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Original research paper

THE EFFECTS OF THE ADDITION OF LYOPHILIZED BERRY FRUITS ON THE LEAVENING PROPERTIES OF DOUGH AND VOLUME PROPERTIES OF BREAD

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Abstract: This study examined the effects of addition of pulverized lyophilized fruits (chokeberries, black elderberries, blackcurrants, Saskatoon berries) mixed with wheat flour (in amounts of 5%, 10% and 15%) on the quality of dough and bread made from this mixed flour. A reofermetometer F4 was used to evaluate the fermentation of the experimental doughs and a Volscan was used to evaluate the volume of the experimental bread. The dough with 15% addition of black elderberries had the best ability to form fermentation gases, and the dough with 15% addition of Saskatoon berry had the lowest. Doughs supplemented with chokeberry and blackcurrant produced a significantly increased total volume of CO_2, but also lost a significant amount of gas during fermentation. The best bread volumes were achieved with the application of elderberry in all investigated amounts, and with the addition of Saskatoon berries in amounts of 5% and 10%. The sensory analysis showed that breads with 5% and 10% fruit additions had the best overall appearance, colour, and textural properties. In the evaluation of the taste properties, breads with the addition of chokeberry, elderberry and Saskatoon berry in the amount of 5% were rated the best.

Key words: *dough rheology, rheofermentometer, gas retention, loaf volume, fruits powder, sensory evaluation*

INTRODUCTION

Bread and bakery products are some of the most important foods people consume in large quantities (Krishtafovich, Krishtafovich, Bronnikova & Savina, 2021). Currently, the prevailing trend is to enrich individual types of cereal foods with health-promoting ingredients. One way to improve the nutritional quality of bread is to partially replace wheat with raw materials with nutritional potential, resulting in various products with beneficial health effects (Torbica, Belović & Tomić, 2019; Ersus et al., 2024). Along with the well-

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known ingredients used in bakery, non-bakery/non-traditional plant raw materials have great potential, the application of which to increase the nutritional value of breads and bakery products has received significant research attention (Krishtafovich et al., 2021; Romano, Gallo, Ferranti & Masi, 2021; Bojňanská, Musilová & Vollmannová, 2021). There are a large number of plant species that contain effective bioactive substances capable of reducing oxidative stress, strengthening the immune system, and providing other health benefits. Red fruits are particularly popular for their attractive taste, pleasant appearance and bioactive composition (Martinsen, Aaby & Skrede, 2020). For example, elderberry (*Sambucus nigra*) attracts attention for its easy cultivation (locally, naturally occurring branched shrub or tree in most of Europe) and the high availability of phytonutrients and biologically active substances with beneficial therapeutic effects (Moldovan, David, Achim, Clichici & Filip, 2016; Mlynarczyk, Walkowiak-Tomczak & Lysiak, 2018).

Red fruit, also known as berries, is a small fruit that is valued for its typical sour-sweet taste, reddish-purple colour and many health benefits. These berries contain a significant content of phenolic compounds, the main classes of which are phenolic acids, flavonoids and stilbenes. Phenolic compounds are important for human health, and their consumption has been associated with reduced risk of several chronic diseases such as cancer (Leite-Legatti et al., 2012), Alzheimer's disease (Jha, Panchal & Shah, 2018), diabetes (Cásedas et al., 2019) and obesity (Lenquiste et al., 2019). They have antioxidant properties that prevent the formation of free radicals (Apak, Ozyürek, Güçlü & Çapanoglu, 2016).

Red fruits are also significant because they accumulate high amounts of anthocyanins which are mainly responsible for their colour (Albuquerque, Pinela, Barros, Oliveira & Ferreira, 2020; Mikulic-Petkovsek, Koron & Rusjan, 2020). In addition to nutritional benefits, red fruits have antimicrobial properties, providing effective protection against external agents (bacteria, viruses and yeasts) that can cause infections and degradation of food and beverages (Bobinaitė, Viškelis, Šarkinas & Venskutonis, 2013; Joshi, Howell & Souza, 2019). Small berries (red fruits) have several potential uses in food production due to their colour and flavour, health and functional bene-fits, and technological properties (Schulz et al., 2019).

Some of these berry fruits have already been tested as additives in bakery products, e.g. Yoon, Kim, Kim, Kim and Eom (2014), and Petkovic et al. (2020) investigated the addition of chokeberry powder up to 10% on the chemical, antioxidant, qualitative and sensory properties of bread whereas Bustos, Paesani, Quiroga and León (2019) and Bustos, Vignola, Paesani and León (2020) investigated the technological and sensory quality of pasta enriched with berries of black and red currant, blueberries, raspberries. Other studies have sought to increase the nutritional value of bakery products (e.g. muffins, bread, biscuits) by adding Saskatoon berries, and blackcurrants (Lachowicz, Świeca & Pejcz, 2021; Molnar, Brnčić, Vujić, Gyimes & Krisch, 2015). Other authors have incorporated blueberries and defatted grape seed powder into biscuits at the 5% level (Aksoylu, Çağindi & Köse, 2015).

These works mainly investigated the effect of fruit on the chemical, antioxidant and sensory properties of the products, fewer studies have already addressed the rheology of the dough, specifically on the ability of the experimental pathways to retain fermentation gases and on the related technological properties of the final product (bread).

However, the addition of non-baking raw materials to composite flours with wheat or rye flour fundamentally changes the properties of these flours. The significant change is mainly due to the lower proportion of gluten-forming proteins in these flours, but also to the higher proportion of fibre or other components that may influence their technological properties.

The addition of non-bakery raw materials is involved in changes that subsequently affect the whole bread-making process, influencing the dough properties, rheological behaviour, texture, volume and sensory quality of the final product (Bojňanská, Frančáková, Líšková & Tokár, 2012; Bresciani & Marti, 2019). The addition of non-gluten-forming ingredients causes dilution and subsequent weakening of the wheat dough (Autio & Salmenkallio-Marrttila, 2003). The gluten network developed by dough mixing is important for gas retention and bread structure. The formation of gas during fermentation depends mainly on the activity of baker's yeast (*Saccharomyces cere-*

visiae) and the ability of the dough to trap this gas depends on the gluten network. To predict the actual fermentation of the dough, an analysis using a reofermentometer is useful, because it allows estimating the properties of the dough during fermentation by measuring the CO_2 released or the pressure produced.

The CO_2 produced is used to expand the dough and reach the final volume of the bread loaf (Gao, Lyn Tay, Hui Si Koh & Zhou, 2017). Baking is considered as the last critical step to establish the final structure of the bread (Huang, 2014).

During this process, the flour compounds are subjected to mechanical work and heat treatment that alters their physicochemical properties. The baking test is a direct method of determining the quality of composite flours and the raw materials used (Rosell, Collar & Haros, 2007).

The way fresh berries are processed is essential to preserve the valuable components of the fruit as much as possible. Lyophilization is regarded as the most preferred drying technique due to its ability to preserve the high nutritional value of processed products (Calín-Sánchez et al., 2020; Sidor, Drożdżyńska, Brzozowska & Gramza-Michałowska, 2021).

This work aimed to investigate the effect of different amounts of non-traditional lyophilized fruits: elderberry (*Sambucus nigra* L.), chokeberry (*Aronia melanocarpa* L.), blackcurrant (*Ribes nigrum* L.) and Saskatoon berry (*Amelanchier alnifolia*, Nutt.) on the ability of the experimental doughs to retain the fermentation gases and on the related technological properties of the final product (bread).

MATERIALS AND METHODS

Material used

Commercially available wheat flour (WF) (MLYN ZRNO, Miroslav Grznár, Slovak Republic), with parameters guaranteed by the manufacturer, was used in this study: energy value 1464 kJ, fat content 1.3 g/100g of which saturated 0.3 g/100g, protein content 11 g/100g, salt 0.01 g/100g, carbohydrate content 71 g/100g of which sugars 1.59 g/100g, fibre content 3.3 g/100g.

The mixed flours were made using elderberry, blackcurrant, chokeberry, and Saskatoon berry, which were harvested, as they reached full maturity (Nitra, Slovak Republic). Their colour was one of the best ways to tell when they were mature. Only high-quality fruits free of stems and damaged sections were lyophilized for 5 days at -58 °C (ilShin Lab Co., Ltd., Korea) and then homogenized (Bosch TSM6A01, Germany).

In the form of lyophilized powder, they were added to the commercially available wheat flour at 5%, 10% and 15%. Twelve mixtures of wheat flour and lyophilized fruit powders in different proportions were prepared (Table 1). As a control (C) only pure wheat flour was used.

Rheofermentometric analysis

The reofermentometer F4 (Chopin Technologies, France) was utilized to track the dough's development and gas retention and release during fermentation. Individual doughs were prepared by mixing 250 g of flour mixture (Table 1), 5 g of yeast, 5 g of salt, water added according to the consistency of the flour mixture for optimum dough consistency (as determined by the Mixolab). The dough was mixed for 7 min in a spiral mixer SP 12 D (Diosna Dierks & Söhne GmbH, Osnabrück, Germany). After kneading, 315 g of the dough sample was placed in a fermentation chamber and covered with an optical sensor. The dough was evaluated at a temperature of 28.5 °C for 180 minutes. Parameters were obtained by measuring curve *a*: Hm (maximum height of the dough, mm); and curve *b*: H´m (maximum height of the gas release curve, mm); T'1 (time of maximum gas production; time required to obtain H´m, minutes); Tx (time when the dough starts to release CO_2, minutes); total volume (volume of gas produced in mL of CO_2); volume of CO_2 lost in mL (volume of gas escaped to the environment); and retention volume (volume of gas retained in the dough at the end of the test).

Experimental baking

The baking experiments were carried out in three variations in the amount of addition of lyophilized fruit ingredients (5%, 10% and 15%) (Table 1). For the test loaves of bread, individual mixed flours, 2.0% NaCl, 2% dry yeast, 1% sugar, were used. The water addition ranged from 57.1% to 64% (determined for optimum dough consistency according to Mixolab), namely from 141 ml to 154 ml per 100 g

Table 1.
Combinations of evaluated mixed flours and their use in experimental tests

Samples of mixed flours								Exp.
C	WF (100)	**C**	WF (100)	**C**	WF (100)	**C**	WF (100)	BE / rheo
SN5	WF(95):SN(5)	**RN5**	WF(95):RN(5)	**AM5**	WF(95):AM(5)	**AA5**	WF(95):AA(5)	BE
SN10	WF(90):SN(10)	**RN10**	WF(90):RN(10)	**AM10**	WF(90):AM(10)	**AA10**	WF(90):AA(10)	BE
SN15	WF(85):SN (15)	**RN15**	WF(85):RN (15)	**AM15**	WF(85):AM(15)	**AA15**	WF(85):AA (15)	BE / rheo

C (control), WF (wheat flour), SN (S. nigra), RN (R. nigrum), AM (A. melanocarpa), AA (Am. alnifolia), BE (baking experiment), rheo (rheology)

of flour. All ingredients were kneaded for 3 minutes at a lower speed and 4 minutes at a higher speed in a spiral kneader SP 12 D (Diosna Dierks & Söhne GmbH, Osnabrück, Germany). The bread samples were left to rise for 40 minutes at 32 °C and baked as follows: 10 minutes at 240 °C (140 ml water for steaming/with steam) and 25 minutes at 220 °C (MIWE condo, Germany).

Physical properties of bread

After the bread was baked and cooled at room temperature, the loaves were analysed with a 3D laser-based scanner Volscan Profiler volume analyser (Stable Micro Systems, Surrey, UK). The vertical measurement speed and rotation speed were set to 0.5 rps. The following parameters were evaluated: weight of the bread (g), bread volume (ml), specific volume (ml/g; calculated as the ratio between the bread volume and its weight), volume yield (ml/100g flour), aspect ratio of a middle slice.

Sensory analysis

The sensory evaluation of bread according to ISO 6658:2017 was carried out by a sensory panel consisting of a group of 10 trained evaluators. Their task was to evaluate 5 sensory attributes of the loaves of bread, namely: overall appearance (attractiveness and shape), aroma, texture and elasticity, taste and overall impression. The results of the evaluation of the experimental breads were compared with the control (C) without the addition of lyophilized fruits. A 9-point hedonic scale ranging from 9 (excellent) to 1 (unacceptable) for each characteristic was used for evaluation. In addition to the point evaluation, respondents could enter their comments and observations on individual product samples in a note.

Statistical analysis

Analysis of variance (ANOVA) and Fisher's test were used to evaluate differences between the reference sample and the fruit-supplemented mixture samples ($p<0.05$). Assays were performed in triplicate and statistical analysis was performed using MS Excel 2016 (Microsoft Corporation, Redmond, Washington, USA). Correlations between gas release, dough properties and dough quality attributes were assessed by Pearson's correlation at the 0.05 significance level.

RESULTS AND DISCUSSION

Rheofermentometric analysis

The development of the dough and the gas retention capacity of the dough, which contained different types of fruit additions in an amount of 15%, were analysed using a reofermentometer F4, which registers two curves during the dough fermentation. The first curve *(a)* describes the evolution of the dough and the second curve *(b)* (Fig. 1) records the formation and retention of gas. The results presented in Table 2 showed a significant ($p<0.05$) reduction of the Hm value (the maximum height of the development of the dough under stress) with the addition of chokeberry, blackcurrant and saskatoon berry. Hm values decreased by 42.3% and 43% in the samples with the addition of saskatoon berry (AA15) and chokeberry (AM15), respectively, and by up to 71.6% in the sample with the addition of blackcurrant (RN15) compared to the control. A different trend was observed with the addition of black elderberry, which strongly supported an increase in the Hm value.

The curves of gas formation and retention in the dough of the experimental flours (curves *b*) are shown in Fig. 1.

The doughs with the addition of lyophilized chokeberry, elderberry and blackcurrant fruit powders reached a value of H´m (the highest point on curve *b*, when the maximum amount of gas release is reached), demonstrably higher than the control dough, in order: SN15 > RN15

> AM15. The dough containing Saskatoon berries was the exception, as evidenced by its significantly lowest H´m value (Table 2).

The time required to reach the maximum gas production T´1, which corresponds to the highest point of the *b* curve, was the shortest in the control. Fruit additions in the dough increased this time significantly.

For leavened bread, the time measured from the start of the test to the release of fermentation gas into the environment Tx (break point) should be as long as possible.

The longest Tx time was found in the dough with the addition of black elderberry, the other additions to the dough compared to the control dough shortened the Tx, which indicates earlier gas release.

The dough with the addition of Saskatoon berry powder evidently had the worst *b*-curve, which was due to the low gas production and low volume of retained gas in this sample.

We believe that the amount of gas produced was so low and that it was not released from the dough within two hours of the method, therefore the rheofermentometer did not record a value (Table 2, Fig. 1).

The results were significantly worse ($p<0.05$) than the other experimental samples. Compared to the control dough, the other samples with the addition of lyophilized fruit (chokeberry, black elderberry and blackcurrant) showed significantly a higher total volume of CO_2 produced in the dough, even though the time T´1 (maximum curve height) was reached later than in the control dough.

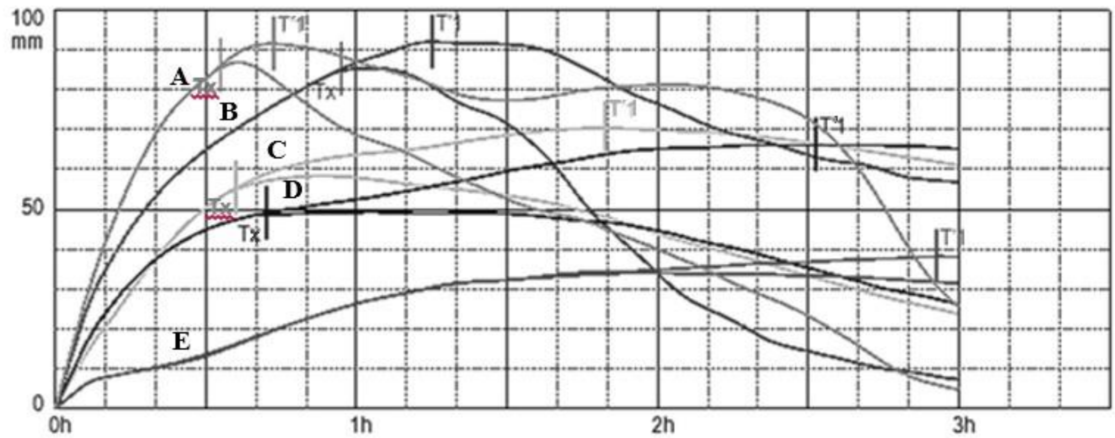


Figure 1. Reofermentometric curves *b* - comparison of dough with 15% addition of different types of lyophilized fruits with the control sample (WF). A – control; B – *S. nigra*; C – *R. nigrum*; D – *A. melanocarpa*; E – *Am. alnifolia*

Table 2.
Rheofermentometer parameters of dough from the control flour and the studied flour mixtures

Sample	H_m (mm)	H´m (mm)	T´1 (min)	T_x (min)	Total volume (mL)	Retention volume (mL)	Lost CO_2 volume (mL)	Retention coefficient
C	84.1±0.5^c	61.6±1.1^b	55.5±2.6^a	49.5±1.6^d	1385±35.1^b	1165±42.5^a	220±7.4^d	84.1±0.9^d
AM15	47.9±3.9^a	66.2±0.7^c	151.5±0.8^b	42±0.8^c	1539±31.0^c	1140±9.8^a	399±21.2^c	74.1±0.9^c
SN15	114±1.6^d	92.1±0.7^e	75.0±2.5^c	57±1.6^e	1981±18.8^e	1323 ± 8.9^c	658±9.8^a	66.8±0.2^a
RN15	23.9±2.5^b	70.3±1.2^d	109.5±0.8^d	36±0.8^b	1667±17.2^d	1200.3±5.7^a	467±22.9^b	72±1.1^b
AA15	48.5±6.6^a	38.1±2.4^a	175.5±1.4^e	0±0	778±58.8^a	740±46.5^b	38±12.3^e	95.2±1.2^e

Hm (maximum height of dough development); H´m (maximum height of the gas release curve); T'1 (time of maximum gas formation; time required to obtain H'm); Tx (time of gas release); Total volume (volume of gas produced); Retention volume (CO_2 volume still retained in the dough at the end of the test); Volume of CO_2 lost (CO_2 volume that the dough has lost during proofing); Gas retention coefficient (Retention volume/Total volume). $^{a-e}$ *Means followed by different letters in the same column are significantly different ($p<0.05$)*

In addition to the amount of gas produced, the ability of the dough to hold this gas is also important. During the test (180 minutes), the experimental doughs with the addition of chokeberry, elderberry and blackcurrant lost significantly ($p<0.05$) higher amounts of CO_2 compared to the control, demonstrating a reduction in the retention coefficient of 10% for chokeberry, 17.3% for elderberry and 12.1% for blackcurrant.

The resulting volume of gas retained in the dough at the end of the test (Retention volume) was significantly ($p<0.05$) higher in the dough with the addition of elderberry, and since this dough produced significantly the largest amount of fermentation gas (Total volume), the high losses were not significant either. There is a negative correlation between the total gas volume and the volume of CO_2 released to the environment (Volume of CO_2 lost) ($r = -0.97$, $p<0.05$) and between Retention volume and Retention coefficient ($r = -0.90$, $p<0.05$). The fermentation of the dough with the addition of Saskatoon berries (AA15) can be characterized as insufficient and slow. The prediction for such an addition was not favourable. The time required to obtain a maximum height of the gas release curve was reached only quite at the end of the analysis, and the maximum was extremely low. Retention volume was 44% lower than in the case of the best-rated dough with the addition of elderberry.

The dough's structure and gas retention depends on a viscoelastic three-dimensional network made of starch, gluten protein, and other ingredients (Verheyen, Albrecht, Becker & Jekle, 2016). When the starch-gluten matrix is disturbed by the inclusion of non-wheat ingredients, the dough's ability to retain gas is often diminished. This leads to a decrease in the specific volume and porosity of the bread (Rubel, Pérez, Manrique & Genovese, 2015; Bojňanská, Vollmannová & Musilová, 2020).

The instability of dough development and low gas retention capacity, which was most markedly observed in our experiment with Saskatoon fruit (curve E), suggests that the addition of this fruit powder weakened and disrupted the structure of the gluten network the most. Several authors confirmed that using low-protein flour results in poorer dough strength (Gao et al., 2017).

Preliminary results (determined by Mixolab) suggested that lyophilized berries in higher additions (10 - 15%) may be recommended for the preparation of more durable baked goods or biscuits, which do not require the formation of a compact spatial gluten network during kneading (Kolesárová et al, 2022).

The Saskatoon berry differs from the above-mentioned fruits (chokeberry, blackcurrant and elderberry) not only in its chemical composition but also in the presence of certain biologically active components. We believe that it is these differences, and those mentioned subsequently in the text, that may influence the rheological properties of the dough, namely its ability to produce and hold gas. For example, the Saskatoon berry and chokecherry we applied are rich in caffeic acid (181.2 mg kg-1 and 222.8 mg/kg) and myricetin (178.9 mg/kg and 266.6 mg/kg), black elderberry contained a lot of rutin (2029.6 mg/kg) compared to other fruits (chokeberry - 1304.2 mg/kg, Saskatoon berries - 120.9 mg/kg, blackcurrant - 95.3 mg/kg) as found in our research (unpublished results).

High saccharide content can promote fermentation, while a lower content can lead to a lower gas volume. The total sacharide content of Saskatoon berries (10.5 g/100g) is lower than that of elderberries (17.4 g/100g), chokeberries (20.1 g/100g) and blackcurrants (18.3 g/100g) (Online potravinová databáza, 2008-2023)

Berries are an important source of dietary fibres (Mazza, 2006; Lachowicz, Oszmiański & Pluta, 2017), which has a high water retention capacity and thus can increase the viscosity of the dough. Dough quality can also be largely influenced by its composition, for example, pectin content, which is found in oligomeric forms in Saskatoon berry (*Amelanchier alnifolia)* at 0.67-1.3% (Lachowicz, Oszmiański, Seliga & Pluta, 2017) and in Aronia (*Aronia melanocarpa*) at 10.7-14% of fibre (Borycka & Stachowiak, 2008).

The acidity of the fruit can promote yeast activity. Different fruit acids may have different abilities to stimulate or inhibit fermentation. Within the added fruits, Saskatoon berries contain the lowest organic acid content of 0.63 g/kg (Zatylny, Ziehl & St-Pierre, 2005), elderberries 0.98 g/100g, chokeberries 0.93

g/100g, and blackcurrants 2.6 g/100g (Online potravinová databáza, 2008-2023).

Each fruit has its unique chemical composition and interaction with other ingredients affects the fermentation process and is a key to the rheological properties of the dough. There is no doubt that this issue still needs scientific attention and further testing of different ratios and combinations could help to identify the appropriate conditions to achieve optimum gas volume.

Qualitative properties of bread

Assessment of the suitability of the studied fruit ingredients in breadmaking can be determined by test baking under specified conditions, with a key quality attribute being the loaf's volume. Breads with a larger volume are usually preferred by consumers and considered technologically superior.

In the baking experiment, 13 experimental variants were prepared by adding lyophilized fruit at 5%, 10%, and 15% levels (Table 1). As can be seen in Table 3 and Fig. 2, the highest bread volumes were obtained with the addition of black elderberries at all three enrichment levels, and with Saskatoon berry at 5% and 10% levels, confirmed by the volume yield (ml per 100g flour) which was higher or at the same level in these samples compared to the control sample. Significantly lower bread volumes than the control were found in the samples enriched with chokeberry and blackcurrant, at all addition levels, and in the samples with 15% Saskatoon berry. Specific volume was the highest in the samples with the addition of elderberry, at all enrichment levels. The lowest specific volume was found in the bread variants with the highest (15%) level of other fruits - chokeberries, blackcurrants and Saskatoon berries.

Our results showed that the loaf volume and the specific volume decreased with increasing amounts of all types of lyophilized fruits. However, the type and amount of fruit/functionnal additive were shown to play an important role in influencing both the rheological properties of the dough and the volumetric properties of the baked bread. The best technological properties were observed with the addition of elderberry, which positively influenced the volumetric properties of the bread at all addition levels. The baking test confirmed the positive properties of the lyophilized elderberry powder, highlighting its significance from several aspects.

As mentioned earlier, the enrichment level also influenced the breadmaking potential of the fruit ingredients; only the addition of 5% and 10% Saskatoon berries did not significantly reduce bread volume. The most significant negative impact on bread volume was observed for blackcurrants and chokeberries which limits their use as breadmaking ingredients at a level not higher than 10%. In general, berries are considered valuable sources of pectin. Blackcurrant pectin forms a gel with higher viscosity and has a higher thickening effect (Bélafi-Bakó, Cserjési, Beszédes, Csanádi & Hodúr, 2012) which may have a negative effect on the dough. The viscosity of the dough is related to its ability to hold air during baking. It has been reported that low dough consistency gives low-volume products (Lakshminarayan, Rathinam & KrishnaRau, 2006). The increase in dough viscosity can also be attributed to the high water retention capacity of fibre (Rosell, Santos & Collar, 2021). Some authors have also found a decrease in cake volume when fiber from different fruits was incorporated (Grigelmo-Miquel, Carreras-Boladeras & Martin-Belloso, 1999).

The baking test results for Saskatoon berries at 5% and 10% enrichment levels were surprisingly better than expected. Despite the poor dough characteristics, a sufficient amount of fermentation gas was produced during the experimental baking, resulting in a bread volume comparable to the control loaf. Contrary to expectations, the other fruit berry ingredients did not perform as predicted, except for black elderberry.

Undoubtedly, further research is needed to reveal the reasons for such performance.

Generally valid correlations (Gao et al., 2017; Bojňanská, Vollmannová & Musilová, 2020) between retention volume determined by rheofermentography and the volume of bread determined by a bakery experiment proved to be less reliable in the case of lyophilized fruit additions. Only a moderate dependence ($r = 0.49$; $p>0.05$) was confirmed in the samples with the addition of chokeberry, elderberry and blackcurrant at 15%. A strong positive correlation ($r = 0.98$; $p<0.05$) was found between specific volume and Hm (maximum dough development height under stress) for all dough samples analysed. Our hypotheses are supported by the results of other authors (Gül & Şen, 2017), who found that the addition of dried and ground pomegranate seeds (PSF) at 5%, 7.5%, and 10% significantly reduced the volume, height, and width of the loaf of bread, respectively. The high proportion of PSF caused the doughs to become stiffer and less elastic, unable to reach a greater volume due to the adverse effect of PSF on the formation of the gluten network. However, the greater the substitution of wheat flour with PSF, the higher the protein and fibre content of the functional bread.

A decrease in bread volume has also been confirmed by several other studies in which wheat flour has been substituted in varying amounts with, for example, apple pomace (Masoodi & Chauhan, 1998), grape seed flour (Hoye & Ross, 2011), blackcurrant seed flour (Korus et al., 2012) and dried and powdered leaves of the Moldavian dragonhead (*Dracocephalum moldavica* L.) (Dziki et al., 2019).

Table 3.
Bread quality parameters

Sample	Volume (ml)	Weight (g)	Specific volume (ml/g)	Volume-Yield (ml/100g flour)	Aspect Ratio of middle slice
C	292.8 ±12.7 ^{f}	143.0 ± 2.7^{cd}	2.0 ±0.10 ^{e}	292.9 ± 12.8 ^{de}	0.8 ± 0.0 ^{f}
AM5	269.5 ± 0.50 ^{e}	139.5 ± 0.4 ^{b}	1.9 ± 0.0 ^{d}	278.5 ± 12.7 ^{d}	0.9 ± 0.1 ^{g}
AM10	242.9 ± 0.05 ^{cd}	138 ± 0.0 ^{b}	1.8 ± 0.0 ^{c}	242.9 ± 0.05 ^{c}	0.7 ± 0.0 ^{cde}
AM15	192.9 ± 0.74 ^{b}	132.3 ± 0.94 ^{a}	1.5 ± 0.01 ^{b}	192.9 ± 0.74 ^{ab}	0.7 ± 0.03 ^{abc}
SN 5	328.3 ± 0.70 ^{g}	144.5 ± 0.41 ^{de}	2.3 ± 0.01 ^{g}	328.3± 0.70 ^{f}	0.8 ± 0.01 ^{fg}
SN 10	304.8 ± 0.14 ^{f}	139.5 ± 1.22 ^{b}	2.2 ± 0.02 ^{fg}	304.8 ± 0.14 ^{e}	0.8 ± 0.0 ^{fg}
SN 15	293.9 ± 1.41 ^{f}	139.0 ± 3.27 ^{b}	2.1 ± 0.06 ^{ef}	293.9 ± 1.41 ^{de}	0.8 ± 0.01^{def}
RN 5	251.9 ±0.10 ^{de}	144.0 ± 0 ^{cde}	1.7 ± 0.0 ^{c}	251.9 ± 0.10 ^{c}	0.7 ± 0.0 ^{bcd}
RN 10	201.8 ± 0.20 ^{b}	146 ± 0.0 ^{e}	1.4 ± 0.0 ^{b}	201.8 ± 0.20 ^{b}	0.6 ± 0.0 ^{a}
RN 15	173.6 ± 0.05 ^{a}	145 ± 0.0 ^{de}	1.2 ± 0.0 ^{a}	173.6 ± 0.05 ^{a}	0.6 ± 0.0 ^{ab}
AA 5	299.7 ± 0.50 ^{f}	141.1 ± 0.5 ^{bc}	2.1 ± 0.0 ^{ef}	299.8 ± 0.60 ^{e}	0.8 ± 0.0 ^{efg}
AA 10	288 ± 0.82 ^{f}	140.9 ± 1.64 ^{bc}	2.0 ± 0.02 ^{de}	287.7 ± 0.67 ^{de}	0.8 ± 0.01 ^{fg}
AA 15	233 ± 0.0 ^{c}	140.3 ± 0.5 ^{b}	1.7 ± 0.0^{c}	233.1 ± 0.19 ^{c}	0.7 ± 0.01 ^{cde}

$^{a-g}$ *Means followed by different letters in the same column are significantly different (p <0.05)*

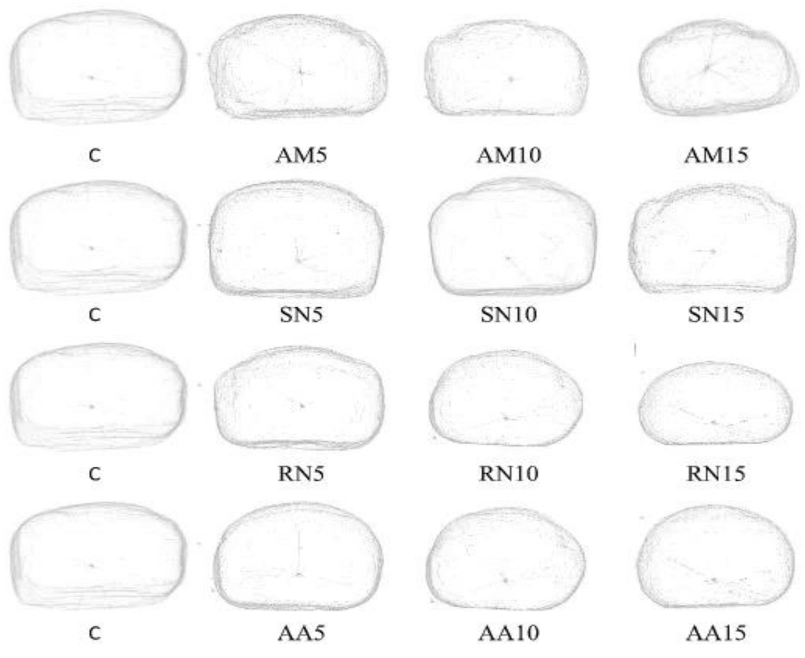


Figure 2. Volscan profiler - Bread volume and bread aspect ratio

The suitability of using lower amounts of fruit ingredients to composite flour was described by Krishtafovich et al. (2021) who found that bread obtained by an accelerated preparation method (yeast activation 15-20 min) with the addition of juniper berry powder (4%) had a 1.5% higher porosity compared to the control, indicating a more intense gas development.

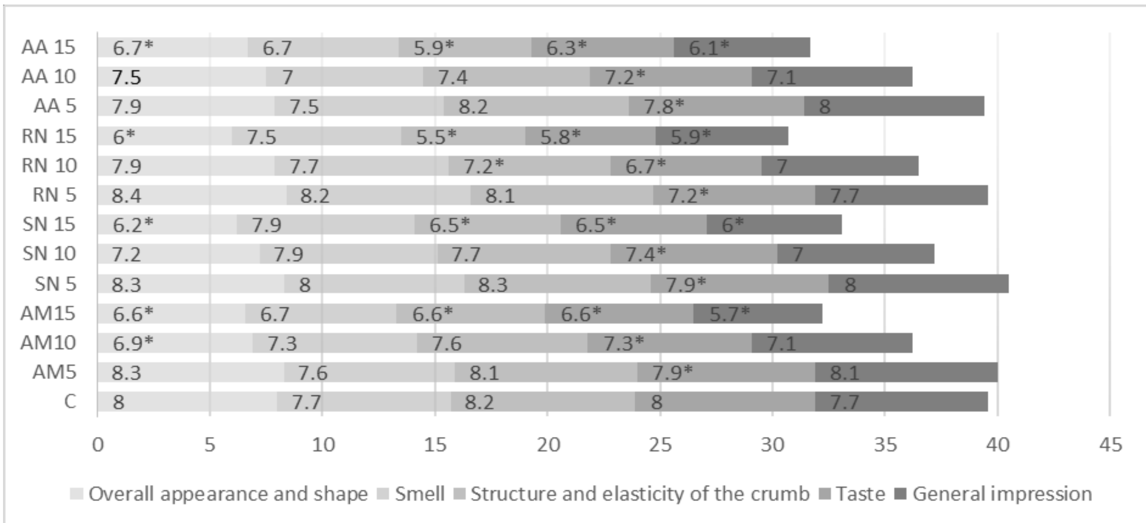
Sensory evaluation of bread

Test breads with additions of 5%, 10% and 15% of lyophilized fruit powder were sensory evaluated. The breads were characterized by their regular shape and colour depending on the type of addition. The results of the assessment are presented in Fig. 3. The overall appearance of the products was best evaluated by the respondents in the samples with the addition of chokeberry, black elderberry and blackcurrant at 5%, which had a higher score than the control sample.

Colour is an important parameter that affects consumer acceptance of food (Spence, 2015). In terms of colour intensity of the crumb and crust compared to the control sample, the addition of different types of fruit additives caused a darker colour, which can be perceived positively from a marketing point of view (5% additions) as dark baked goods are perceived by consumers as healthier and are in higher demand. However, this was not the case with higher incorporation levels of fruit ingredients (AM10, AM15, SN15, RN15, AA15), which already caused a pronounced burgundy-purple colour. Such colour spectra differ significantly from the typical yellow-brown colour of tradetional breads and were, therefore, less accepted by the evaluators and obtained significantly lower scores ($p<0.05$). Lachowicz, Świeca & Pejcz (2021) reported that powder from *Amelanchier alnifolia* Nutt. as a fruit component in bread had a significant effect on crust colour and crumb. The higher the amount of this ingredient used, the more red and less yellow pigments the bread contained.

In general, the odour of all samples was evaluated as pleasant, harmonious and typical for the fruit ingredient used and relatively balanced. All experimental breads with added 5% fruit powder, as well as those with 10% chokeberry, black elderberry, and Saskatoon berry, had texture properties comparable to the control. The bread samples with the highest enrichment level (15%), including sample RN10, exhibited a significant decline in the crumb structure ($p<0.05$), characterized by poor porosity.

Significant differences ($p<0.05$) were recorded when evaluating the taste of the studied bread samples, which was expected given the type of ingredients used. All experimental bread samples tasted different from the conventional wheat bread respondents were accustomed to. The highest taste scores were evaluated for the samples with the addition of chokeberries, black elderberries and Saskatoon berries at 5% level. Notably, the sample enriched with 15% blackcurrants that scored the lowest points for taste (5.8 points out of 9), was still considered acceptable and was not disqualified.



**Significant difference between the control sample and the samples with added lyophilized berry powders*

Figure 3. Sensory evaluation of the trial breads

The higher the amount of berries in the bread formulation, the more pronounced the taste became. For instance, the sample with Saskatoon berries was rated as having an earthy, nutty flavour, while the samples with chokeberry and blackcurrant were predominantly described as lemony and tasting of sour berry fruit.

Based on consumer ratings, the experimental breads containing 5% and 10% fruit ingredients received the highest overall impressions. In contrast, the breads with 15% fruit powder were rated significantly lower in overall impression ($p<0.05$).

Considering the maximum possible score of 45 points for evaluating sensory attributes, the bread samples with a 5% addition of chokeberry (40 points) and black elderberry (40.5 points) emerged as the best variants. The bread with a 15% addition of blackcurrant received the lowest rating, scoring 30.7 points. Notably, none of the experimental variants scored below 30 points, which would be considered very poor sensory quality.

Różyło et al. (2019) proposed the use of freeze-dried chokeberries and elderberries as natural colourants and valuable functional components for gluten-free wafers. They added these fruit powders to the dough and found positive changes in the colour of both the dough and the wafers as the fruit content increased from 1 to 5%. The lyophilized elderberry powder was significantly darker than the chokeberry powder and had significantly higher mineral and total flavonoid content.

Powder from Saskatoon berries was also added to wheat flour by Lachowicz et al. (2021), who found that powder additions below 4% produced no effect on the bread quality, but significant differences were observed with additions of 4%, 5%, and 6% pure Saskatoon berry powder. The bread from this experiment with the addition of 4% and 5% had a slightly bitter taste, but the bread with the addition of 6% already had a sweet fruity taste.

Another study found that the incorporation of juniper berry powder at 4% flour weight into bread did not cause deterioration of sensory properties. The taste was spicy, without bitterness, with a light aroma of pine needles (Krishtafovich, Krishtafovich, Bronnikova, & Savina, 2021). Dried chokeberry powder was added by Petkovic et al. (2020) up to 10%. They found that bread with 5% addition had the best sensory quality. These results follow those of Hwang and Thi (2014) in which sensory evaluation showed that 5% chokeberry powder showed the best preference in colour, taste, flavour, hardness, and overall acceptance. Other authors have also demonstrated how flour composition can affect the evaluation and overall acceptance of products by consumers, specifically how the acceptability of a product by consumers can be reduced when the functional ingredient content is increased (Man et al., 2021), which was also confirmed for our samples with a high additive application (15%).

The sensory attributes of bread are thus significantly influenced by the type of fruit ingredient and the amount of incorporation into bread formulation. It is important to find the optimum level of ingredients to ensure a final product that is fully acceptable to consumers. The added value is the higher nutritional value of enriched products, which is a consequence of the content of biologically valuable substances in fruit-based ingredients.

The addition of non-cereal raw materials can provide interesting sensory properties in addition to nutritional benefits, which were also evident in the application of fruit powders, especially regarding taste and colour. However, given the results of sensory evaluation of the studied breads enriched with lyophilized berries, we would preferably recommend their application in sweet bakery products.

CONCLUSIONS

Lyophilized berry fruits have been shown to significantly affect the properties of the dough, as well as the sensory properties of the bread. Regarding the important ability of the dough to form and retain fermentation gases, exceptional results were found with the addition of elderberries and the poorest with the addition of Saskatoon berries. The baking test showed that the bread volume and the specific volume of the experimental loaves decreased with increasing levels of all studied lyophilized fruits. Regarding bread volume and other quality attributes evaluated, the best results were obtained with the application of black elderberries at all amounts studied (5%, 10%, 15%). All studied bread variants were sensory acceptable to the evaluators, but the best evaluated were those with 5% and 10% lyophilized berries. There were significant differences in flavour characteristics and the best-rated breads were those with 5% chokeberries, elderberries and Saskatoon berries.

This study demonstrated that developing innovative foods can effectively utilize lyophilized fruit species that are locally grown, including wild varieties. These fruits, whose nutritional potential is still under investigation, have already shown several scientifically confirmed health benefits. The intense colour of these innovative products is a positive sensory attribute, making them particularly suitable for sour-sweet bakery items. Additionally, the nutritional benefits and appealing colour of these products enhance their marketability by increasing their attractiveness.

AUTHOR CONTRIBUTIONS

Conceptualization, supervision, methodology, analysis, writing – review and editing, An.K.; Conceptualization, methodology, writing – review and editing, T.B.; Visualization, writing – review and editing, M.S.; Methodology, and writing – review and editing, A.M.; Software, data curation, J.K.; Funding acquisition, project administration, Ad.K.

DATA AVAILABILITY STATEMENT

Data contained within the article.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest or personal relationships that might influence the work presented in this paper.

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UTICAJ SASTOJAKA NA BAZI LIOFILIZOVANOG BOBIČASTOG VOĆA NA FERMENTATIVNA SVOJSTVA TESTA I POKAZATELJE ZAPREMINE HLEBA

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Sažetak: Ova studija je ispitivala efekte dodavanja praha liofilizovanih plodova bobičastog voća (aronije, crne zove, crne ribizle, merale (Saskatoon bobica)) u pšenično brašno (u količinama od 5%, 10% i 15%) na kvalitet testa i hleba napravljenog od mešavina ovih brašna. Reofermetometar F4 je korišćen za određivanje fermentacionih svojstava eksperimentalnih testa a laserski volumometar Volscan je korišćen za merenje zapremine eksperimentalnih hlebova. Testo sa 15% dodatkom crne zove pokazalo je najbolju sposobnost formiranja gasova, a testo sa 15% dodatkom merale imalo je najnižu sposobnost stvaranja CO_2. Testo obogaćeno liofilizovanim prahom aronije i crne ribizle pokazalo je značajno veću ukupnu zapreminu CO_2, ali je takođe izgubilo značajnu količinu gasa tokom fermentacije. Najbolje zapremine hleba postignute su primenom bobica zove u svim istraživanim količinama, te dodatkom Saskatoon bobica u količinama od 5% i 10%. Senzorska ispitivanja su pokazala da su hlebovi sa dodatkom 5% i 10% praha liofilizovanog bobičastog voća pokazali najbolji izgled, boju i teksturna svojstva. Najbolji ukus i aromu su imali hlebovi obogaćeni aronijom, crnom zovom i meralom u količini od 5%.

Ključne reči: *reologija testa, reofermentometar, moć zadržavanja gasa, zapremina hleba, voćni prah, senzorska ocena*

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