chokeberry. The values are significantly different at $p < 0.05$

BC, % / Characteristic	0	2.5	5	7.5	10	15
H, mm	48±1	58.33±1.53	57±1	56±1	54±1	51.33±0.58
D, mm	118±1	105±1	107.67±1.53	109.33±1.15	109.33±2.08	110.33±3.06
H/D	0.41	0.56	0.53	0.51	0.49	0.47
V, mm^3	442±8.49	418±2.83	407.5±10.61	406.5±2.12	405±7.07	400±2.83
MC, %	45.76±0.06	44.37±0.07	44.64±0.04	44.6±0.46	45.74±0.05	45.86±0.07
pH	6.73±0.15	6.57±0.15	6.47±0.06	6.3±0.1	6.23±0.06	6±0.1
EC, µS/cm	876.67±20.82	1191±10.54	1528.33±9.02	1573.33±21.39	1599.33±19.6	1687.67±18.93
TDS, ppm	301±8	385±10.58	530.33±3.51	516.67±17.9	529.67±13.65	504±3.61
ORP, mV	231.67±10.07	116.33±5.69	102.67±2.08	100.67±2.52	108±3.61	99±3.61
TA, °N	3.73±0.12	5.13±0.12	5.93±0.12	6.53±0.12	7.53±0.12	8.33±0.12

Table 8. Results from organoleptic assessment of bread with addition of black chokeberry (BC). The values are significantly different at p<0.05

Characteristic / BC, %	Appearance	Structure	Chewness	Flavour	Taste
0	4.08±0.92	4.05±0.95	4.98±0.32	4±1	4.96±0.96
2.5	4.1±0.9	4.06±0.94	4.99±0.91	4.03±0.97	4.06±0.94
5	4.12±0.88	4.07±0.93	4.1±0.9	4.06±0.94	4.09±0.91
7.5	4.13±0.87	4.08±0.92	4.11±0.89	3.09±0.91	4.11±0.89
10	4.15±0.85	3.1±0.9	4.12±0.88	4.12±0.88	3.13±0.87
15	4.17±0.83	2.11±0.89	2.13±0.87	2.15±0.85	3.15±0.85

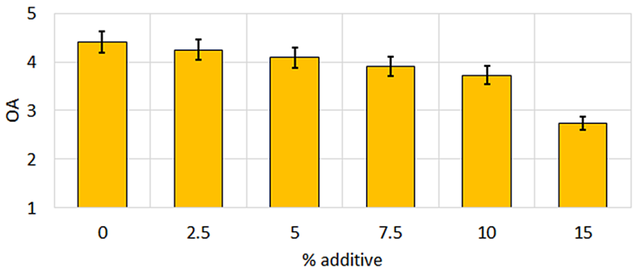

Fig. 2. Overall evaluation (OA) of bread with addition of black chokeberry. The values are significantly different at p < 0.05

Table 9 shows the values normalized in the interval [0;1] of the characteristics that are most affected by the change in the content of black chokeberry flour in bread. Since the number of rows is 14 and that of columns is 6, the data can be reduced to 13 principal components in rows and 5 in columns. The number of components required was determined under the condition that the sum of the principal components should describe more than 95% of the variance in the data.

Figure 3 shows the results of a PCA analysis of the influence of the amount of black chokeberry addition on the technological characteristics of bread. Three principal components are used. As observed from the graph they describe over 95% of the variance in the data. It can be seen that there is an equal influence on the characteristics of the bread, at all amounts of the additive. It is clearly distinguished that changing the amount of additive has a significant effect on the volume (V) and the redox potential (ORP). The least impact, the change in the amount of additive, has on the TDS.

Table 10 shows the values of the color components from the Lab model. As the amount of black chokeberry supplementation increases, the L-component values decrease. Which shows that the color of the bread is getting darker. A smaller reduction in L was observed in the crust of the bread, and in the crumb, the reduction in L values was significantly greater. The values of the a-component decrease, both in the crust and

Table 9. Normed value of bread characteristics with addition of black chokeberry flour (BC)

BC, % / Characteristic	0	2.5	5	7.5	10	15
H	0.05	0.05	0.04	0.04	0.03	0.03
D	0.13	0.09	0.07	0.07	0.07	0.07
H/D	0.00	0.00	0.00	0.00	0.00	0.00
V	0.50	0.35	0.27	0.26	0.25	0.24
MC	0.05	0.04	0.03	0.03	0.03	0.03
pH	0.01	0.01	0.00	0.00	0.00	0.00
EC	1.00	1.00	1.00	1.00	1.00	1.00
TDS	0.34	0.32	0.35	0.33	0.33	0.30
ORP	0.26	0.10	0.07	0.06	0.07	0.06
TA	0.00	0.00	0.00	0.00	0.00	0.00
OA	0.00	0.00	0.00	0.00	0.00	0.00
L	0.06	0.04	0.03	0.03	0.02	0.02
a	0.01	0.00	0.00	0.00	0.00	0.00
b	0.04	0.02	0.01	0.01	0.01	0.00

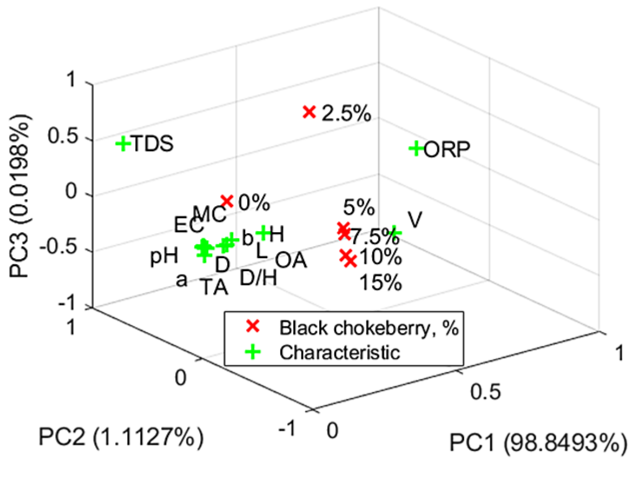

Fig. 3. PCA of data from bread with black chokeberry flour

Table 10. Lab values of crumb and crust of the bread with addition of black chokeberry (BC). The values are significantly different at $p < 0.05$

Part of bread	Crumb			Crust		
Lab / BC, %	L	a	b	L	a	b
0	53.55±8.6	6.25±2.86	36.7±2.72	40.45±3.95	1.64±1.54	25.65±2.03
2.5	44.01±9.3	4.76±1.53	25.06±3.37	46.15±4.01	-0.39±0.28	1.72±0.67
5	42.05±8.36	2.43±0.76	15.01±1.77	19.17±2.57	2.58±0.59	5.93±1.06
7.5	42.06±8.95	1.14±0.65	11.9±1.55	17.31±2.14	1.73±0.62	3.79±0.91
10	38.75±8.7	1.14±0.5	10.14±1.79	16.52±2.11	1.3±0.6	2.63±0.64
15	39.32±8.73	1.16±0.88	7.28±1.82	13.58±1.84	0.23±0.5	1.47±0.29

in the crumb of the bread. In the crumb, the values of this color component are lower, compared to those of the crust. This a-component changes from high values to lower values of red, at the crust, while at the crumb it goes from red to a red-green color direction. The values of the b-component are also in the direction of decrease, with increasing amount of black chokeberry supplement. As in the other cases, the values of this color component are higher in the bread crust than in the crumb. This component changes in the direction from a lighter yellow to a darker yellow color. The processes of melanoid formation, non-enzymatic browning and caramelization that occur during baking of the product also have an additional influence on the color characteristics of the baked bread.

Figure 4 shows a graph of the Lab components. In the crust, the values of the components are close but separable, especially for the control sample and those with up to 5% black chokeberry flour. The values change mainly along the vertical axis, in the direction from b = 30 to the origin of the coordinate system. In the color components of the crumb of the bread, the control sample and the one with 2.5% black chokeberry flour were highly distinguishable from the other samples. As the amount of additive increases, the color components visibly overlap, indicating that they are close to each other. Moreover, when increasing the amount of black chokeberry flour, the values of the color components are at their low levels, close to the origin of the coordinate system.

Figure 5 shows the color difference ΔE between the control sample and those with different percentages of black chokeberry supplement. As the additive amount increases,

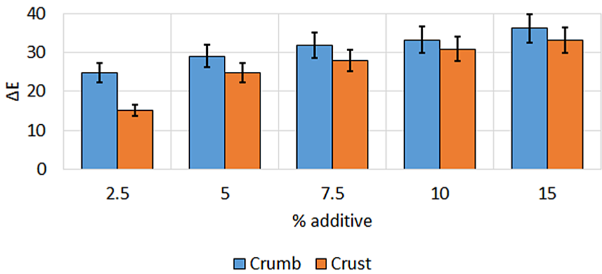

Fig. 5. Color difference ΔE. The values are significantly different at $p < 0.05$

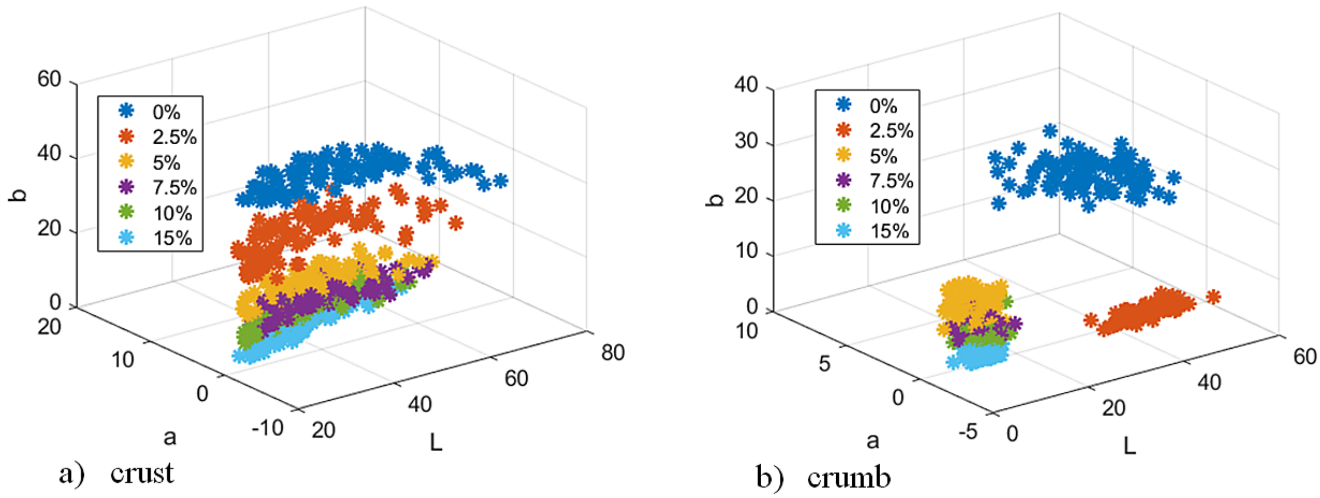

Fig. 4. Lab color components chart according to the addition of black chokeberry in bread

Table 11. Color indices (cix) values of bread crumb with addition of black chokeberry (BC). The values are significantly different at $p < 0.05$

cix \ BC, %	0	2.5	5	7.5	10	15
ci1	40.45±3.95	46.15±4.01	19.17±2.57	17.31±2.14	16.52±2.11	13.58±1.84
ci2	1.81±1.34	0.41±0.26	2.58±0.59	1.73±0.62	1.3±0.6	0.41±0.36
ci3	25.65±2.03	1.72±0.67	5.93±1.06	3.79±0.91	2.63±0.64	1.47±0.29
ci4	5.22±0.23	1.11±0.31	2.9±0.26	2.33±0.3	1.97±0.27	1.28±0.26
ci5	1.5±0.05	0±0	1.16±0.07	1.15±0.11	1.12±0.16	1.31±0.21
ci6	91.14±8.26	5.27±1.91	44.41±7.09	31.22±6.26	22.8±4.64	15.66±3.29
ci7	35.06±3.37	46.12±4	18.9±2.52	17.2±2.11	16.46±2.09	13.56±1.84
ci8	63.08±19.03	88.94±10.57	24.32±3.47	23.98±3.37	23.97±3.34	22.32±3.13
ci9	25.75±2	1.78±0.67	6.48±1.13	4.19±1.01	2.98±0.75	1.56±0.33
ci10	3.95±0.35	0±0	8.23±1.09	9.23±1.14	9.82±1.2	12.36±1.84
ci11	18.06±14.46	0±0	93.65±21.17	85.24±24.8	78.33±30.15	45.32±36.18
ci12	0.07±0.05	0±0	0.44±0.08	0.46±0.13	0.49±0.2	0.28±0.24
ci13	0.12±0.09	0±0	0.57±0.11	0.56±0.16	0.57±0.24	0.31±0.26
ci14	14.8±3.47	44.43±3.77	13.24±2.2	13.53±1.82	13.88±1.84	12.11±1.78
ci15	1.58±0.15	0±0	3.3±0.57	4.77±0.99	6.54±1.41	9.64±2.64
ci16	46.04±37.3	0±0	128.6±32.46	94.83±33.5	74.62±34.61	28.64±24.38

the color difference values increase. This difference is greater in the crust of the bread and slightly smaller than that in the crumb of the bread. The larger difference in the color difference in the crust of the bread is due to the changes that occur during baking.

Since the characteristics of the bread crumb change significantly from those of the crust, they are considered in the rest of the work. Table 11 shows the calculated values of the color indices of the crumb of the bread. The color index corresponding to the L-component (Lab) shows a significant variation, depending on the content of black chokeberry flour in bread. It is followed by the C and h-components (LCh). The indices of white and brown ci6 and ci7 also show a similar trend. It is necessary to make a selection of informative color indices by which to determine which of them are suitable in determining the appropriate amount of black chokeberry flour in bread.

Figure 6 shows the spectral characteristics of the crust of bread with the addition of black chokeberry flour. It can be seen that in the control sample, the reflectance values change

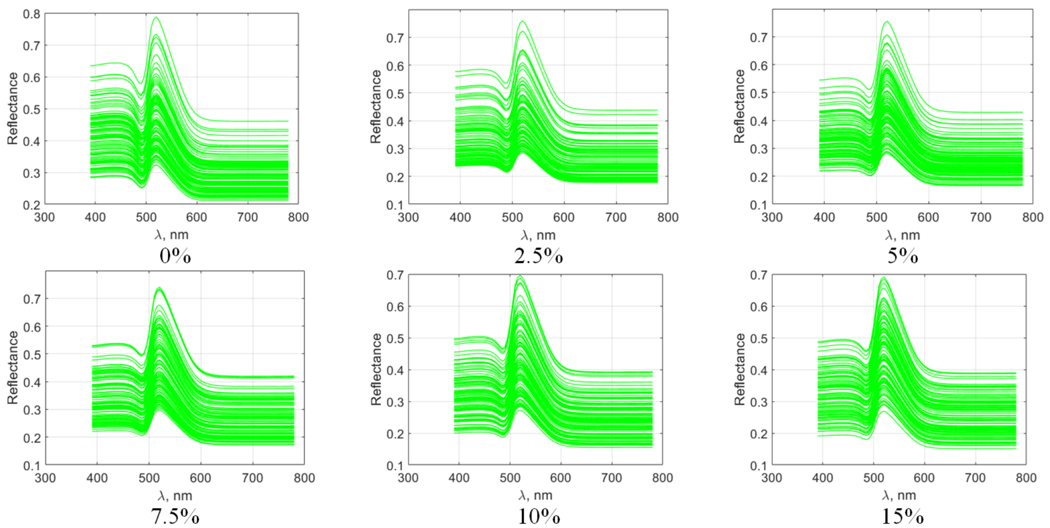

Fig. 6. Spectral characteristics of bread crust with addition of black chokeberry

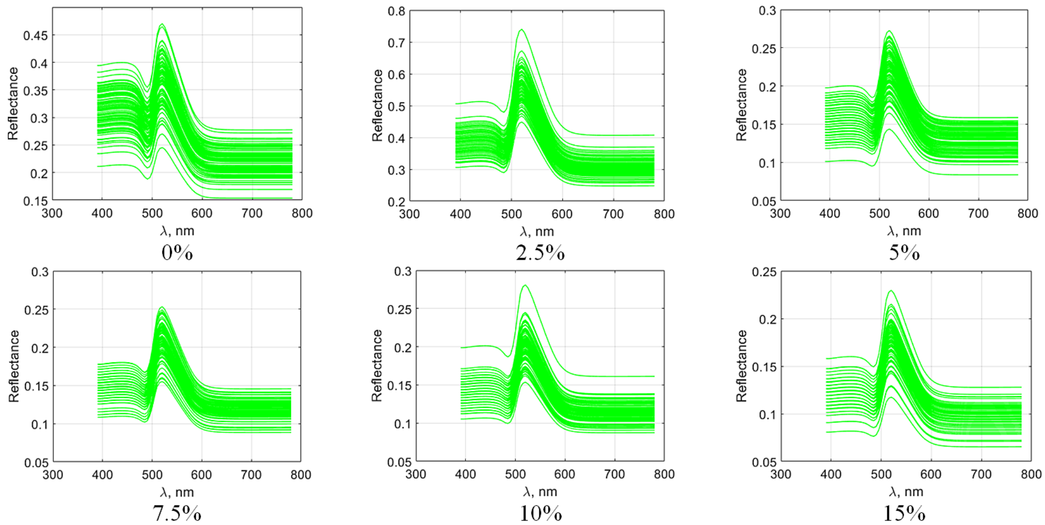

Fig. 7. Spectral characteristics of bread crumb with addition of black chokeberry

over a wider range, compared to the samples with additive. As the amount of additive increases, the range of change in the bread crust reflectance values also narrows. The processes of melanoid formation, non-enzymatic browning and caramelization that occur during baking of the product also have an additional influence on the spectral characteristics of the baked bread crust.

Figure 7 shows the spectral characteristics of the crumb of a bread with the addition of black chokeberry flour. The change in spectral characteristics is similar to that of the crust, but here it is more clearly observed. Increasing the amount of the additive leads to a decrease in the reflectance values and the spectral characteristics change within narrower limits, compared to the control sample.

Figure 8 shows the range of reflectance variation in the spectral characteristics for the crust and crumb of bread with black chokeberry flour supplementation. The ranges of variation in the crumb are wider, due to the direct influence of the

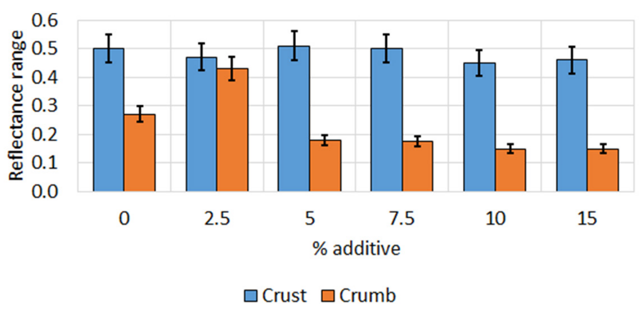

Fig. 8. Reflectance range (RR) of spectral characteristics of bread with addition of black chokeberry. The values are significantly different at $p < 0.05$

baking process and obtaining areas of different reflectance. The crumb is more homogeneous and, accordingly, the variation in the spectral characteristics is in a narrower range, compared to the crust of the bread. Increasing the amount of black chokeberry flour, also reduces the range of variation of the spectral characteristics to a narrower one. This is seen in both the crust and the crumb of the bread. More significantly this change is seen in the crumb of the bread.

Since the characteristics of the bread crumb change significantly from those of the crust, they are considered in the rest of the work. Table 12 shows the calculated values of the spectral indices of the middle of the bread. The red indices and the photochemical index (SI1 and SI2) did not show a significant change when the amount of black chokeberry flour was changed. The orange SI3 index shows that it is affected by changing the amount of chokeberry in the bread. It is necessary to make a selection of informative spectral indices, by which to find out which of them are suitable in determining the appropriate amount of black chokeberry flour in bread.

Figure 9 shows the results of a selection of informative features. FSRNCA method was used for their selection. These features change depending on the amount of chokeberry in the bread. Those of them that have weight coefficients with a value above 0.6 have been selected.

The number of color indexes is the largest. Nine of them have been selected. After them are the organoleptic and physicochemical characteristics, a total of six are selected. The number of spectral indices is the smallest. Only three of them are selected. The resulting vector of informative features has the form:

Table 12. Spectral indices (SIx) values of crumb of the bread crumb with addition of black chokeberry (BC). The values are significantly different at p<0.05

SIx \ BC, %	0	2.5	5	7.5	10	15
SI1	0.93±0	0.92±0	0.92±0	0.92±0	0.92±0	0.92±0
SI2	0.03±0	0.03±0	0.03±0	0.03±0	0.03±0	0.03±0
SI3	0.09±0.01	0.06±0.01	0.17±0.02	0.18±0.02	0.18±0.02	0.21±0.02
SI4	6.91±0.99	14.96±1.33	5.51±0.66	5.35±0.55	5.33±0.56	4.62±0.53
SI5	0.9±0.02	0.72±0	0.75±0.01	0.74±0.01	0.73±0.01	0.73±0.01
SI6	0.01±0.01	0.08±0	0.07±0	0.07±0	0.08±0	0.08±0
SI7	0.01±0.01	0.12±0	0.1±0.01	0.11±0	0.11±0	0.11±0
SI8	0.01±0.01	0.11±0	0.1±0.01	0.1±0	0.11±0	0.11±0
SI9	0.01±0.01	0.11±0	0.1±0.01	0.1±0	0.11±0	0.11±0
SI10	0.03±0.02	0.21±0	0.18±0.01	0.19±0.01	0.2±0.01	0.2±0.01
SI11	0.01±0.01	0.1±0.01	0.03±0	0.03±0	0.04±0	0.03±0

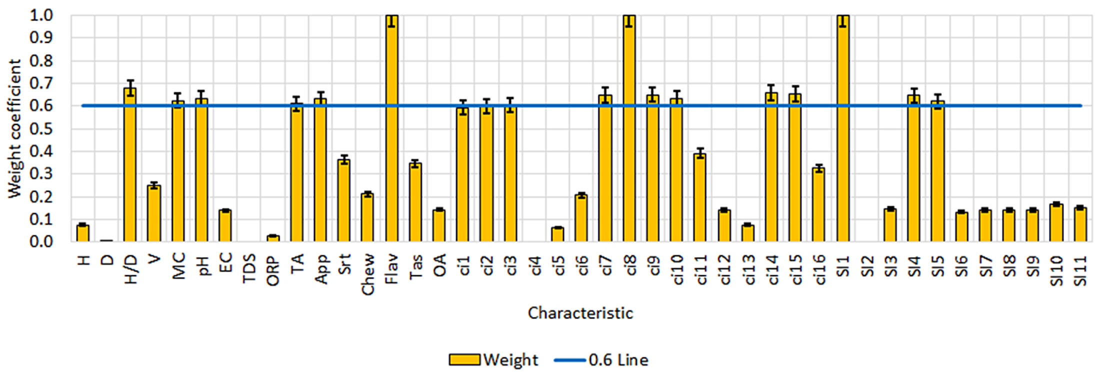

Fig. 9. Results from feature selection. The values are significantly different at p < 0.05

$$FV = [H/D\ MC\ pH\ TA\ Appearance\ Flavor\ ci1\ ci2\ ci3\ ci7\ ci8\ ci9\ ci10\ ci14\ ci15\ SI1\ SI4\ SI5] \quad (38)$$

Figure 10 shows a general view of the obtained model. The two principal components to which the feature vector was reduced together explained over 95% of the variance in the data. The values for the first principal component influence more than 70%, in determining the permissible amount of black chokeberry flour in bread. The obtained value of the coefficient of determination is R2 = 0.83. The standard error value is 1.43. Degrees of freedom DF = (4, 593), F = 699.88 >> Fcr = 2.39 and $p < 0.00$ were determined. It follows that the obtained model describes the experimental data with sufficient accuracy. The resulting appropriate value of the amount of black chokeberry flour is plotted. Analysis of the residuals showed that they were located close to a normal distribution. It can be considered that the prerequisites of the regression analysis are fulfilled. From the calculations and analysis by linpprog function in Matlab program environment, it was found that 8.62% of black chokeberry flour added to bread is acceptable to consumers and does not significantly change the physicochemical, geometrical, spectral and color characteristics of bread.

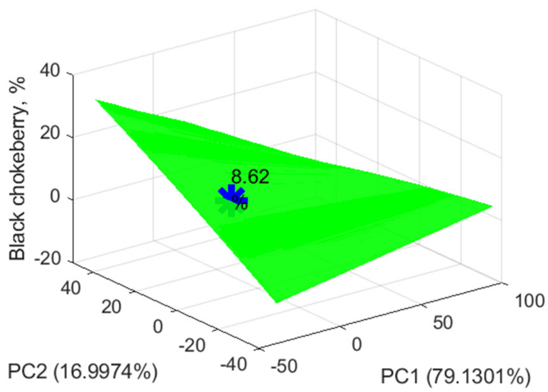

Fig. 10. Determining the appropriate amount of black chokeberry flour in bread

In the present work, the data on the influence of black chokeberry flour on the main characteristics of bread have been updated and supplemented. Catana et al. (2018) used white wheat flour for their bread. This results in significant changes in the L (Lab) color component and significant differences in the appearance of the resulting bread compared to the control sample. The whole wheat flour used in this work is not affected to such a great extent by the coloring obtained from the additive and accordingly chokeberry flour can be added in a higher percentage amount, which on the other hand leads to a more complete utilization of the waste raw materials in food production.

The results of Petković et al. (2019), are supplemented. The authors recommend the use of 10% whole dried black chokeberry fruit flour. An advantage of the results obtained here is that flour is used, which is a waste product from food production. Also, the appropriate amount of this supplement is more precisely determined.

Petković et al. (2020), used a PCA method to analyze the influence of black chokeberry flour on the main characteristics of bread. In the present work, these results are enriched by computer-based statistical methods being used in the selection of bread characteristics that are significantly affected by the amount of black chokeberry flour addition. Also, data processing and analysis methods were used in constructing a regression model by which the appropriate amount of this supplement was determined.

The established acceptable level of black chokeberry flour in bread of 8.62% is at the upper levels of the 5-10% range indicated in the available literature. For the studied bread, the results are close to those reported by Filipović et al. (2021), who recommend incorporating 10% black chokeberry flour into bread.

Conclusion

In the present work, using appropriate computer-based statistical methods, the appropriate amount of black chokeberry flour in bread was determined.

It has been established that the amount of black chokeberry flour added to bread has a significant effect on the color characteristics, followed by the physico-chemical and organoleptic characteristics, and to a lesser extent on the spectral characteristics of the bread.

An analysis was made of a total of 43 characteristics describing the change in the physico-chemical, geometric, organoleptic and optical properties of bread with the addition of black chokeberry. It was found that only 18 of them were informative. Shape stability, dry matter content, active and titratable acidity, general appearance and aroma, as well as 9 color and 3 spectral indices have been shown to adequately reflect changes in bread, depending on the amount of black chokeberry flour added.

The specific interrelation between the data reduced to two principal components of the created vector of 18 features was investigated. It was found that this relationship could be described with an accuracy of up to 83%.

As a result of the analysis of the influence of the amount of black chokeberry flour on the main characteristics of bread from whole grain wheat flour type 1850. It was found that the addition of 8.62% raw material of black chokeberry flour improves the physico-chemical, organoleptic and optical bread characteristics.

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