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Research article

Rheological and fermentation properties of doughs and quality of breads from colored wheat varieties

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A R T I C L E I N F O

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A B S T R A C T

The objective of this study was to examine the rheological and fermentation behavior of doughs prepared from five different colored wheat varieties (black AF Zora, yellow KM 111-18, purple AF Jumiko, blue AF Oxana and red Vanessa – chosen as a standard), which contain polyphenolics in the outer layers of grains. Three wholemeal flour fractions (fine, semi-coarse and coarse) were used for each variety. The flour fractions differed in the particle size of the bran, the ash content and thus the phenolic compound content. The baking trials, texture and sensory analyses of breads were performed, to assess their overall acceptability.

The coarser granulation of flour fractions, average hardness (8.5<12.6<20.2 N) and chewiness (584<796<1053 N) of breads increased, while other parameters: springiness (90>87>77%), cohesiveness (78>75>70%) and resilience (35>32>27%) decreased. Moreover, the increase in off-flavors was detected with higher bran content. Regarding the flour granulation, the fine fraction seemed to be the most suitable due to its high gas-retention capacity. The best products in terms of both dough and bread quality reached blue AF Oxana and yellow KM 111-18.

Utilization of colored wheat in bakery industry may present a good strategy of providing value-added products to the consumers.

1. Introduction

Ever since popularity of functional foods has started growing, manufacturers and scientists throughout many fields have been searching for the new materials, that could have been used in their production. One of the possible ingredients, which presents great potential as a component for food production is colored wheat. This is mainly due to the increased nutritional value brought by the presence of anthocyanin dyes, carotenoids and other phytochemicals, which occur naturally in the outer layers of grains, and their antioxidant, anti-inflammatory, anticarcinogenic and antidiabetic effects [1–5].

Therefore, the possible utilization of these specific varieties in the food industry has been examined for more than two decades. While some research groups focused on traditional bread-making [1,6,7], others tested the production of another common foods, for

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Abbreviations and legends

TAC	total anthocyanin content
WA	water absorption
DDT	dough development time
ST	dough stability
DS	degree of softening
C2	lowest torque value
C3	local maximum of torque during heating
C4	local minimum of torque during heating
C5	highest torque value (at the end of the test)
α	slope of mixolab curve between the end of the period of 30 °C and C2
β	slope of mixolab curve between C2 and C3
γ	slope of mixolab curve between C3 and C4
Hm	maximum dough height
h	ough height at the end of the measurement
(Hm-h)/Hm	decline in dough development
T1	time until the curve reached the maximum
H'm	height of maximum gas formation during leavening
T'1	time of maximum gas formation
Tx	time when gas was released from the dough
Vt	total gas volume
Vr	retention gas volume
Vc	released carbon dioxide volume
Vr/Vt	gas retention coefficient

example muffins, chapatti, soy sauce, vinegar, breakfast cereals, noodles, pasta and vermicelli, beer, wheatgrass juices or biscuits [1,8–16]. Some even suggested the separation of anthocyanins and their use as a natural dye in the food industry [4,17].

Nevertheless, most of the studies have focused especially on the use of colored wheat bran and its addition to the foodstuff (including bakery products) instead of using the colored wheat flour [7,18]. This is consistent with the fact that phenolic compounds, possessing previously mentioned significant nutritional value are primarily present in outer layers of grains, i.e. in the bran [2,5]. Besides, bran itself represents a very important source of dietary fiber and other nutrients. Therefore, provides many health benefits, for example reduced risk of gastro-intestinal cancers [5,19]. However, a major part of the research papers is focused on one color exclusively and do not compare the different colored wheat properties among themselves [20–22].

As bread is an example of a daily-consumed staple food worldwide, our research focused on the examination of technological properties of doughs and breads. Initially, grains of colored-wheat varieties (black AF Zora, yellow KM 111-18, purple AF Jumiko, blue

Fig. 1. Grains of colored wheat varieties (A) AF Oxana – blue; (B) AF Jumiko – purple; (C) AF Zora – black; (D) Vanessa – red (as a standard); (E) KM 111-18 – yellow. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 1
Material characterization of colored wheat grain samples.

Variety	Color	Situation of dyes	Origin	Company/Institution	Country	Note	Year
AF Zora	Black	Aleurone, Pericarp	(Skorpion x Bohemia) x (Indigo x Bohemia)	Agrotest Fyto, Ltd Kroměříž	Czech Republic	Registered	2021
KM 111-18	Yellow	Endosperm	Citrus x Bona Vita	Justus-Liebig-University in Giessen, ISTROPOL Solary a.s.	Germany, Slovakia	Registration terminated (susceptibility to lodging)	2018/2019
Vanessa	Red	/	SG-S2040-97 x Rhapsody	SELGEN a.s.	Czech Republic	Registered	2013
AF Jumiko	Purple	Pericarp	ANK-285A x Meritto	Agrotest Fyto, Ltd Kroměříž	Czech Republic	Registered	2018
AF Oxana	Blue	Aleurone	RU 440-6 x Ludwig	Agrotest Fyto, Ltd Kroměříž	Czech Republic	Registered	2019

AF Oxana and red Vanessa – as a standard) were milled to three fractions of wholemeal flour. Then, differences between dough rheological behaviors were observed, and breads were baked and evaluated.

Thus, the main aim of this research was to investigate the effect of colorants on the technological quality of flours milled from colored wheat grains. The specific objective was to assess the utilization of these unique varieties in the bakery industry as sources of new ingredients providing interesting alternatives for both functional-foods producers and consumers.

2. Material and methods

The five different wheat varieties used for this study were sourced in Czech Republic.

2.1. Material characterization

Five winter wheat varieties (*Triticum aestivum* L.) of different grain colors were examined in this study (Fig. 1 (A – E)). Characterization of varieties was summarized in Table 1.

The standard grain color is considered to be the red color, which occurs in the vast majority of commonly grown wheat varieties. Therefore, the Vanessa variety is used as a control variety in this experiment. The grains of the samples used were obtained from the 2019 harvest.

2.1.1. Flour samples' preparation

Samples of colored wheat grains were sorted to remove foreign bodies before milling. Wholemeal flour was prepared using the laboratory mill LM 3100 (Perten Instruments AB, Hägersten, Sweden). The milling process adopted in this study was described in standard ISO 3093:2009 [24]. Grains of each variety were ground to a homogenous flour and sieved by the vibratory sieve shaker Analysette 3 PRO (Fritsch GmbH, Idar-Oberstein, Germany), which was equipped by the sieves of the following sizes: 485 μm, 366 μm and 257 μm. The three flour fractions were obtained and labelled as fine (drop through the 257-μm sieve), semi-coarse (particles smaller than 366-μm) and coarse (fall through the 485-μm sieve).

2.2. Total anthocyanin content (TAC) determination

Samples of colored wheat grains (4 g) were ground in a laboratory mill Analysette 3 SPARTAN (Fritsch GmbH, Idar-Oberstein, Germany) approximately for 5 min each. Extraction of anthocyanins was accomplished according to Varga et al. (2013) in duplicate as follows. Ground samples (3 g) were extracted with 24 mL of methanol:1 M hydrochloric acid (85:15, v/v) on a vertical shaker for 3 h. The pH of the suspensions was adjusted if necessary. The mixtures were centrifuged (10000 rpm, 4 °C, 15 min) and crude extracts were diluted 10 times with pH 1.0 buffer (potassium chloride, 0.025 M) and 4.5 buffer (sodium acetate, 0.4 M). The extracts were filtered using 0.2 mm filters. The spectrophotometer Sunrise (Tecan Group Ltd., Männedorf, Switzerland) was used to measure the absorbance at 520 nm against distilled water as blank in the obtained filtrates. Values of TAC were calculated and expressed as cyanidin-3-glucoside equivalents (mg/kg) [23].

2.3. Chemical compositions' determination

The chemical compositions were determined according to the relevant ISO standard, namely moisture content 712 (ISO, 2010), ash content 2171 (ISO, 2007), crude fat content 11085 (ISO, 2015), nitrogen content and crude protein content 20483 (ISO, 2013), wet gluten amount 21415 (ISO, 2007), Hagberg falling number 3093 (ISO, 2009) and Zeleny sedimentation volume 5529 (ISO, 2011) [24–30]. The Hagberg falling number is a parameter defined as a total time, necessary for a viscometer stirrer to fall through an aqueous gel, which was prepared from heating a flour and water suspension in a viscometer tube under defined conditions. During the measurement, the gel is liquified by the activity of α-amylase enzyme. The falling number is expressed in seconds [29]. The Zeleny sedimentation volume measurement is based on the swelling ability of wheat proteins in a solution of lactic acid and propan-2-ol in the presence of bromophenol blue dye. After a procedure of defined periods of shaking and resting in the graduated cylinder with a cap, the sediment volume is read and expressed in mL [30].

2.4. Rheological determination of doughs

The properties of the doughs were evaluated using Mixolab 2 device (Chopin Technologies, Villeneuve-la-Garenne, France). During the experiment each dough was prepared from flour samples and an appropriate amount of demineralized water to obtain optimal consistency of 1.10 ± 0.05 N m. Its behavior was observed during simultaneous mixing and heating. To characterize rheological properties, two protocols were used. The Chopin S protocol was performed to simulate the farinographic measurement at stable temperature of 30 °C, and the Chopin + protocol allowed to determine dough behavior during the mixing and a defined cycle of heating and cooling [31,32].

2.4.1. Farinographic measurement

The results were evaluated from the dependency curves of torque (N·m) over time (min). Farinographic measurements at the constant temperature provided parameters of water absorption (WA, %), dough development time (DDT, min), dough stability (ST, min) and degree of softening (DS, FU). Water absorption is defined as water addition necessary to obtain a dough of the optimal consistency. The dough development is generally measured as the time required to reach the maximum torque of 1.1 N m from the beginning of the experiment. Dough stability is evaluated as a difference in min between the time at which the top of the curve reaches the 1.1 N·m line and the time at which the top of the curve falls below the 1.1 N·m line. The degree of softening means the difference in torque between the maximum reached and the value measured 12 min after achieving it, expressed in farinographic units.

2.4.2. Mixolab mode

Determination of rheological behavior as a function of mixing and temperature increase was done as described in standard ISO 17718:2013 [31].

The measurement in the mixolabic mode brought about the values of C2–C5 (N·m) and parameters α, β, γ (N·m/min), which can be used to depict protein denaturation, starch gelatinization and amylase activity of the dough:

C2 – lowest torque value, describes protein weakening during mixing and temperature increase;

C3 – local maximum of torque during heating, expresses the starch gelatinization;

C4 – local minimum torque during heating, indicates the stability of the starch gel;

C5 – highest torque value (at the end of the test), measures the starch retrogradation during the cooling phase;

α – slope of mixolab curve between the end of the period of 30 °C and C2, infers about the rate of the proteins denaturation and dough thermal weakening;

β – slope of mixolab curve between C2 and C3, suggests the gelatinization rate;

γ – slope of mixolab curve between C3 and C4, indicates about the rate of enzymatic hydrolysis [32].

2.5. Gas production and retention ability of doughs

Dough development and ability to retain gas during leavening was recorded using rheofermentometer RheoF4 (Chopin Technologies, Villeneuve-la-Garenne, France). Unlike the rest of the methods used, the measurement was not governed by any international standard, so we followed the basic instructions provided by the device manufacturer.

The dough was prepared from flour (250 g, considering the moisture content of the sample), dried yeast (3 g), salt (5 g) and water. To produce the best results, the amount of water added was calculated according to water absorption value, which was obtained from the farinographic measurement. The amount of water was in the range of 135–170 mL. After weighing and mixing of dry ingredients, water was added slowly, the dough was formed and kneaded for 6 min using the food processor (Eta Gratus Original, Czech Republic). Then, 315 g of compact smooth dough was inserted into the test bowl, loaded with a piston and 2 kg weight, and sealed into the rheofermentometer.

The Chopin + protocol was chosen to display the dough behavior over time, with the preset measurement conditions (temperature 28.5 ± 0.2 °C and 3-h of time). The device logged two curves, the first graph describing the development of the dough-height (mm) versus time (min). The second graph showed the volume of produced and trapped leavening gas (mL) over time (min). The values resulting from the curves were used to evaluate dough stability, ability to retain the fermentation gas.

2.6. Bread-baking procedure and volume measurement

The standard ICC 131:1980 was used to evaluate baking properties of the flour samples. The doughs were prepared from flour, water, reactivated dry yeast, salt, sucrose and malt flour. Then, doughs were divided in 3 pieces of equal weight, rested 30 min, molded, proofed 50 min in the proofing chamber (30 °C, 85% RH) and baked (230 °C, 20 min). Volume, texture and sensory analyses were performed the following day [33].

The volume of the loaves was measured according to the standard AACC Method 10–05.01:1998. The principle of the method is based on the displacement of rapeseed by the bread. Volume of displaced rapeseed represents the volume of the bread and was measured using a 500 mL graduated cylinder [34].

2.7. Texture analysis

The bread crumb characteristics were analyzed on the round samples of size 45 mm in diameter and 10 mm height, cut from the center of each loaf by hand using the stainless-steel cutter. These samples were covered with plastic foil before the texture analysis to prevent fast drying. The compression test was then performed using a texture analyzer TA. XT plus (Stable Micro Systems Ltd., Godalming, United Kingdom) through a 75.0 mm diameter cylinder probe P/75. Device settings were as follows: pre-test speed 1.00 mm s-1, test speed 5.00 mm s-1, post-test speed 5.00 mm s-1, strain required to compress the bread slice to 60% of the initial height, trigger force 5.0 g. Finally, the texture parameters: crumb hardness, springiness, cohesiveness, resilience and chewiness were determined by Exponent Lite software [35]. The results were assessed as an average of up to 14 values.

2.8. Sensory analysis

The sensory evaluation of colored breads was performed in accordance with The IFST Guidelines for Ethical and Professional Practices for the Sensory Analysis of Foods, The Code of Ethics of the World Medical Association (Declaration of Helsinki) and Callejo, M. J. (2011) [36–38] by a trained panel of 10 members (the department staff and students). Both males and females between the ages of 19–55 were included and all the panelists were thoroughly informed, healthy and without a medical history or known allergies to the breads' ingredients. They were given the Terms of Informed Consent to sign. An unstructured 10-cm long scale was used to evaluate the characteristics of bread crumb and crust, such as shininess, color, uniformity, flavor, and aftertaste intensity etc. [36–38]. The results were calculated as an average of 10 evaluation marks.

2.9. Statistical analysis

The values obtained from the determination of flours' chemical composition, doughs' rheological determination and behavior during proofing and bread-baking were calculated as an average of triplicate.

The results were statistically evaluated using the method of analysis of variance (ANOVA). The differences were tested at the significance level $\alpha = 0.01$ and 0.05 by Fisher LSD test. Then, Tukey HSD test was performed to investigate the effect of variables on rheological and textural properties at the level of significance $\alpha = 0.05$. In addition, the correlation between dough parameters and bread quality attributes was expressed by Pearson correlation coefficients at the $\alpha = 0.05$ significance level. The data was analyzed with Statistica 13 software [39].

The TAC were evaluated using Microsoft Excel software and statistical differences were tested by one-way ANOVA and F-test at the level of significance $\alpha = 0.05$.

Ethical statement: This study does not involve any animal testing. Informed Consent from the trained sensory panelists was received and the organoleptic evaluation was performed according to The Code of Ethics of the World Medical Association (Declaration of Helsinki) and The IFST Guidelines for Ethical and Professional Practices for the Sensory Analysis of Foods.

3. Results and discussion

Basic characterization of colored wheat flour samples can be found in Table 2. As can be seen from the results, an increase of ash content could be observed in coarser fractions.

3.1. Total anthocyanin content in grains (cyanidin 3-glucoside (mg/kg))

The results of total anthocyanin content (TAC) were calculated from equations and expressed as cyanidin-3-glucoside (mg/kg), as given in research of Varga et al. [23]. The total anthocyanin contents decreased in the order AF Zora (black; 43.75 ± 0.24 mg/kg) > AF Oxana (blue; 18.12 ± 0.23 mg/kg) > AF Jumiko (purple; 11.17 ± 0.18 mg/kg) > KM 111-18 (yellow; 3.86 ± 0.18 mg/kg) > Vanessa (red; 3.04 ± 0.26 mg/kg). The highest anthocyanin content was obtained in black wheat while the red (standard) wheat had the lowest anthocyanin content.

Varga et al. examined different varieties of purple and blue wheat varieties in their study and measured up to 304.6 mg/kg of TAC. They also state, that the TAC values are affected by many factors, such as variety, year of harvest and environmental factors, e.g., soil and weather conditions, fertilization and more [23].

3.2. Rheological behavior of the dough during mixing and heating

3.2.1. Farinograph

As can be seen in Table 3, colored wheats showed higher water absorption compared to the standard Vanessa variety. Specifically, the coarse fraction of the black variety AF Zora had the highest value (68.60%), while the fine fraction of the red variety Vanessa (55.80%). An increase of absorption ability was measured amongst the three fractions, from fine to coarse.

Table 2
Basic characterization of colored wheat flour samples.

Variety	Granulation	Ash [%]	Crude fat [%]	Crude protein [%]	Wet gluten [%]	Hagberg falling number [s]	Zeleny sedimentation volume [ml]
AF Zora/Black	fine	0.68	1.48	15.90	41.75	427	21
	semi-coarse	1.13	1.71	16.33	39.99	405	30
	coarse	1.75	1.93	15.78	34.94	351	38
KM 111-18/ Yellow	fine	0.57	1.55	15.05	33.57	440	<10
	semi-coarse	0.74	1.86	15.61	40.06	433	<10
	coarse	1.43	2.33	15.38	32.95	386	<10
Vanessa/Red	fine	0.80	2.13	11.06	21.00	328	<10
	semi-coarse	1.03	2.21	12.33	23.90	312	<10
	coarse	1.16	2.43	12.00	19.84	291	<10
AF Jumiko/ Purple	fine	0.77	1.64	15.72	34.24	529	<10
	semi-coarse	1.13	1.64	14.07	30.73	501	<10
	coarse	1.37	1.81	13.80	30.65	436	<10
AF Oxana/Blue	fine	0.53	1.47	16.71	41.17	590	22
	semi-coarse	0.74	1.50	15.33	38.05	603	12
	coarse	1.51	1.72	14.91	36.17	489	14

The purple variety AF Jumiko, had the dough development time increased with coarser granulation as follows: 3.2 min; 5.0 min and 19.3 min. In comparison to the purple variety, the blue variety AF Oxana decreased with increase in particle sizes. However, there were no significant differences found between the results of black AF Zora and red Vanessa flour fractions. The highest value of dough development time (DDT) was obtained for the semi-coarse fraction of yellow variety KM 111-18 (25 min). According to the study of Boita et al. (2016), the greater mixing time to achieve maximum consistency is required for the whole grain flours when compared to refined wheat flour. This effect is attributed to the interaction which occurs between fibers and gluten which prevents hydration of proteins [40].

With the exception of the purple variety AF Jumiko, an increase of dough stability (ST) was observed across the fractions for the individual colored-wheat varieties. While the fine fractions of black AF Zora, yellow KM 111-18 and red Vanessa showed stability shorter than 10 min, the values of their semi-coarse fraction fell within the range of 9–31 min. The highest dough stability was measured for the coarse fractions of black AF Zora, yellow KM 111-18, purple AF Jumiko and blue AF Oxana (45–57 min), except the red Vanessa, that had dough stability of 26.6 min. A value decrease of degree of softening (DS) could be observed amongst the fractions of most of colored varieties, except yellow KM 111-18. The results suggest that wheat bran makes the dough more resistant to over-kneading. It is in agreement with findings of Boita et al. who also observed a decrease of ST and an increase of mixing tolerance with the increased amount of bran [40].

The WA and DDT might be influenced by the nature and amount of grain outer layers in the samples, because these parameters are affected by many factors such as protein and starch properties, the amount of damaged starch, bran, fiber and arabinoxylan content and particle size of the flour sample [19,41,42].

The dough stability parameter (ST) is a time range, when the torque exhibits 1.1 N m and is particularly dependent on gluten quality and its tolerance to mixing and kneading. Both ST and DS are also affected by various factors such as wheat variety, agro-ecological conditions during wheat growing, protease activity, milling conditions etc. [41]. The decrease of the DS values also might suggest that bran addition provided increased resistance against over-kneading to the doughs.

The results suggested that there was no significant difference in the behavior of colored wheat dough compared to the conventional red wheat variety, thus, anthocyanin dyes do not affect the rheological properties of doughs. Also, no statistically significant interaction of variables was found in the results.

3.2.2. Mixolab

The results showed (see Table 4) that fine fractions of the black AF Zora, yellow KM 111-18 and purple AF Jumiko varieties exhibited lower C2 values compared to semi-coarse and coarse fractions. The red Vanessa semi-coarse fraction showed lower C2 than fine fraction, the blue AF Oxana had the lowest C2 torque followed by a coarse fraction, but there were no significant differences found between the data of this variety. The lowest C2 was measured for the fine fraction of black AF Zora (0.455 N m), the highest value was obtained for the coarse fraction of purple AF Jumiko (0.790 N m). Therefore, the amount, character, and particle size of bran in the samples could affect the protein denaturation, which is in agreement with Bressiani et al. (2019) who stated that the torque decline is induced by an increase in temperature and caused by protein denaturation [43].

The highest values of C3 were obtained in the fine and semi-coarse fraction of yellow wheat KM 111-18 (4.14 N m), and the lowest torque was measured in the coarse fraction of black AF Zora (1.91 N m). There were no differences among the flour fractions and the varieties. The C3 point represents the curve's maximum consistency after reaching 90 °C and describes the starch gelatinization. Dough behavior at this point is dependent on starch amount and quality. The swelling of starch is particularly dependent on the water availability in the dough, which is in agreement with Bressiani et al. [43].

The highest torque, C4 was obtained for semi-coarse fraction of yellow KM 111-18 (3.4 N m), meanwhile, the coarse fraction of blue AF Oxana, had the lowest value (1.67 N m). There were no significant differences observed among the fractions which could refer to

Table 3
Farinographic measurement.

Variety	Granulation	WA [%]	DDT [min]	ST [min]	DS [FU]
AF Zora/Black	fine	60.67 ± 0.06^{g}	3.8 ± 0.5^{a}	8 ± 1^{a}	66 ± 11^{g}
	semi-coarse	62.70 ± 0.10^{j}	3.0 ± 2.0^{a}	16 ± 13^{ab}	46 ± 9^{def}
	coarse	68.60 ± 0.10^{m}	3.0 ± 2.0^{a}	47 ± 4^{de}	26 ± 2^{bc}
KM 111-18/Yellow	fine	56.15 ± 0.07^{b}	2.8 ± 0.8^{a}	7 ± 1^{a}	52 ± 9^{ef}
	semi-coarse	57.55 ± 0.07^{d}	25.0 ± 4.0^{e}	31 ± 4^{bcd}	54 ± 3^{fg}
	coarse	62.65 ± 0.07^{j}	15 ± 13^{cd}	57 ± 5^{e}	38 ± 7^{cde}
Vanessa/Red	fine	55.80 ± 0.30^{a}	2.3 ± 0.4^{a}	6.95 ± 0.1^{a}	51 ± 10^{def}
	semi-coarse	57.15 ± 0.07^{c}	1.0 ± 0.1^{a}	9 ± 1^{a}	38 ± 5^{cde}
	coarse	61.10 ± 0.01^{h}	1.00 ± 0.01^{a}	27 ± 1^{b}	9 ± 1^{a}
AF Jumiko/Purple	fine	59.75 ± 0.07^{f}	3.2 ± 0.3^{a}	44 ± 20^{cde}	46 ± 3^{def}
	semi-coarse	61.65 ± 0.07^{i}	5.0 ± 1.0^{ab}	51 ± 2^{e}	36 ± 1^{cd}
	coarse	64.75 ± 0.07^{k}	19.3 ± 0.2^{de}	44 ± 2^{cde}	13 ± 1^{ab}
AF Oxana/Blue	fine	58.15 ± 0.07^{e}	17.8 ± 0.2^{cde}	19 ± 13^{ab}	38 ± 1^{cde}
	semi-coarse	59.90 ± 0.01^{f}	11.0 ± 1.0^{bc}	29 ± 1^{bc}	25 ± 14^{bc}
	coarse	67.20 ± 0.01^{l}	6.9 ± 0.5^{ab}	45 ± 4^{cde}	18 ± 2^{ab}

Values of water absorption (WA), dough development time (DDT), dough stability (ST) and degree of softening (DS) of three flour fractions of five colored wheat varieties. The mean values ± standard deviation ($n = 3$) in one column followed by various letters differ significantly ($P < 0.01$).

Table 4
Mixolab mode.

Variety	Granulation	C2 [N·m]	C3 [N·m]	C4 [N·m]	C5 [N·m]	α [N·m/min]	β [N·m/min]	γ [N·m/min]
AF Zora/Black	fine	0.455 ± 0.006^{a}	3.40 ± 0.10^{cde}	2.09 ± 0.05^{abc}	3.40 ± 0.10^{de}	−0.100 ± 0.020^{ab}	0.03 ± 0.02^{a}	0.100 ± 0.030^{cde}
	semi-coarse	0.494 ± 0.002^{b}	2.90 ± 0.70^{bc}	2.00 ± 0.04^{abc}	3.21 ± 0.08^{cd}	−0.097 ± 0.003^{ab}	0.10 ± 0.10^{ab}	0.400 ± 0.100^{abcde}
	coarse	0.536 ± 0.006^{c}	1.91 ± 0.01^{a}	1.73 ± 0.05^{ab}	2.70 ± 0.10^{b}	−0.107 ± 0.001^{a}	0.34 ± 0.04^{abc}	−0.051 ± 0.001^{a}
KM 111-18/ Yellow	fine	0.600 ± 0.040^{d}	4.14 ± 0.01^{e}	2.58 ± 0.01^{d}	4.04 ± 0.02^{h}	−0.076 ± 0.003^{bcd}	0.05 ± 0.01^{ab}	0.084 ± 0.008^{bcde}
	semi-coarse	0.708 ± 0.004^{g}	4.10 ± 0.10^{e}	3.40 ± 0.90^{e}	4.00 ± 0.10^{h}	−0.040 ± 0.030^{efg}	0.045 ± 0.03^{ab}	0.400 ± 0.100^{abcde}
	coarse	0.721 ± 0.002^{g}	2.80 ± 0.50^{abc}	2.40 ± 0.08^{cd}	3.02 ± 0.07^{c}	−0.030 ± 0.010^{fg}	0.20 ± 0.30^{abc}	−0.010 ± 0.040^{ab}
Vanessa/Red	fine	0.554 ± 0.001^{c}	2.32 ± 0.01^{ab}	2.22 ± 0.02^{cd}	3.80 ± 0.10^{g}	−0.074 ± 0.003^{bcd}	0.43 ± 0.08^{bc}	−0.010 ± 0.020^{ab}
	semi-coarse	0.551 ± 0.004^{c}	2.27 ± 0.02^{ab}	2.14 ± 0.03^{abcd}	3.63 ± 0.07^{fg}	−0.085 ± 0.004^{abc}	0.05 ± 0.08^{c}	−0.010 ± 0.040^{ab}
	coarse	0.600 ± 0.020^{d}	2.20 ± 0.07^{ab}	1.93 ± 0.03^{abc}	3.32 ± 0.01^{de}	−0.080 ± 0.010^{abc}	0.60 ± 0.30^{c}	−0.050 ± 0.030^{a}
AF Jumiko/ Purple	fine	0.680 ± 0.020^{f}	3.00 ± 1.00^{bcd}	2.30 ± 0.20^{cd}	3.70 ± 0.10^{g}	−0.030 ± 0.010^{fg}	0.35 ± 0.47^{abc}	0.020 ± 0.100^{abcde}
	semi-coarse	0.727 ± 0.005^{g}	3.72 ± 0.09^{de}	2.36 ± 0.05^{cd}	3.64 ± 0.09^{fg}	−0.040 ± 0.010^{efg}	0.04 ± 0.03^{ab}	0.130 ± 0.030^{e}
	coarse	0.790 ± 0.030^{h}	3.46 ± 0.06^{cde}	2.37 ± 0.03^{cd}	3.38 ± 0.07^{de}	−0.020 ± 0.020^{g}	0.04 ± 0.04^{ab}	0.110 ± 0.006^{de}
AF Oxana/Blue	fine	0.638 ± 0.001^{e}	2.33 ± 0.01^{ab}	2.24 ± 0.03^{cd}	3.60 ± 0.10^{fg}	−0.060 ± 0.010^{cde}	0.32 ± 0.05^{abc}	−0.010 ± 0.030^{abc}
	semi-coarse	0.645 ± 0.007^{e}	2.26 ± 0.02^{ab}	2.16 ± 0.03^{bcd}	3.48 ± 0.09^{ef}	−0.050 ± 0.010^{def}	0.26 ± 0.05^{abc}	−0.003 ± 0.004^{abcd}
	coarse	0.633 ± 0.008^{e}	2.06 ± 0.04^{a}	1.67 ± 0.01^{a}	2.35 ± 0.01^{a}	−0.031 ± 0.004^{fg}	0.50 ± 0.50^{c}	−0.041 ± 0.001^{a}

Results of mixolabic measurement, points C2–C5 and the curve slopes α-γ of three flour fractions of five colored wheat varieties. The mean values ± standard deviation ($n = 3$) in one column followed by various letters differ significantly ($P < 0.01$).

any dependency. The local minimum C4 depicts the amylase activity of the sample by a decline of the torque at the constant temperature of 90 °C. The amylase activity of the flour samples depends on a variety, the particle size of a bran and outer layers, which are transferred to the dough through bran. For example, α-amylase from the pericarp could cause dough weakening [19]. Although, the amylase activity was not measured directly, a decline of Hagberg falling number was observed in our samples.

The values of C5 reached the previous torque similar to C3 (black AF Zora, yellow KM 111-18, purple AF Jumiko), or exceeded (red Vanessa, blue AF Oxana). Nevertheless, there was no tendency or trend of the fraction influence that could be deduced from the data. The C5 exhibits the local maximum torque caused by cooling down and the starch retrogradation [32].

Significant differences were found between the results of curve's slopes α, β and γ, but no trends were found that would allow conclusions to be drawn. In case of parameters C2 and C5, statistically significant interaction of variables was confirmed by the outputs of the Tukey HSD test.

According to the results, flours from colored wheats exhibits similar dough behavior during mixing and heating and are affected by the same factors as the red variety.

3.3. Dough development and gaseous release during fermentation

The parameters of dough height development depending on time can be found in the left side of Table 5.

Fine flour fractions had a higher maximum height than the semi-coarse and coarse fraction (see Fig. 2 (A – E). Furthermore, the highest value was measured for the yellow variety KM 111-18 (44 mm), while the lowest value was shown by the coarse fraction of red Vanessa (20.6 mm).

There were no significant differences between the values of h among the fractions of red Vanessa, purple AF Jumiko and blue AF Oxana, thus the bran in the samples probably did not influence their ability to maintain dough height. Fine fractions of black AF Zora and yellow KM 111-18 showed a more significant decline in dough development compared to the semi-coarse and coarse, which might have been linked with the bran incorporation.

There were no significant differences between the time until the curve reached the maximum (T1). This was probably due to the reproducible measurement conditions. The values fell within the range of 76–98 min. The T1 parameter is important from the point of view of the optimal timing of dough processing, so that it is neither under-proofed nor over-proofed prior baking.

The values which depict gas retention ability of the dough and can be seen on the right section of Table 5. The H'm values fell within the range 58–76 mm. Except the results of blue AF Oxana variety, the values of T′1 tended to rise among the flour fractions. This would mean that the fine fractions reached the maximum gas production sooner compared to the semi-coarse and coarse fractions. On the

Table 5
Gas production and retention ability of doughs.

Variety	Granulation	Dough development				Gaseous release						
		Hm [mm]	h [mm]	(Hm-h)/Hm [%]	T1 [min]	H'm [mm]	T'1 [min]	Tx [min]	Vt [mL]	Vr [mL]	Vc [mL]	Vr/Vt [%]
AF Zora/ Black	fine	36.0 ± 1.0^{g}	24.0 ± 3.0^{cd}	34 ± 8^{h}	76 ± 10^{a}	74 ± 4^{bc}	66 ± 2^{a}	58 ± 1^{ab}	1213 ± 37^{a}	1045 ± 39^{a}	169 ± 2^{a}	86 ± 1^{bc}
	semi-coarse	28.0 ± 0.2^{de}	21.0 ± 1.0^{b}	26 ± 3^{efgh}	86 ± 20^{a}	76 ± 4^{c}	74 ± 6^{ab}	53 ± 11^{ab}	1330 ± 20^{abc}	1101 ± 4^{ab}	230 ± 15^{ab}	83 ± 1^{ab}
	coarse	22.0 ± 1.0^{ab}	16.0 ± 1.0^{a}	28 ± 8^{fgh}	83 ± 20^{a}	72 ± 4^{bc}	83 ± 11^{ab}	49 ± 16^{a}	1384 ± 25^{abcd}	1127 ± 40^{abc}	258 ± 15^{ab}	81 ± 2^{ab}
KM 111-18/ Yellow	fine	44.0 ± 1.0^{h}	30.0 ± 2.0^{hi}	31 ± 3^{gh}	91 ± 4^{a}	76 ± 2^{c}	75 ± 1^{ab}	70 ± 4^{abc}	1433 ± 9^{bcd}	1183 ± 9^{bc}	250 ± 1^{ab}	82.6 ± 0.1^{ab}
	semi-coarse	38.0 ± 4.0^{g}	28.2 ± 0.3^{gh}	26 ± 7^{efgh}	92 ± 3^{a}	73 ± 7^{bc}	81 ± 8^{ab}	70 ± 9^{abc}	1472 ± 57^{cd}	1230 ± 48^{c}	242 ± 9^{ab}	83.6 ± 0.1^{abc}
	coarse	32.1 ± 0.1^{f}	25.6 ± 0.1^{def}	20 ± 1^{cdef}	98 ± 20^{a}	74 ± 3^{bc}	91 ± 1^{abc}	81 ± 2^{c}	1546 ± 71^{d}	1385 ± 163^{d}	161 ± 92^{a}	90 ± 6^{c}
Vanessa/ Red	fine	26.0 ± 1.0^{cd}	24.0 ± 2.0^{cd}	8 ± 2^{a}	87 ± 6^{a}	58 ± 1^{a}	97 ± 1^{bcd}	74 ± 10^{bc}	1269 ± 36^{ab}	1059 ± 6^{a}	210 ± 30^{ab}	84 ± 2^{abc}
	semi-coarse	23.0 ± 1.0^{abc}	20.8 ± 0.2^{b}	10 ± 2^{ab}	82 ± 4^{a}	63 ± 9^{ab}	$100 \pm 17b^{cd}$	66 ± 9^{abc}	1344 ± 130^{abc}	1095 ± 60^{ab}	250 ± 70^{ab}	82 ± 3^{ab}
	coarse	20.6 ± 0.1^{a}	19.0 ± 1.0^{b}	7 ± 4^{a}	97 ± 20^{a}	63 ± 6^{ab}	118 ± 15^{d}	73 ± 13^{bc}	1342 ± 136^{abc}	1089 ± 54^{ab}	253 ± 82^{ab}	81 ± 4^{ab}
AF Jumiko/ Purple	fine	30.0 ± 1.0^{ef}	27.0 ± 1.0^{efg}	13 ± 1^{abc}	90 ± 8^{a}	64 ± 6^{ab}	87 ± 25^{ab}	68 ± 16^{abc}	1409 ± 108^{bcd}	1121 ± 39^{abc}	289 ± 70^{b}	80 ± 3^{ab}
	semi-coarse	$28.1 \pm 0.4d^{e}$	24.4 ± 0.1^{de}	13 ± 1^{abc}	95 ± 20^{a}	65 ± 5^{abc}	92 ± 14^{bc}	71 ± 6^{bc}	1393 ± 105^{abcd}	1119 ± 42^{abc}	274 ± 62^{ab}	80 ± 3^{ab}
	coarse	24.0 ± 1.0^{bc}	21.6 ± 0.5^{bc}	9 ± 3^{a}	91 ± 4^{a}	65 ± 8^{abc}	115 ± 22^{cd}	71 ± 15^{bc}	1387 ± 166^{abcd}	1107 ± 67^{ab}	280 ± 99^{ab}	80 ± 5^{ab}
AF Oxana/ Blue	fine	39.0 ± 1.0^{g}	31.2 ± 0.3^{i}	19 ± 3^{bcde}	98 ± 11^{a}	65 ± 5^{abc}	92 ± 10^{bc}	85 ± 12^{c}	1366 ± 87^{abcd}	1136 ± 23^{abc}	230 ± 63^{ab}	83 ± 4^{abc}
	semi-coarse	33.0 ± 1.0^{f}	27.7 ± 0.1^{fgh}	15 ± 1^{abcd}	87 ± 6^{a}	69 ± 4^{abc}	84 ± 11^{ab}	71 ± 6^{bc}	1415 ± 39^{bcd}	1143 ± 6^{abc}	272 ± 32^{ab}	81 ± 2^{ab}
	coarse	26.0 ± 1.0^{cd}	20.0 ± 1.0^{b}	23 ± 7^{defg}	79 ± 8^{a}	72 ± 5^{bc}	94 ± 4^{bcd}	66 ± 6^{abc}	1470 ± 49^{cd}	1143 ± 8^{abc}	328 ± 42^{b}	78 ± 4^{a}

Dough development measurement characteristics: values of maximum dough height (Hm), dough height at the end of the measurement (h), decline in dough development ((Hm-h)/Hm), time until the curve reached the maximum (T1) and parameters of gaseous release during dough fermentation: height of maximum gas formation during leavening (H'm), time of maximum gas formation (T′1), time when gas was released from the dough (Tx), total gas volume (Vt), retention gas volume (Vr), released carbon dioxide volume (Vc) and retention coefficient (Vr/Vt) of three flour fractions of five colored wheat varieties. The mean values ($n = 3$) in one column followed by various letters differ significantly ($P < 0.01$).

other hand, the Tx values were not significantly different between the samples, thus the measurement conditions were reproducible, and the bran might not influence the gas release time.

Table 5 presents the results of Vt, Vr and Vc, which stand for total gas volume, retained gas volume, and released carbon dioxide volume, respectively. These values were used to calculate the retention coefficient (Vr/Vt), which described dough's ability to entrap the leavening gas. Meanwhile, there were no significant differences between the gas retention coefficients of the red variety Vanessa and purple AF Jumiko fractions, but a decrease in retention ability was observed for semi-coarse and coarse fractions of the black AF Zora and blue AF Oxana. Only the yellow KM 111-18 variety showed an increase of Vr/Vt among the fractions and the highest retention coefficient was measured for the coarse fraction (90%) compared to the other varieties.

Coarse fractions of purple AF Jumiko (80%) and red Vanessa (86%) possessed the lowest ability to retain gas.

The Hm is directly connected to a dough's final volume and its value can be either positively or negatively affected by the dough composition [44]. Along with the h parameter and the Tx, it might be related to the dough's gluten network character and strength and possibly the amount, character, and particle size of the bran, which might interfere with it [19]. However, h was mainly used to calculate the decline in dough development ((Hm-h)/Hm).

Singh, Singh Gujral and Singh in their paper state that H'm and the T′1 are mostly affected by the fermentation temperature and dough ingredients [44]. However, the basic dough was prepared without additional components like acids or fat, and the temperature was set to 28.5 ± 0.2 °C. Therefore, the parameter could be predominantly influenced by the yeast activity and nutrient availability [45]. There were significant differences between the flour fractions and wheat varieties. This showed that colored wheats had comparable proofing abilities to the red wheat and in some cases (for example Hm and Vr/Vt) even surpassed the standard red variety. In case of parameter Hm, statistically significant interaction of variables was revealed by the Tukey HSD test.

3.4. Bread texture and quality

The decrease of the loaf specific volume (LSV) was evident from the results (see Table 6) and was also supported by the data from

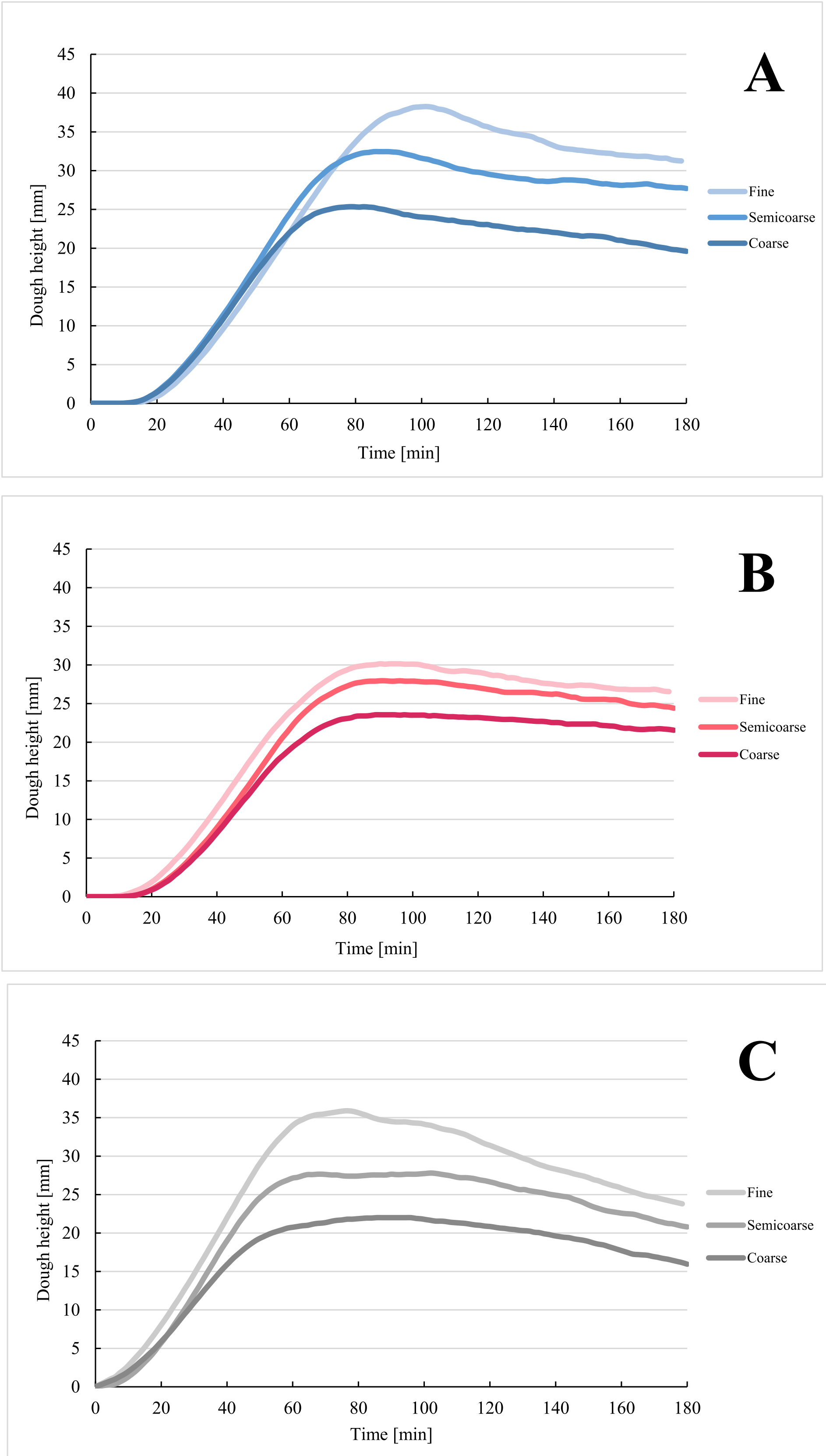
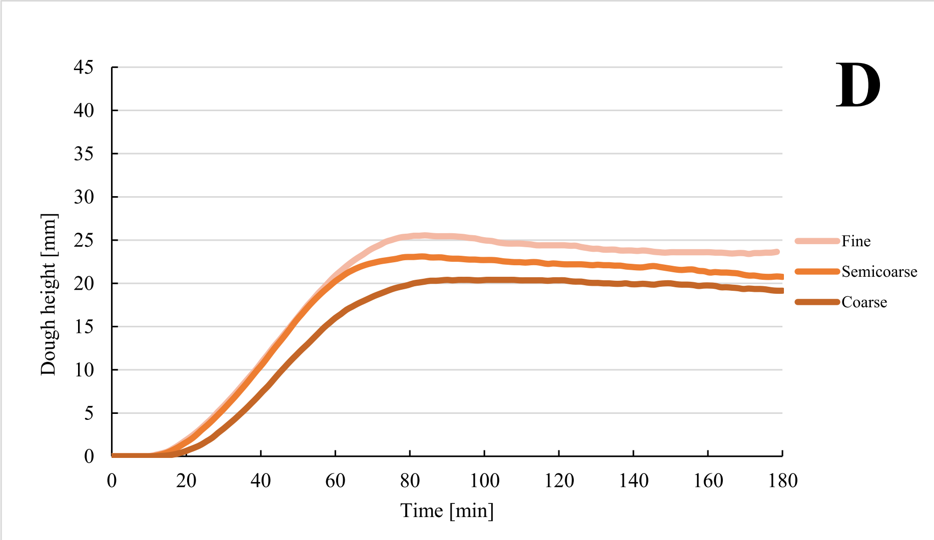


Fig. 2. Rheofermentograms of doughs (A) AF Oxana – blue; (B) AF Jumiko – purple; (C) AF Zora – black; (D) Vanessa – red (as a standard); (E) KM 111-18 – yellow. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)



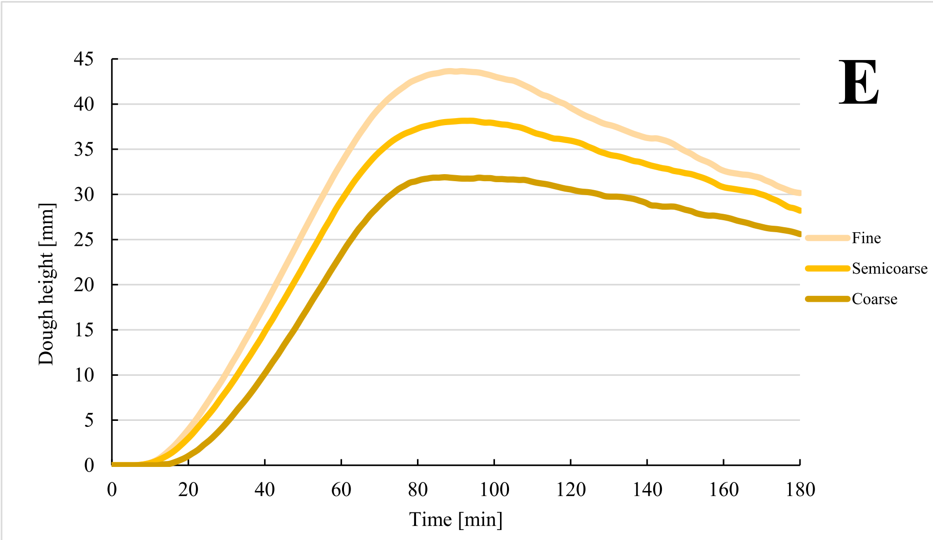


Fig. 2. (*continued*).

the rheofermentograms, where the coarse and semi-coarse fractions had lower dough volume; there was correlation between the maximum dough height H'm and the LSV (0.71). The LSV decline could be related to the water-binding capacity of the bran: the absorbed water that is not available to the starch and gluten network and the dough does not stretch properly nor retain the leavening gas. Or, the coarse bran could disrupt and pierce the doughs' structure and lower the gas retention capacity [19,40].

With the exception of the yellow KM 111-18 variety, a decrease of the baking loss could be observed among the fractions, which represented the amount of water evaporated from the dough during baking. Therefore, the water absorbed by bran could not be released from the product as steam. As in case of the loaf specific volume, this parameter is also associated with the presence, size, and water-binding capacity of the bran [19,40]. This relationship was also reflected in the correlation between ash content and baking losses (−0.78).

The lower the ability to retain the leavening gas the dough possessed, the less the proofing of the product and the harder the texture would be. In general, with the coarser granulation of flour fractions, average hardness (8.5 < 12.6<20.2 N) and chewiness (584 < 796<1053 N) of breads increased. On the other hand, springiness (90 > 87>77%), cohesiveness (78 > 75>70%) and resilience (35 > 32>27%) decreased. The worst textural properties had the bread from coarse fraction of black AF Zora and purple AF Jumiko. For example, the highest hardness was measured for the coarse fraction of black AF Zora (25 N) and semi-coarse and coarse fractions of purple AF Jumiko (24 N and 25 N respectively). The lowest springiness was had the coarse AF Zora (71.2%) and the highest chewiness was measured for the coarse AF Jumiko (1257 N).

In case of chewiness parameter, statistically significant interaction of variables was found by the Tukey HSD test. These findings are in accordance with the study of Boita et al. (2016) [40].

Table 6
Texture analysis of breads produced from three flour fractions of five colored wheat varieties.

Variety	Granulation	LSV [mL/g]	Baking loss [%]	Hardness [N]	Springiness [%]	Cohesiveness [%]	Resilience [%]	Chewiness [N]
AF Zora/Black	fine	2.8[de]	10.7[fg]	10[de]	89.4[e]	78.7[ef]	36.3[g]	678[d]
	semi-coarse	2.7[cd]	9.3[de]	13[f]	84.6[cd]	74.3[cd]	31.7[de]	835[e]
	coarse	2.1[a]	7.9[ab]	25[i]	71.2[a]	67.7[a]	25.5[a]	1188[fg]
KM 111-18/ Yellow	fine	3.8[h]	10.7[g]	4[a]	94.0[f]	82.0[g]	38.2[h]	304[a]
	semi-coarse	3.4[g]	11.1[gh]	8[c]	90.5[e]	77.2[e]	33.3[f]	522[c]
	coarse	2.6[cd]	8.2[abc]	19[g]	82.5[c]	71.7[b]	29.7[b]	1083[f]
Vanessa/Red	fine	2.8[de]	10.9[gh]	13[f]	85.4[d]	73.3[bcd]	30.7[bcd]	809[e]
	semi-coarse	2.8[def]	9.8[def]	12[f]	84.9[cd]	72.9[bc]	31.3[cde]	752[de]
	coarse	2.2[ab]	8.8[bcd]	23[h]	77.5[b]	67.0[a]	26.4[a]	1157[fg]
AF Jumiko/ Purple	fine	2.9[ef]	11.4[gh]	12[ef]	88.9[e]	75.1[d]	32.9[ef]	763[de]
	semi-coarse	2.5[bc]	9.8[e]	24[hi]	85.2[cd]	72.7[bc]	30.8[bcd]	1471[h]
	coarse	2.3[ab]	7,5[a]	25[hi]	75.2[b]	68.5[a]	25.7[a]	1257[g]
AF Oxana/Blue	fine	3.0[f]	11.5[h]	7[bc]	90.5[e]	79.5[f]	36.6[g]	500[c]
	semi-coarse	3.5[g]	9.2[cde]	5[ab]	89.6[e]	79.7[f]	35.7[g]	327[ab]
	coarse	3.3[g]	8.2[ab]	8[cd]	77.0[b]	72.9[bcd]	29.8[bc]	436[bc]

Loaf specific volume (LSV) was obtained by dividing bread volume by the bread weight. The mean values (n = 3–14) in one column followed by various letters differ significantly ($P < 0.05$).

3.5. Sensory analysis

As can be found in Table 7, the highest marks of color intensity were observed in the samples of black AF Zora, followed by purple AF Jumiko and blue AF Oxana, while the yellow KM 111-18 had the lowest score. Furthermore, an increase in color was observed within the fractions and the uniformity and shininess decreased. This was consistent with the idea that more dyes could be extracted from the coarse fractions due to the higher particle size of bran [1,5,10].

With the exception of the red Vanessa and purple AF Jumiko varieties, the fine fractions showed better texture and higher softness by the assessors. This finding was in agreement with the correlation between the maximum dough height H'm and the softness of the crumb (0.73), which proved that doughs with a lower amount of bran, and thus a higher gas retention capacity, were considered softer. The results of the sensory evaluation were consistent with the texture measurement.

Apart from the blue AF Oxana breads, the strong bitter aftertaste and off-flavors were observed in most breads with the higher amount of bran. Based on Hemdane et al. [19] suggestion in their study, this phenomenon might be caused by enzymes, which were present in the bran and might cause an unpleasant taste. According to the review of Dhua et al. [46], the bitter taste could also be attributed to proanthocyanidins synthesized from flavonoid biosynthetic pathway. The off-flavors would also affect the overall acceptability of the products. However, the highest ratings of overall acceptability were observed in blue AF Oxana semi-coarse (9.5) and yellow KM 111-18 semi-coarse (9.3) in contrary to the black AF Zora coarse, which had the lowest rating (4.2).

4. Conclusion

Black, purple, blue and yellow wheats presented considerable potential for the functional-foods processing industry. This study compared rheological properties of doughs prepared from various colored wheat varieties and described their behavior during fermentation. The influence of bran content and particle size on dough and bread properties were observed. The mechanism of bran incorporation into dough has not been fully described yet, its different impacts on dough rheological characteristics could be noticed. Neither bran nor anthocyanin dyes had a negative impact on rheological properties of doughs. The prolongation of the doughs' stability, resistance to overmixing and decrease in the degree of softening were noted.

On the other hand, the coarse bran negatively affected the ability to retain leavening gas, breads' texture, the sensory quality attributes and the overall acceptability of the products. The average hardness and chewiness of breads increased, while springiness, cohesiveness and resilience decreased with the coarser fractions. Moreover, some samples with higher bran content were observed to have a bitter aftertaste and a burnt off-flavor, namely black AF Zora and purple AF Jumiko. This indicates the possible limitation for use of colored wheat varieties in the bakery industry. In other words, suitable processing conditions have to be developed for the purpose of flour and bread preparation to prevent the presence of unpleasant flavor. Furthermore, in case of C2, C5, Hm and chewiness parameters, statistically significant interaction of variables was revealed by the outputs of the Tukey HSD test. Thus, explaining of the variables' interaction is our current aim of further research.

Regarding the doughs' and breads' qualities among the varieties, the best results were observed in yellow KM 111-18 and blue AF Oxana. However, the results of examined materials showed that colored wheat varieties possess good dough quality and high ability to retain leavening gas, which is essential, particularly in the bakery industry. For this purpose, the fine fractions were found to be the most appropriate in overall quality attributes. The possible utilization of semi-coarse and coarse fractions could be in the productions of foods that does not require ability to retain the largest possible amount of leavening gas, such as pasta, dumplings, crackers or cookies. Apart from the bakery industry, results can be useful also for the farmers and the policy makers to make an informed policy.

As the grain quality is strongly affected by the factors such as cultivation, harvest and weather conditions, the further research is

Table 7
Sensory analysis of breads baked from three flour fractions of five colored wheat varieties.

Variety/ color	Granulation	Crust					Crumb								Flavor		Odor		Overall acceptability
		Appearance			Texture		Appearance					Texture							
		Shininess	Color	Uniformity	Thickness	Texture	Shininess	Color	Bran size	Pores' size	Uniformity	Elasticity	Softness	Bran influence	Intensity	Aftertaste	Intensity	Burnt	
AF Zora/ Black	fine	4.4^{h}	7.7^{f}	5.7^{c}	5.0^{ab}	6.8^{f}	7.1^{ef}	8.8^{ef}	0.3^{a}	5.3^{cde}	5.3^{e}	5.9^{g}	7.0^{g}	9.3^{j}	5.9^{c}	5.9^{e}	9.5^{e}	0.2^{a}	8.1^{c}
	semi-coarse	1.4^{b}	8.6^{gh}	5.3^{b}	5.0^{ab}	5.2^{d}	5.0^{b}	9.3^{fg}	0.5^{a}	3.2^{abc}	4.5^{d}	4.7^{def}	6.3^{f}	5.1^{b}	4.1^{b}	6.5^{fg}	9.1^{de}	0.6^{ab}	6.0^{b}
	coarse	0.2^{a}	9.2^{i}	8.7^{hi}	5.1^{ab}	4.6^{bc}	3.2^{a}	9.8^{g}	0.7^{a}	1.5^{a}	4.0^{c}	3.7^{abc}	5.8^{ef}	3.2^{a}	3.0^{a}	7.6^{i}	9.1^{de}	0.8^{abc}	4.2^{a}
KM 111-18/ Yellow	fine	5.7^{h}	2.7^{a}	4.9^{b}	5.0^{ab}	6.8^{f}	7.5^{g}	1.5^{a}	0.3^{a}	5.8^{de}	5.8^{f}	5.5^{g}	7.9^{i}	9.4^{j}	6.0^{c}	5.6^{e}	9.5^{e}	0.2^{a}	9.2^{fg}
	semi-coarse	5.1^{j}	4.9^{b}	8.1^{efg}	5.1^{ab}	5.9^{e}	9.0^{i}	2.8^{b}	0.4^{a}	7.3^{e}	9.0^{i}	6.8^{h}	7.5^{hi}	8.7^{i}	8.0^{efg}	0.4^{a}	9.0^{de}	0.3^{a}	9.3^{fg}
	coarse	2.3^{c}	6.4^{e}	5.3^{b}	5.1^{ab}	4.3^{ab}	6.2^{c}	2.8^{b}	0.9^{a}	1.5^{a}	4.2^{cd}	3.9^{bcd}	5.3^{de}	6.0^{c}	5.2^{c}	7.3^{hi}	8.9^{de}	0.5^{a}	4.8^{a}
Vanessa/ Red	fine	3.2^{ef}	5.0^{bc}	7.9^{de}	5.0^{ab}	4.2^{ab}	7.9^{h}	4.0^{c}	0.2^{a}	4.0^{bcd}	9.1^{i}	3.1^{a}	5.0^{cd}	8.2^{gh}	6.9^{d}	3.8^{c}	8.0^{cde}	0.5^{a}	8.9^{ef}
	semi-coarse	2.8^{d}	5.5^{cd}	4.9^{b}	5.0^{ab}	7.0^{f}	7.4^{fg}	3.9^{c}	1.1_{ab}	5.0^{cd}	8.9^{i}	6.1^{gh}	5.1^{cd}	7.7^{ef}	8.3^{fg}	4.1^{c}	7.8^{bcde}	0.7^{ab}	8.3^{cd}
	coarse	2.3^{c}	5.9^{d}	9.2^{i}	5.2^{ab}	6.0^{e}	6.7^{d}	4.1^{c}	1.5^{ab}	5.4^{cde}	7.4^{g}	5.5^{fg}	4.5^{bc}	7.0^{d}	7.9^{efg}	6.1^{ef}	6.2^{ab}	1.4^{d}	6.0^{b}
AF Jumiko/ Purple	fine	4.7^{hi}	8.7^{hi}	3.7^{a}	5.1^{b}	4.2^{ab}	7.9^{h}	6.3^{d}	0.2^{a}	4.1^{bcd}	9.1^{i}	4.2^{cde}	4.2^{ab}	8.3^{gh}	5.6^{c}	6.5^{fg}	8.0^{cde}	0.3^{a}	8.9^{def}
	semi-coarse	3.0^{de}	8.1^{fg}	8.4^{fgh}	5.1^{b}	4.8^{cd}	8.0^{h}	8.1^{e}	0.5^{a}	2.9^{ab}	2.9^{b}	6.1^{g}	7.6^{hi}	8.6^{hi}	7.6^{def}	5.0^{d}	6.9^{bc}	1.3^{cd}	8.5^{cde}
	coarse	1.5^{b}	8.9^{hi}	8.5^{gh}	5.0^{ab}	4.0^{a}	5.0^{b}	9.0^{fg}	0.9^{a}	1.5^{a}	2.0^{a}	3.5^{ab}	3.9^{a}	5.0^{b}	3.6^{ab}	6.9^{gh}	4.4^{a}	1.5^{d}	6.0^{b}
AF Oxana/ Blue	fine	4.7^{ij}	7.7^{f}	7.7^{d}	4.9^{a}	4.0^{a}	7.9^{h}	5.7^{d}	0.2^{a}	4.2^{bcd}	9.0^{i}	5.4^{fg}	7.4^{gh}	8.7^{i}	7.3^{de}	3.9^{c}	8.2^{cde}	0.7^{ab}	9.1^{efg}
	semi-coarse	4.0^{g}	8.0^{f}	8.0^{def}	5.0^{ab}	6.0^{e}	7.5^{g}	6.0^{d}	0.5^{a}	9.5^{f}	9.5^{j}	8.0^{i}	7.5^{ghi}	8.0^{fg}	8.5^{g}	0.5^{a}	9.0^{de}	1.1^{bcd}	9.5^{g}
	coarse	3.5^{f}	8.5^{gh}	8.5^{gh}	5.0^{ab}	4.0^{a}	7.0^{de}	8.1^{e}	2.9^{b}	3.5^{bc}	8.5^{h}	4.8^{ef}	5.4^{de}	7.6^{e}	5.5^{c}	1.9^{b}	7.8^{bcd}	1.3^{cd}	8.6^{cde}

The mean values ± standard deviation ($n = 10$) in one column followed by various letters differ significantly ($P < 0.05$).

necessary to compare findings from this research with the results of yields of colored wheats from following years.

Author contribution statement

Romana Šebestíková: Performed the experiments; Analyzed and interpreted the data; Wrote the paper. Iva Burešová: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper. Tomáš Vyhnánek: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data. Petr Martinek: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper. Matej Pospiech: Contributed reagents, materials, analysis tools or data.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] T. Beta, W. Li, F.B. Apea-Bah, Flour and bread from black-, purple-, and blue-colored wheats, in: V.R. Preedy, R. Watson (Eds.), Flour and Breads and Their Fortification in Health and Disease Prevention, second ed., Elsevier, 2019 https://doi.org/10.1016/B978-0-12-814639-2.00006-X. (Accessed 11 February 2023).

[2] M. Garg, S. Kaur, A. Sharma, A. Kumari, V. Tiwari, S. Sharma, M. Krishania, Rising demand for healthy foods-anthocyanin biofortified rich colored wheat is a new research trend, Front. Nutr. 913 (2022), https://doi.org/10.3389/fnut.2022.878221.

[3] J. Lachman, P. Martinek, Z. Kotíková, M. Orsák, M. Šulc, Genetics and chemistry of pigments in wheat grain: a review, J. Cereal. Sci. 74 (2017) 145–154, https://doi.org/10.1016/j.jcs.2017.02.007.

[4] J. Shipp, E.-S.M. Abdel-Aal, Food applications and physiological effects of anthocyanins as functional food ingredients, Open Food Sci. J. 4 (2010) 7–22, https://doi.org/10.2174/1874256401004010007.

[5] W. Tian, Y. Zheng, W. Wang, D. Wang, M. Tilley, G. Zhang, Y. Li, A comprehensive review of wheat phytochemicals: from farm to fork and beyond, Compr. Rev. Food Sci. F. (2022), https://doi.org/10.1111/1541-4337.12960.

[6] J. Hernandez, L. Hřivna, V. Šottníkova, Y. Dostálová, L. Machálková, A. Ruban, H. Koubková, T. Vyhnánek, E. Mrkvicová, V. Trojan, I. Burešová, The use of color wheat spent grain as an ingredient for the production of bakery products, Conference paper MendelNet 2016 23 (2016) 571–576. Conference: International Ph. D. Students Conference At: At Fac Agron, Brno, Czech Republic Volume: 2 Available at: https://www.researchgate.net/publication/309772828_THE_USE_OF_COLOR_WHEAT_SPENT_GRAIN_AS_AN_INGREDIENT_FOR_THE_PRODUCTION_OF_BAKERY_PRODUCTS. (Accessed 11 February 2023).

[7] L. Hřivna, V. Zigmundová, I. Burešová, R. Maco, T. Vyhnánek, V. Trojan, Rheological properties of dough and baking quality of products using colored wheat, Plant Soil Environ. 64 (2018) 203–208, https://doi.org/10.17221/62/2018-PSE. (Accessed 11 February 2023).

[8] A. Kumari, S. Kaur, N. Sharma, J. Kaur, M. Krishania, V. Tiwari, M. Garg, Effect of processing on the phytochemicals and quality attributes of vermicelli developed from colored wheat, J. Cereal. Sci. 108 (2022), 103560, https://doi.org/10.1016/j.jcs.2022.103560.

[9] A. Kumari, S. Sharma, N. Sharma, V. Chunduri, P. Kapoor, S. Kaur, M. Garg, Influence of biofortified colored wheats (purple, blue, black) on physicochemical, antioxidant and sensory characteristics of chapatti (Indian flatbread), Molecules 25 (21) (2020) 5071, https://doi.org/10.3390/molecules25215071. (Accessed 11 February 2023).

[10] W. Li, T. Beta, Flour and bread from black-, purple-, and blue-colored wheats, in: Flour and Breads and Their Fortification in Health and Disease Prevention, Academic Press, 2011, pp. 59–67, https://doi.org/10.1016/B978-0-12-380886-8.10006-6. (Accessed 11 February 2023).

[11] Y. Li, D. Ma, D. Suna, Ch Wang, J. Zhang, Y. Xie, T. Guo, Total phenolic, flavonoid content, and antioxidant activity of flour, noodles, and steamed bread made from different colored wheat grains by three milling methods, Crop J 3 (2015) 328–334, https://doi.org/10.1016/j.cj.2015.04.004. (Accessed 11 February 2023).

[12] A. Pasqualone, A.M. Bianco, V.M. Paradiso, C. Summo, G. Gambacorta, F. Caponio, A. Blanco, Production and characterization of functional biscuits obtained from purple wheat, Food Chem. 180 (2015) 64–70, https://doi.org/10.1016/j.foodchem.2015.02.025.

[13] A. Sharma, M. Yadav, N. Sharma, A. Kumari, S. Kaur, M. Meenu, M. Garg, Comparison of wheatgrass juices from colored wheat (white, black, blue, and purple) for health promoting phytochemicals, Food Res. Int. 161 (2022), 111833, https://doi.org/10.1016/j.foodres.2022.111833.

[14] N. Sharma, A. Kumari, V. Chunduri, S. Kaur, J. Banda, A. Goyal, M. Garg, Anthocyanin biofortified black, blue and purple wheat exhibited lower amino acid cooking losses than white wheat, LWT–Food Sci. Technol. 154 (2022), 112802, https://doi.org/10.1016/j.lwt.2021.112802.

[15] N. Sharma, V. Tiwari, S. Vats, A. Kumari, V. Chunduri, S. Kaur, M. Garg, Evaluation of anthocyanin content, antioxidant potential and antimicrobial activity of black, purple and blue colored wheat flour and wheat-grass juice against common human pathogens, Molecules 25 (24) (2020) 5785.

[16] M. Zanoletti, P. Abbasi Parizad, V. Lavelli, C. Cecchini, P. Menesatti, A. Marti, M.A. Pagani, Debranning of purple wheat: recovery of anthocyanin-rich fractions and their use in pasta production, LWT–Food Sci. Technol. 75 (2017) 663–669, https://doi.org/10.1016/j.lwt.2016.10.016.

[17] E.-S.M. Abdel-Aal, P. Hucl, I. Rabalski, Compositional and antioxidant properties of anthocyanin-rich products prepared from purple wheat, Food Chem. 254 (2018) 13–19, https://doi.org/10.1016/j.foodchem.2018.01.170.

[18] Y. Seo, Y. Moon, M. Kweon, Effect of purple-colored wheat bran addition on quality and antioxidant property of bread and optimization of bread-making conditions, Appl. Sci. 11 (9) (2021) 4034, https://doi.org/10.3390/app11094034.

[19] S. Hemdane, P.J. Jacobs, E. Dornez, J. Verspreet, J.A. Delcour, ChM. Courtin, Wheat (Triticum aestivum L.) bran in bread making: a critical review, Compr. Rev. Food Sci. F. 15 (2016) 28–42, https://doi.org/10.1111/1541-4337.12176. (Accessed 11 February 2023).

[20] P. Bartl, A. Albreht, M. Skrt, B. Tremlová, M. Ošťádalová, K. Šmejkal, N.P. Ulrih, Anthocyanins in purple and blue wheat grains and in resulting bread: quantity, composition, and thermal stability, Int. J. Food Sci. Nutr. 66 (5) (2015) 514–519, https://doi.org/10.3109/09637486.2015.1056108.

[21] L. Yu, T. Beta, Identification and antioxidant properties of phenolic compounds during production of bread from purple wheat grains, Molecules 20 (9) (2015) 15525–15549, https://doi.org/10.3390/molecules200915525.

[22] M. Eliášová, Z. Kotíková, J. Lachman, M. Orsák, P. Martinek, Influence of baking on anthocyanin content in coloured-grain wheat bread, Plant Soil Environ. 66 (8) (2020) 381–386, https://doi.org/10.17221/210/2020-PSE.

[23] M. Varga, J. Bánhidy, L. Cseuz, J. Matuz, The anthocyanin content of blue and purple coloured wheat cultivars and their hybrid generations, Cereal Res. Commun. 41 (2) (2013) 284–292, https://doi.org/10.1556/crc.41.2013.2.10. (Accessed 11 February 2023).

[24] International Organization for Standardization, ISO/TC 34/SC 4. Wheat, rye and their flours, durum wheat and durum wheat semolina – Determination of the falling number according to Hagberg-Perten, ISO 3093, 2009. edt 4, 13 pgs.

[25] International Organization for Standardization, ISO/TC 34/SC 4. Cereals and Cereal Products – Determination of Moisture Content – Reference Method, ISO 712, 2010. edt 4, 16 pgs.

[26] International Organization for Standardization, ISO/TC 34/SC 4. Cereals, Pulses and By-Products – Determination of Ash Yield by Incineration, ISO 2171, 2010. edt 4, 11 pgs.

[27] International Organization for Standardization, ISO/TC 34/SC 4. Cereals, Cereals-Based Products and Animal Feeding Stuffs – Determination of Crude Fat and Total Fat Content by the Randall Extraction Method, ISO 11085, 2015. edt 2, 16 pgs.

[28] International Organization for Standardization, ISO/TC 34/SC 4. Cereals and Pulses – Determination of the Nitrogen Content and Calculation of the Crude Protein Content – Kjeldahl Method, ISO 20483, 2013. edt 2, 13 pgs.

[29] International Organization for Standardization, ISO/TC 34/SC 4. Wheat and Wheat Flour – Gluten Content – Part 1: Determination of Wet Gluten by a Manual Method, ISO 21415-1, 2006. edt 1, 9 pgs.

[30] International Organization for Standardization, ISO/TC 34/SC 4. Wheat – Determination of the Sedimentation Index – Zeleny Test, ISO 5529, 2007. edt 3, 12 pgs.

[31] International Organization for Standardization, ISO/TC 34/SC 4. Wholemeal and Flour from Wheat (Triticum aestivum L.) – Determination of Rheological Behavior as a Function of Mixing and Temperature Increase, ISO 17718, 2013. edt 1, 36 pgs.

[32] I. Banu, G. Stoenescu, V. Ionescu, I. Aprodu, Estimation of the baking quality of wheat flours based on rheological parameters of the mixolab curve, Czech J. Food Sci. 29 (2011) 35–44, https://doi.org/10.17221/40/2009-CJFS. (Accessed 11 February 2023).

[33] International Association for Cereal Science and Technology, ICC Standard No. 131 (1980) Method for Test Baking of Wheat Flours, International Association for Cereal Science and Technology, Vienna, Austria, 2018.

[34] American Association of Cereal Chemists (AACC), AACC standard method No. 10-05. 01. (1998), in: Guidelines for Measurement of Volume by Rapeseed Displacement. Approved Methods of the AACC, tenth ed., AACC International, St. Paul, MN, USA, 2000.

[35] Exponent Lite, Vienna Court, Lammas Road, Godalming, Surrey GU7 1YL, United Kingdom, Stable Micro Systems Ltd (2007). Available from:, v. 4.0.13.0. https://www.stablemicrosystems.com/SoftwareUpdateExponentLite.html. (Accessed 11 February 2023).

[36] Institute of Food Science and Technology, Guidelines for Ethical and Professional Practices for the Sensory Analysis of Foods, London, United Kingdom, 2020, p. 7.

[37] World Medical Association, Code of Ethics of the World medical association: declaration of Helsinki. Helsinki, Finland: WMA, BMJ 2 (1964) 177.

[38] M.J. Callejo, Present situation on the descriptive sensory analysis of bread, J. Sensory Stud. 26 (4) (2011) 255–268, https://doi.org/10.1111/j.1745-459X.2011.00341.x.

[39] TIBCO Statistica, TIBCO Software Inc, Palo Alto, CA, USA (2017). Available from:, v. 13.3.0. https://docs.tibco.com/products/tibco-statistica/archive. (Accessed 11 February 2023).

[40] E.R. Boita, T. Oro, J. Bressiani, G.S. Santetti, T.E. Bertolin, L.C. Gutkoski, Rheological properties of wheat flour dough and pan bread with wheat bran, J. Cereal. Sci. 71 (2016) 177–182, https://doi.org/10.1016/j.jcs.2016.08.015.

[41] T. Dapčević, M. Hadnađev, M. Pojić, Evaluation of the possibility to replace conventional rheological wheat flour quality control Instruments with the new measurement tool – mixolab, Agric. Conspectus Sci. 74 (2009) 169–174.

[42] A.S. Sivam, D. Sun-Waterhouse, S.Y. Quek, C.O. Perera, Properties of bread dough with added fiber polysaccharides and phenolic antioxidants: a review, J. Food Sci. 75 (2010) 163–174, https://doi.org/10.1111/j.1750-3841.2010.01815.x.

[43] J. Bressiani, T. Oro, P.M.L. Da Silva, F.M. Montenegro, T.E. Bertolin, L.C. Gutkoski, M.A. Gularte, Influence of milling whole wheat grains and particle size on thermo-mechanical properties of flour using Mixolab, Czech J. Food Sci. 37 (2019) 276–284, https://doi.org/10.17221/239/2018-CJFS.

[44] N. Singh, H. Singh Gujral, J. Singh, Effect of baking ingredients and mixing duration on dough development, gas release and bread making properties, J. Food Qual. 25 (2002) 305–315, https://doi.org/10.1111/j.1745-4557.2002.tb01027.x. (Accessed 11 February 2023).

[45] C. Verheyen, A. Albrecht, D. Elgeti, M. Jekle, T. Becker, Impact of gas formation kinetics on dough development and bread quality, Food Res. Int. 76 (2015) 860–866, https://doi.org/10.1016/j.foodres.2015.08.013. (Accessed 11 February 2023).

[46] S. Dhua, K. Kumar, Y. Kumar, L. Singh, V.S. Sharanagat, Composition, characteristics and health promising prospects of black wheat: a review, Trends Food Sci. Technol. 112 (2021) 780–794, https://doi.org/10.1016/j.tifs.2021.04.037. (Accessed 11 February 2023).