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EFFECT OF SELECTED NATURAL EXTRACTS ON ANTIOXIDANT PROPERTIES AND SENSORY QUALITY OF VARIOUS CEREAL PRODUCTS

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ABSTRACT

The aim of this study was to observe antioxidant properties as well as possible changes in sensory quality of selected bakery products after their enrichment with chosen natural extracts. Four types of natural extracts in mixture with wheat flour were used in various amounts for preparation of selected bakery products (wheat bread, sweet biscuits, salty crackers, and muffins). Specifically: turmeric (*Curcuma longa*, L.) rhizome extract (curcumin), quercetin dihydrate extracted from the pods of *Sophora japonica*, L., and extracts from medicinal fungus Shiitake (*Lentinula edodes*) and Maitake (*Grifola frondosa*) were used as additions. Antioxidant properties in total antioxidant activity (TAA; using DPPH radical scavenging assay), total polyphenols content and total phenolic acids content were examined, as well as the effect of selected natural extracts on the sensory properties of bakery products (intensity of certain characteristics and overall preference). The results of antioxidant properties varied according to the used extract and its amount. Compared with control products, the TAA was significantly higher in all enriched products. While the total polyphenol content was the highest in the bread and biscuits with quercetin (20.623 mg and 18.117 mg GAE.g^{-1}, respectively), the total phenolic acids content was the highest in those with curcumin (8.846 mg and 3.286 mg CAE.g^{-1}, respectively). The intensity of other smell and taste of enriched bakery products influenced considerably overall acceptance, e.g. the products with quercetin associated with bitter taste were evaluated as unfavourable. On the other hand, the breads and crackers with Shiitake extract with indistinct antioxidant properties were evaluated the best, followed with curcumin and Maitake extract. Considering our overall results, we can recommend chosen non-bakery raw materials for a production of new, innovative designed cereal-based products.

Keywords: curcumin, quercetin, shiitake, maitake extracts, antioxidant activity, sensory evaluation

INTRODUCTION

Consumer choice of food products is no longer determined only by their sensory features but also, increasingly, by health considerations and the nutritional value of these products **(Krystyjan *et al.*, 2015).** Due to consumers lack of trust in synthetic antioxidant in food, which were commonly used in the past, natural extracts are being extensively researched. Therefore, naturally sourced antioxidants are utilized and experimented with in order to improve oxidative stability of various products **(Budryn *et at.*, 2013).**
Bakery products are popular thanks to wide variety and worldwide availability. They are also well accepted by consumers. These types of food products can be an excellent carrier of enriching additions boosting the nutritional value of a common foods. One of the advantages of bakery products is that they are typically stored at room temperature before being consumed (**Żbikowska *et al.*, 2017**).
Various studies showed that the addition of non-bakery polyphenol rich materials could alter the technological, nutritional, or sensory quality parameters of bakery products (**Bojňanská, Musilová and Vollmannová, 2021**; **Kolesárová *et al.*, 2022**; **Ivanišová *et al.*, 2023**). **Górnaś *et al.* (2016)** and **Mildner-Szkudlarz *et al.* (2016)** suggested adding fruit extracts as a source of polyphenols to sponge cakes to improve their nutritional value. Incorporating pomegranate rind powder into wheat flour increased the various parameters (total acidity, ash, total phenolic and flavonoid content, antioxidant activity) of the cookies, including phenolic and flavonoid content, as well as antioxidant activity (**Morina and Shehaj, 2022**).
Natural extracts such as quercetin, curcumin, and extracts from medicinal fungus as Shiitake and Maitake belong to the interesting non-bakery raw materials that could enhance the antioxidant capacity, phenolic content, or sensory properties of food products. Curcumin, also known as diferuloymethane, is a hydrophobic polyphenol produced from the rhizomes of the perennial herb *Curcuma longa*, a member of the ginger family (*Zingiberaceae*) **(Shirsath *et al.*, 2017).** Curcumin demonstrates a variety of activities, including antioxidant activity through free radical scavenging and anti-inflammatory activity through inhibition of NF-kB and AP-1 activation. Curcumin has commercial potential thanks to its diverse pharmacological effects used in various industries such as food productions, cosmetics, and pharmaceutics **(Jiang *et al.*, 2021).** Microencapsulated curcumin powder altered antioxidant activity in term of increased phenolics content and sensorial profile in term of decreased hardness, volume, crust colour and symmetry of designer bread during study of **Ashraf *et al.* (2022).**
Quercetin (3,3′,4′,5,7-entahydroxyflavone) is a major flavonoid widely distributed in edible plants. Among commonly consumed foods with high concentration of quercetin glycosides are onions, kale, apples (unpeeled), berries, citrus fruits, and tea plant *(Camellia sinensis)* **(Burak *et al.*, 2015).** Quercetin and its glycosides have sparked widespread interest because of their potential applications in illness prevention and treatment. Quercetin occurs naturally in both free and glycoside forms, including isoquercitrin, rutin, avicularin, hyperoside, quercetin, and others **(Hamed *et al.*, 2023).**
The antioxidant capacity and total phenolic content of the bread were significantly enhanced also by the quercetin fortification in the study of **Lin and Zhou (2018).**
Shiitake *(Lentinula edodes)*, an edible fungus, has long been used as part of the human diet thanks to its strong umami flavour and is used for medicinal purposes in various nations throughout the world. In recent years, numerous scientific materials on the nutritional value of shiitake mushrooms have been published. Furthermore, research efforts discovered that shiitake mushrooms contain significant levels of bioactive substances such as phenols and polyphenols. Those bioactive components found within shiitake mushroom have a variety of confirmed biological functions, including antibacterial, antioxidant, anticancer, antidiabetic, and antihypertensive actions **(Jiang *et al.*, 2015; Tian *et al.*, 2016).** Morphologically, we could divide Shiitake mushrooms into two parts: the cap and the stipe. The top part, the cap, is used usually in gastronomy, but the stipe is normally discarded due to its harsh texture. However, research have demonstrated that the stipe of the mushroom has a higher nutritional value and amounts of bioactive chemicals than the cap part **(Zhang *et al.*, 2013; Van Ba *et al.*, 2016).**
Compared to Shiitake, Maitake mushroom *(Grifola frondosa)*, is not primarily used as a part of diets. It is a giant fungus native to northern Japan and has long been employed in Japanese folk medicine. It is recently examined for many bioactive characteristics, drawing worldwide attention. Polysaccharides found in Maitake mushroom have been identified as numerous forms of glucans (e.g., β-1,6, β-1,3-) **(Masuda *et al.*, 2009)** and they were observed namely thanks to their numerous interesting biological actions, including anti-tumour, anti-hypertensive, antidiabetic, and anti-hyperlipidaemic properties **(Konno, 2007; Minamino *et al.*, 2008).** Maitake and Shiitake glucans are among the most extensively researched

glucans. Maitake mushroom extract is high in β-glucans, while Shiitake whole mushroom powder contains α-glucans. Active hexose correlated compound (AHCC) is an α-glucan-rich nutraceutical component derived from Shiitake and other *Basidiomycetes* mushrooms. AHCC was first created to decrease blood pressure, but strong immunostimulatory effects were discovered later **(Ina *et al.*, 2013; Větvička and Větvičková, 2014).**

The aim of our study was to observe antioxidant properties as well as possible changes in sensory properties of selected bakery products after addition of selected natural extracts (quercetin, curcumin, Shiitake and Maitake mushrooms) into the recipes.

MATERIAL AND METHODS

Material

In the experiment, 4 types of natural extracts in mixture with wheat flour were used for selected bakery products (wheat bread, sweet biscuits, salty crackers, and muffins); specifically: turmeric (*Curcuma longa*, L.) rhizome extract (curcumin), quercetin dihydrate extracted from the pods of *Sophora japonica*, L., and extracts from medicinal fungus Shiitake (*Lentinula edodes*) and Maitake (*Grifola frondosa*). The extracts were obtained from Natural Field (Xi'an Natural Field Bio-Technique Co., Ltd., Xi'an, China) and they fulfil the satisfactory results concerning heavy metal content and microbiological contamination as they are also being used in the pharmacological industry. Used wheat flour (Type 650) was from the commercial supplier (Mlyn Grznár, Veľké Hoste, Slovakia).

Preparation of experimental bakery products

The mixtures used during preparation of experimental breads included wheat flour T650 combined with natural substances (control [CH_WF]; quercetin addition of 2.5% [CH_Qu_2.5]; curcumin addition of 5% [CH_Cc_5]; Shiitake extract addition of 7.5% [CH_Sh_7.5] and Maitake extract addition of 7.5% [CH_Ma_7.5]). Addition of water was determined by the results of S-protocol (determined by the Mixolab, version 4.05, Chopin Technologies, Villeneuve-la-Garenne, France), ranging from 60.7% to 63.2%. All experimental breads were prepared by the same technological process. Other materials and further technological process was realized according to the methodology by **Bojňanská *et al.* (2024)**.

During the baking experiment II 3 kinds of sweet biscuits were prepared – with addition of quercetin and curcumin in amount of 2.5% ([S_Qu_2.5] and [S_Cc_2.5], respectively) and control biscuits without enrichment [S_WF], all in the amount of approximately 80 pieces. Basic recipe of biscuits as well as the technological process was the same, the only difference was the addition of extracts. Recipe and preparation were realized according to **Kolesárová *et al.* (2022)**.

In the baking experiment III, three kinds of salty crackers were prepared – with addition of extracts from medicinal fungus Shiitake a Maitake in amount of 10 % ([C_Sh_10] and [C_Ma_10], respectively) and control crackers without enrichment of medicinal mushrooms [C_WF]. Moreover, two types of muffins were prepared – with addition of 5% of curcumin [M_Cc_5] and control muffins without enrichment [M_WF], in amount of approximately 80 pieces per kind. Basic recipe of crackers (wheat flour T650, baking powder, olive oil, water, and salt) and muffins (made from wheat flour T650, sugar, baking powder, vanilla sugar, eggs, semi-fat milk and plant oil), as well as technological process were the same, only difference was in the selected enrichment.

Selected extracts additions of all products were determined in a previous small sensory testing realized by a panel of experienced evaluators. Baking of all experimental bakery products was made in the bakery oven (MIWE Condo, Arnstein Germany).

Dry matter

Determination of dry matter (DM) was carried out according to AACC Approved Method 44–15.02 **(AACC, 1999)**. Weighted samples were dried according to the method conditions and final DM was expressed as the proportion of the weight of the sample after drying from the original weight of the sample. Results of DM were evaluated for calculation purposes only in breads, sweet biscuits and salty crackers, and are presented in the Table 1.

Table 1 Dry mater of experimental breads (a), sweet biscuits (b), salty crackers (c)

Tab 2a. Breads					
Sample	CH_WF	CH_Qu_2.5	CH_Cc_5	CH_Sh_7.5	CH_Ma_7.5
DM (%)	90.310	90.249	90.818	91.029	91.051
Tab 2b. Sweet biscuits					
Sample	S_WF	S_Qu_2.5	S_Cc_2.5		
DM (%)	95.031	93.993	94.520		
Tab 2c. Salty crackers					
Sample	K_WF	K_Sh_10	K_Ma_10		
DM (%)	92.128	92.530	92.584		

Legend: WF – wheat flour; Qu – quercetin; Cc – curcumin; Sh – Shiitake; Ma – Maitake

Extracts preparation

Samples of bakery products were dried a laboratory temperature, homogenized and then 0.5 g was weighed on analytical laboratory scales. Subsequently, extraction took place for 2 hours at laboratory temperature in 80% ethanol on a laboratory shaker (MS 3 Control, IKA-Werke, Staufen im Breisgau, Germany). The obtained extract was filtered through filter paper and the supernatant was used for measurements (DPPH, total polyphenols content, and total phenolic acids content).

Antioxidant activity – DPPH radical scavenging assay

In the presence of antioxidants, the purple colour of the stable DPPH radical changes to yellow, and this colour change is recorded as a decrease in absorbance at 515 nm **(Sanchéz-Moreno *et al.*, 1998)**. For determination, 0.4 ml of extract and 3.6 ml of DPPH radical (2,2-diphenyl-1-picrylhydrazyl) were pipetted into the test tube. The samples were mixed on a laboratory vortex (Genius 3, IKA-Werke, Staufen im Breisgau, Germany) and placed in the dark for 15 minutes at laboratory temperature. Subsequently, the decrease in absorbance was monitored on a spectrophotometer (PV4, VWR, Radnor, USA) at a wavelength of 515 nm. The antioxidant activity was expressed as a percentage of DPPH radical inhibition compared to the inhibitory activity of Trolox.

Total polyphenols content

To determine the total amount of polyphenols, a calorimetric method with the Folin-Ciocalteu reagent was used. Polyphenolic compounds are reacting with the Folin-Ciocalteu reagent to produce a blue colour **(Singleton and Rossi, 1965)**. 0.5 ml of the extract was pipetted into the test tubes and then 0.1 ml of Folin-Ciocalteu reagent and 1 ml of Na_2CO_3 solution at a concentration of 20% were added. The samples were mixed on a laboratory vortex (Genius 3, IKA-Werke, Staufen im Breisgau, Germany) and placed in the dark for 4 hours at laboratory temperature. Subsequently, the absorbance was monitored on a spectrophotometer (PV4, VWR, Radnor, USA) at a wavelength of 700 nm. The total content of polyphenols is expressed as mg of gallic acid equivalent (GAE) in mg. g^{-1} sample (R2=0.9978) based on the gallic acid calibration curve in terms of dry weight.

Total phenolic acids content

For the determination of phenolic acids, a spectrophotometric method was used, which is based on an increase in absorbance – phenolic acids form a purple complex with Arnow reagent, the intensity of which is directly proportional to the absorbance **(Petitjean-Freytet, Carnat, and Lamaison, 1991)**. The following ingredients were successively pipetted into the test tubes: 0.5 ml of extract, 0.5 ml of 0.5 M HCl, 0.5 ml of Arnow reagent (10% $NaNO_2$ + 10% Na_2MoO_4), 0.5 ml of 1 M NaOH and 0.5 ml of distilled water. The samples were mixed on a laboratory vortex (Genius 3, IKA-Werke, Staufen im Breisgau, Germany) and subsequently the absorbance was measured on a spectrophotometer (PV4, VWR, Radnor, USA) at a wavelength of 490 nm. The content of phenolic acids was expressed as caffeic acid equivalent (CAE) in mg. g^{-1} (R^2=0.9996) based on the caffeic acid calibration curve in terms of dry weight.

Sensory evaluation

Experimental bakery products (bread, sweet biscuits, salty crackers, and muffins) were subjected to sensory analysis by a panel of trained evaluators (n=38). The detailed composition of the panel of evaluators was as follows: 26.3% men and

73.7% women; 23.7% of smokers and 76.3% of non-smokers; 52.6% of evaluators under 30 years of age and 47.4% of evaluators over 30 years of age (Figure 1). During the sensory evaluation of the prepared products, intensity of several characteristics and overall acceptability were evaluated. Considering the intensity (1 to 5 points; 1 – the lowest intensity and 5 – the highest intensity) products were evaluated according to the following descriptors:

- For breads: crust colour intensity, crumb colour intensity, aroma intensity, bread aroma intensity, other aroma, flavour intensity, bread flavour intensity and other flavour.
- For biscuits, crackers, and muffins: aroma intensity, presence and intensity of other aroma, taste intensity, aftertaste intensity.

During the hedonic evaluation of the bakery products, overall acceptability was monitored by the evaluators based on the assigned points (1 to 9 points; 1 – the lowest rating and 9 – the highest rating). During this evaluation, the evaluators had the opportunity to add a verbal comment. In the overall evaluation of experimental bakery products, preferences were also compared based on the composition of the evaluators (gender, smoking habits, and age – <30 or >30 years).

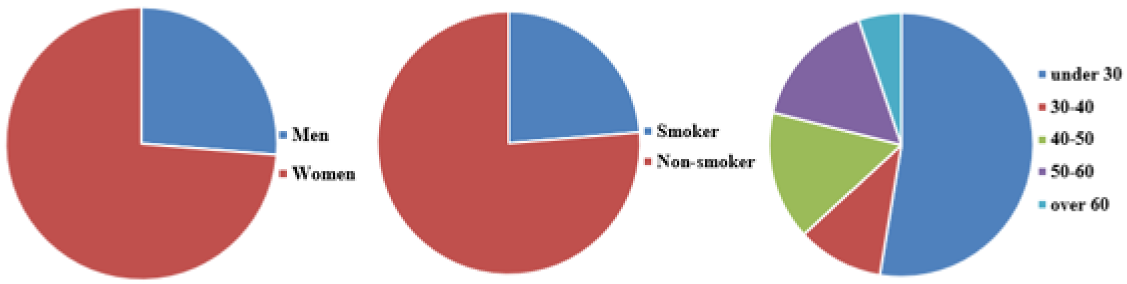

Figure 1 Structure of evaluators panel

Statistical evaluation of results

The realized analyses were performed in at least three repetitions. Microsoft Excel (Microsoft Corporation. Microsoft Excel 365, Redmond, Washington, DC, USA, 2018) was used to evaluate the obtained data, and the XLSTAT 2020.5.1 program (Lumivero, New York, NY, USA, 2023) was used for statistical analysis. Analysis of variance – ANOVA was used for statistical evaluation and Duncan's test was used to determine the evidence of statistically significant differences between individual samples ($P\leq0.05$). Correlations were evaluated between the measured values of antioxidant activity of breads, biscuits and crackers and their overall acceptability in sensory evaluation.

RESULTS AND DISCUSSION

Consumer awareness of the need to eat healthy and functional foods is increasing worldwide, and consumers are consequently favouring new, innovative foods that provide additional health benefits beyond basic nutritional requirements **(Ndlife and Abbo, 2009; Baba *et al.*, 2015)**. This trend is also associated with the development of various functional bakery products made from wheat flour enriched by natural non-bakery ingredients, with a positive effect on the health of consumers **(Dewettinck *et al.*, 2008)**. The use of wheat flour from the grain endosperm leads to the fact that baked products made from it lack components that have a higher added value, e.g. fibre, various phytochemicals with antioxidant potential and others **(Fardet, 2010; Sozer *et al.*, 2014)**. The addition of raw materials with expected nutritional benefits was implemented and evaluated within the presented results.

Evaluation of antioxidant activity

As part of the evaluation of experimental breads, sweet biscuits, and salty crackers with the addition of natural extracts, selected properties partially characterizing the nutritional quality were determined, namely the TAA expressed by the inhibition of the DPPH radical, the total content of polyphenols and the total content of phenolic acids (Table 2).

Table 2 Antioxidant activity of experimental breads (a), sweet biscuits (b) and salty crackers (c)

Sample	% Scavenging of DPPH •	mg GAE.g^{-1} in DM	mg CAE.g^{-1} in DM
Tab. 1a. Breads			
CH_WF	39.071 ± 3.455 d	2.080 ± 0.213 d	0.237 ± 0.017 d
CH_Qu_2.5	69.679 ± 0.741 a	20.623 ± 2.158 a	1.682 ± 0.008 b
CH_Cc_5	59.929 ± 0.724 b	18.934 ± 0.186 b	8.846 ± 0.047 a
CH_Sh_7.5	44.571 ± 3.395 c	2.095 ± 0.483 d	0.237 ± 0.009 d
CH_Ma_7.5	70.750 ± 3.941 a	4.431 ± 0.867 c	0.332 ± 0.006 c
***P*-value**	<0.0001	<0.0001	<0.0001
Tab. 2a. Sweet biscuit			
S_WF	13.214 ± 0.082 b	1.492 ± 0.602 c	0.661 ± 0.013 c
S_Qu_2.5	44.964 ± 0.244 a	18.117 ± 0.363 a	1.153 ± 0.025 b
S_Cc_2.5	45.321 ± 0.786 a	12.268 ± 0.382 b	3.286 ± 0.020 a
***P*-value**	<0.0001	<0.0001	<0.0001
Tab. 3a. Salty crackers			
C_WF	21.857 ± 1.212 c	1.925 ± 0.527 b	0.379 ± 0.034 b
C_Sh_10	44.393 ± 3.375 b	2.925 ± 0.604 a	0.279 ± 0.038 c
C_Ma_10	53.607 ± 0.442 a	3.674 ± 0.369 a	0.449 ± 0.046 a
***P*-value**	<0.0001	0.003	0.001

Legend: CH – experimental breads; S – sweet biscuits; C – salty crackers; M – muffins, WF – wheat flour; Qu – quercetin extract; Cc – curcumin extract; Sh – Shiitake extract; Ma – Maitake extract; results shown as mean ± standard deviation; a, b, c, d – different letters mean significant differences between groups ($P\leq0.05$)

The TAA (TAA) expressed as a percentage of DPPH radical inhibition was significantly higher ($P\leq0.05$) in all breads with the addition of natural extracts compared to the control bread without addition. The highest value of TAA was found in experimental bread with the addition of Maitake extract in the amount of 7.5% (Table 2a). Experimental bread with the addition of 2.5% of quercetin had a 3-times lower extract addition than bread with the addition of Maitake, but the radical inhibition value was found to be at the same level (Table 2a). The content of polyphenols in the experimental breads also fluctuated significantly depending on the natural extracts used. Their total content was significantly higher ($P\leq0.05$) in the bread with the addition of quercetin in the amount of 2.5% (Table 2a) and, compared to the control bread, it was demonstrably higher in the bread with the addition of 5% of curcumin and 7.5% of Maitake (Table 2a). On the other hand, the total content of phenolic acids was significantly higher ($P\leq0.05$) in the bread with the addition of 5% of curcumin, which was almost 6 times more than in the bread with the addition of 2.5% of quercetin (Table 2a). In general, we can state that the experimental breads have excellent antioxidant properties, especially the ones with the addition of quercetin and curcumin extracts. As for the experimental bread with the addition of Shiitake extract, it was comparable to the control bread. Sweet biscuits were made with the addition of quercetin and curcumin in the amount of 2.5%. When monitoring the parameters of antioxidant activity, similar results were found as with the experimental breads. The lowest percentage of radical inhibition ($P≤0.05$), as well as the lowest amount of total polyphenols content and phenolic acids was observed in the control biscuits without addition. While the TAA was similar in both types of biscuits with the addition of natural extracts, the total content of polyphenols was significantly higher ($P≤0.05$) in products with the addition of 2.5% of quercetin (Table 2b) and the total content of phenolic acids was significantly higher ($P≤0.05$) in cookies with the addition of 2.5% of curcumin (Table 2b). This may be related to the varied content of phenolic acids directly in the turmeric root, as reported by **Yang *et al.* (2020)**, on the other hand the plant *Sophora japonica* has a high content of quercetin and its precursor rutin **(Tian, Gong and Li, 2022)**, which largely contribute to the high content of total polyphenols content.

In the production of salty crackers, extracts of medicinal mushrooms Shiitake and Maitake were used in the amount of 10%. They are characterized by a pronounced mushroom taste, which is more suitable for salty products. In crackers with the addition of Maitake 10%, the best results ($P≤0.05$) were found in all monitored parameters of antioxidant activity. On the other hand, crackers with added Shiitake had significantly higher TAA and a higher content of total polyphenols content ($P≤0.05$) compared to the control, but a lower content of total phenolic acids content (Table 2c).

Despite the unfavourable sensory properties (as discussed below), our results indicate a high antioxidant activity and total polyphenol content in baked products with the addition of quercetin. This is in line with the results of **Lin and Zhou (2018)**, who observed a direct increase in polyphenol content and antioxidant activity in breads with different additions of quercetin. The authors further highlighted the ability of quercetin to inhibit the advanced glycation of end products during the protein glycation. Ferulic and coumaric acid are the main phenolic substances in cereals, however, during baking, their representation and form change **(Abdel-Aal and Rabalski, 2013)**. The highest values of phenolic acids were evidently found in experimental breads and biscuits with the addition of curcumin, so it is possible to assume their higher content even after baking the products. **Zhang *et al.* (2014)** investigated the addition of various bioactive compounds, including quercetin at 0.25%, to cookie dough. The authors found that the antioxidant activity and the detectable amount of polyphenols were lower in the finished cookies compared to dough, which points to the thermal instability of these substances. From this point of view, new innovative technologies such as microencapsulation might be suitable. **Ashraf *et al.* (2022)** observed an increase in the content of polyphenols, as well as an improvement in other technological parameters of bread with the addition of microencapsulated curcumin, compared to the use of unencapsulated turmeric powder.

The addition of medicinal mushroom extracts, especially Shiitake, to bakery products has been positively perceived from a sensory point of view, as discussed in the chapter below. The content of polyphenols did not change significantly after the addition of Shiitake extract compared to control products, which is in contrast to the results of **Toan and Thu (2018)**, who observed a constant increase in the amount of total polyphenols content in biscuits with the addition of dried Shiitake powder (5%, 10% and 15%) up to the value of 1.293 mg $GAE.g^{-1}$ at the highest addition. Furthermore, **Tu *et al.* (2022)** observed a lower glycaemic index of biscuits with the addition of Shiitake, black ear, and silver ear mushroom powder, which is positive in regulating glucose levels. **Szydłowska-Tutaj *et al.* (2023)** investigated the addition of dried Maitake and Enoki mushrooms in an amount of up to 10% to a pasta recipe. In the context of the addition of dried Maitake, the authors found almost twice the amount of flavonoids, but did not find differences in the total content of phenolic acids, and found only a slightly higher content of total polyphenols content.

In our research we used the extracts of medicinal mushroom, and this was probably the reason for the demonstrably higher total antioxidant activity, polyphenol content and phenolic acid content after the addition of Maitake extract in the amount of 10% compared to control breads and crackers. Furthermore, it should be noted that medicinal mushrooms such as Shiitake and Maitake are also a source of other valuable substances such as polysaccharides (beta-glucans), terpenoids, steroids, cerebrosides and various proteins with biological potential **(Blagodatski *et al.*, 2018)**. Regular consumption of designed bakery products can contribute to the improvement of selected health indicators as was confirmed in a clinical study among consumers who consumed cereal selenized onion biscuits with bioactive complex of selenium in organic form, quercetin (onion), curcumin (curcuma) and catechins (green tea) during the monitored period **(Maďarič *et al.*, 2013)**.

Table 3 Evaluated intensity characteristics of experimental breads

Sample	Colour of breadcrust	Colour of breadcrumb	Smell intensity	Intensity of bread smell	Other smell	Taste intensity	Intensity of bread taste	Other taste
CH_WF	2.250 ± 1.210 b	1.600 ± 1.051c	2.450 ± 1.175 b	3.200 ± 1.324 a	1.250 ± 0.783 b	2.850 ± 1.065	3.000 ± 1.211	1.450 ± 0.859 b
CH_Qu_2.5	2.750 ± 1.197 b	2.800 ± 0.769 b	2.900 ± 1.175 ab	3.150 ± 1.370 a	1.500 ± 1.517 b	3.050 ± 1.155	2.550 ± 1.293	2.250 ± 1.225 ab
CH_Cc_5	2.737 ± 1.405 b	3.421 ± 1.408 ab	2.789 ± 1.217 ab	2.105 ± 1.210 b	2.474 ± 0.746 a	3.421 ± 1.219	2.000 ± 1.179	2.789 ± 1.363 a
CH_Sh_7.5	3.762 ± 1.018 a	3.143 ± 0.933 b	3.429 ± 1.171 a	2.476 ± 1.366 ab	2.810 ± 1.283 a	3.429 ± 1.005	2.952 ± 1.383	2.286 ± 1.229 ab
CH_Ma_7.5	3.500 ± 0.935 a	4.100 ± 1.247 a	3.550 ± 0.913 a	2.100 ± 1.155 b	3.250 ± 1.599 a	3.450 ± 1.004	2.850 ± 1.192	2.550 ± 1.540 a
***P*-value**	0.001	<0.0001	0.013	0.015	<0.0001	0.213	0.073	0.022

Legend: CH – experimental breads; WF – wheat flour; Qu – quercetin extract; Cc – curcumin extract; Sh – Shiitake extract; Ma – Maitake extract; results shown as mean ± standard deviation; a, b, c, d – different letters mean significant differences between groups ($P≤0.05$)

Table 4 Evaluated intensity characteristics of biscuits, crackers and muffins

Sample	Smell intensity	Other smell intensity	Taste intensity	Aftertaste intensity
Table 4a: Sweet biscuits				
S_WF	3.139 ± 1.222 b	1.306 ± 0.668 b	3.611 ± 1.202 b	2.889 ± 1.389 b
S_Qu_2.5	3.389 ± 1.153 b	1.806 ± 1.167 ab	4.222 ± 1.174 a	4.889 ± 0.398 a
S_Cc_2.5	4.278 ± 0.974 a	2.167 ± 1.444 a	3.889 ± 0.667 ab	3.083 ± 1.317 b
***P*-value**	<0.0001	0.007	0.049	<0.0001
Table 4b: Salty crackers				
C_WF	2.513 ± 1.189 b	1.667 ± 1.155 b	2.821 ± 0.885 b	2.410 ± 1.229 b
C_Sh_10	3.846 ± 1.159 a	3.333 ± 1.493 a	4.013 ± 1.016 a	3.564 ± 1.373 a
C_Ma_10	4.077 ± 0.957 a	3.103 ± 1.410 a	3.872 ± 0.833 a	3.718 ± 1.123 a
***P*-value**	<0.0001	<0.0001	<0.0001	<0.0001
Table 4c: Muffins				
M_WF	3.838 ± 1.214	1.649 ± 1.476	3.730 ± 1.387	2.865 ± 1.686
M_Cc_5	3.216 ± 1.493	1.919 ± 1.622	4.081 ± 0.982	3.297 ± 1.431
***P*-value**	0.053	0.456	0.213	0.238

Legend: S – sweet biscuits; C – salty crackers; M – muffins, WF – wheat flour; Qu – quercetin extract; Cc – curcumin extract; Sh – Shiitake extract; Ma – Maitake extract; results shown as mean ± standard deviation; a, b – different letters mean significant differences between groups ($P≤0.05$)

Sensory evaluation

Sensory evaluation of food is considered an important part of the comprehensive assessment of innovative products, as it ultimately decides whether the developed product will be suitable for consumption. In general, designed products are evaluated in comparison with control (standard) mainly depending on the specific type and amount of non-bakery addition **(Callejo *et al.*, 2015; Toan and Thu, 2018; Boukid *et al.*, 2019; Ribeiro Oliveira *et al.*, 2020; Bojňanská *et al.*, 2024)**. The intensity of characteristics of the experimental breads differed significantly depending on the natural extracts used (Table 3). Considering the colours variety of the individual extracts, the colour intensity of the crust and crumb of the control bread without the addition of natural extracts was significantly lower ($P \leq 0.05$). In comparison to the control, the intensity of both crust and crumb was significantly higher ($P \leq 0.05$) in breads with the addition of medicinal mushroom extracts, which can also be seen in Figure 2 with photographs of individual products. The addition of various natural substances with a colouring effect to bakery products mainly changes the colour of the crumb, while the colour of the crust is more affected by changes associated with the Maillard reaction **(Abdellatif, Ziena and Rozan, 2023)**.
The evaluators clearly noted the highest intensity of aroma in breads with the addition of Shiitake and Maitake medicinal mushroom extracts ($P \leq 0.05$). This is also related to the significantly higher intensity of other aroma ($P \leq 0.05$). On the contrary, the highest intensity of the bread aroma was in the control bread without the addition of extracts. No differences were found in the intensity of the overall taste and bready taste. The intensity of other taste was different compared to the control in breads with the addition of curcumin and Maitake extract ($P \leq 0.05$), while the evaluators mentioned spicy (curcumin), mushroomy, bitter (Maitake), strongly bitter (quercetin) as other taste.
In the case of breads, a slight positive correlation was found between the overall acceptability of the product and the intensity of the bread taste (r=0.479). As for the intensity of other properties, the intensity of the smell was positively correlated with the intensity of the bread smell (r=0.320), but also with the intensity of other identified smells (r=0.330), but this was only a slight dependence.
The evaluation of intensity of other bakery products (biscuits, crackers, and muffins) aimed at determining the intensity of aroma and taste (Table 4). In the case of cookies, the sensory evaluation revealed the highest intensity of aroma and other aroma ($P \leq 0.05$) in cookies with the addition of 2.5% of curcumin, which is probably related to the naturally strong aroma of turmeric as a spice. On the other hand, the intensity of taste and other taste was evidently the highest in cookies with the addition of 2.5% of quercetin ($P \leq 0.05$). This is mainly related to its intense bitter taste, which was also reflected in the negative hedonic evaluation. Both types of experimental crackers with the addition of medicinal mushroom extracts in the amount of 10% had demonstrably more intense aroma, different aroma, taste, and other taste ($P \leq 0.05$) compared to the control crackers. According to the evaluators, the prepared two types of muffins (control and with the addition of curcumin 5%) had similar intensities of the observed characteristics ($P > 0.05$).

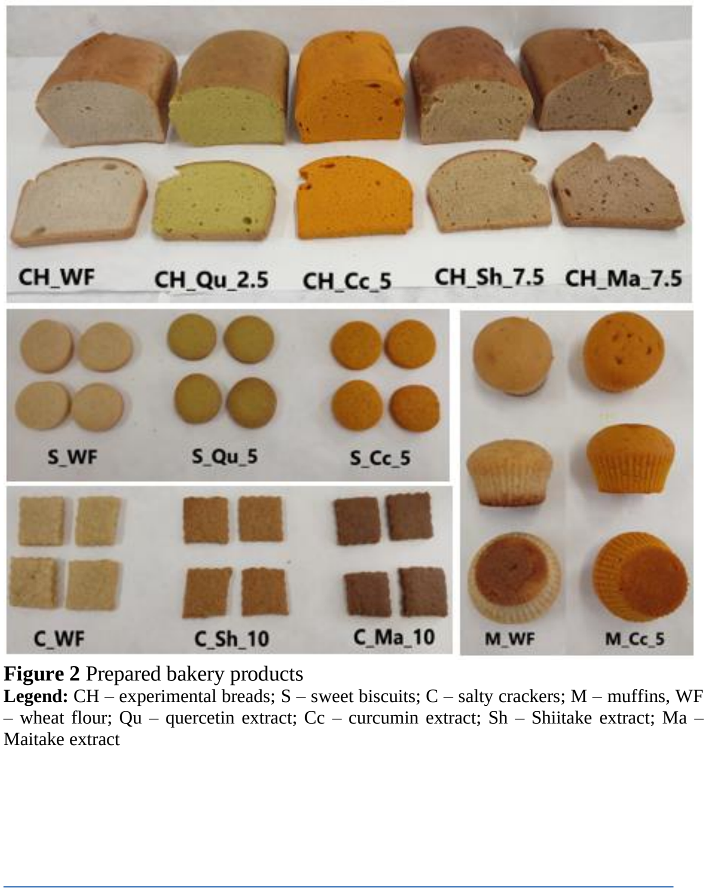

Figure 2 Prepared bakery products
Legend: CH – experimental breads; S – sweet biscuits; C – salty crackers; M – muffins, WF – wheat flour; Qu – quercetin extract; Cc – curcumin extract; Sh – Shiitake extract; Ma – Maitake extract

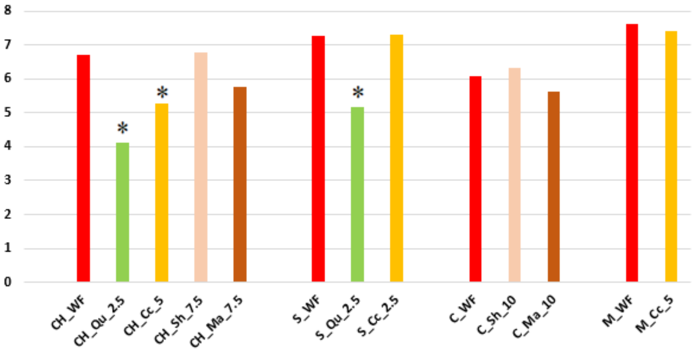

Figure 3 Overall acceptance of evaluated bakery products
Legend: CH – experimental breads; S – sweet biscuits; C – salty crackers; M – muffins, WF – wheat flour; Qu – quercetin extract; Cc – curcumin extract; Sh – Shiitake extract; Ma – Maitake extract; * means significantly different samples compared to control ($P \leq 0.05$)

In the case of cookies, a moderate negative correlation was found between overall acceptability and the intensity of the aftertaste (r=-0.399), in the case of muffins, a positive dependence was found between the intensity of the taste, the intensity of the aftertaste and the presence and intensity of a foreign taste, at the level of moderate to significant dependence (r= 0.471 – r=0.590). In the case of crackers, taste intensity was positively correlated with aftertaste intensity (r=0.369) and aroma intensity (r=0.462). However, it was a mild correlation.

Overall preference

The evaluation of the intensity of certain characteristics of individual bakery products was followed by a hedonic assessment, in which evaluators could express their preferences in relation to individual products (Figure 3). For the different categories of bakery products produced, control without the addition of extracts has generally always been well perceived. In the statistical evaluation compared to controls, breads with the addition of medicinal mushroom extracts were similarly positively perceived, while experimental breads with the addition of curcumin and quercetin were rated significantly worse (*P≤0.05*). For salty crackers with the addition of medicinal mushrooms in the amount of 10%, similar preferences were found as for breads, since designed crackers were rated similarly (Maitake) and slightly better (Shiitake) than control crackers.
In the case of sweet biscuits, the evaluation was probably influenced by the high intensity of the other (bitter) taste of biscuits with the addition of 2.5% of quercetin, which were evidently perceived by the evaluators as the worst ($P \leq 0.05$), compared to the control biscuits and biscuits with the addition of curcumin. Based on the results, the addition of 5% of curcumin was an appropriate choice for the second sweet product – muffins, which obtained a similar or only a slightly lower score than the control muffins.
Non-traditional breads can be less attractive for more conservative consumers, but for more progressive (courageous) consumers, atypical colour, taste, and aroma can make bakery products more attractive, as was recently stated by **Bojňanská *et al.* (2024)**. It was also confirmed in the presented results. The evaluation of overall preferences according to the composition of the evaluators panel (Figure 1) was also interesting. Salty products (breads and crackers) with the addition of extracts of medicinal mushrooms, namely Shiitake, were better perceived by the group of evaluators over 30 years of age, while the group of evaluators under the age of 30 appeared more conservative and preferred control products without the addition of extracts. Also, male evaluators and smokers preferred slightly Shiitake-supplemented bread over non-supplemented control breads, while for crackers, men rated the control sample better than the Shiitake-supplemented sample. For the sweet products, in all groups of evaluators the curcumin-added biscuits and control muffins were perceived slightly better.
Based on the complex sensory results, it can be concluded that the addition of Shiitake extract was evaluated very well, but it had less satisfactory results of antioxidant properties compared to the addition of Maitake. This is also confirmed by the results of **Toan and Thu (2018)**, who found comparable or slightly better results of the evaluators' overall preference for pastries with the addition of dried Shiitake powder in amounts of 5% and 10% compared to control pastries. The authors further state that the bread with an addition of 15% was already not acceptable by the evaluators. On the other hand, **Lin *et al.* (2008)** found significantly lower preferences among evaluators in bread with replacement of wheat flour with Shiitake powder in the amount of 5%, which is not in accordance with our findings.
The generally low rating of bread and biscuits with the addition of quercetin is conditioned by its specific bitter taste, what did not have a pleasant effect on consumers. Similar conclusions were reached by **Lin and Zhou (2018)**, who added quercetin to bread and observed the deterioration of the sensory properties of breads with increasing quercetin addition. On the other hand, the enrichment with curcumin was generally well perceived, which is also confirmed by the results of **Abdellatif, Ziena and Rozan (2023)**, who stated that a low enrichment of bread buns with turmeric powder resulted in an acceptable sensory score in terms of their

appearance and the nature of the crust, crumb colour, texture, aroma and taste and overall acceptability compared to control buns.

The fact is that non-bakery raw materials in most cases worsen the technological parameters of bread, which is associated with a worsened perception by consumers, as stated by several authors **(Sun-Waterhouse *et al.*, 2011; Świeca *et al.*, 2014; Sui *et al.*, 2016)**. It is necessary to individually determine their optimal additions and give appropriate recommendations. Some supplements, despite the health benefits, may be less acceptable already in lower concentrations, as the evaluators reported for quercetin. On the other hand, some products, especially with the addition of Shiitake extract and curcumin, can be evaluated as well as control products without enrichments. Moreover, the incorporation of non-bakery ingredients into bakery products would help significantly reduce the rate of starch digestion in breads and lower their glycaemic index, as confirmed in a study by **Lin *et al.* (2019)** after adding quercetin in amounts of 1.5 – 6% to bread. Non-bakery raw materials with expected biological value, but inappropriate sensory properties, can be processed with innovative technologies before application to food, e.g. by microencapsulation, which can contribute to a higher acceptability of such designed types of baked products. This was confirmed by **Ashraf *et al.* (2022)**, who found better sensory acceptability of breads with the addition of microencapsulated turmeric compared to the use of untreated turmeric powder.

Based on the comparison of nutritional benefits (antioxidant activity determined by DPPH radical scavenging method, total polyphenols content, total phenolic acids content) of designed products with the enrichment with non-bakery ingredients and their sensory acceptability, it can be stated that the best sensorially evaluated products were experimental breads and salty crackers with the addition of Shiitake and Maitake, and sweet biscuits with the addition of curcumin. The nutritional score in these products was compared to the control products evaluated at approximately the same level (experimental bread with 7.5% Shiitake), or significantly higher (experimental bread with 7.5% Maitake, salty crackers with the addition of 10% Maitake and 10% Shiitake, sweet biscuits with the addition of 2.5% curcumin). These non-bakery raw materials can therefore be recommended for cereal-based products.

CONCLUSION

The results presented based on our research aimed at verifying the application of extracts with nutritional potential confirmed that the path of development of innovative cereal foods leads to designed products with nutritional benefits and at the same time with good and acceptable sensory quality for consumers.

From the point of view of the antioxidant activity of cereal products (bread, salty crackers, sweet biscuits), the following was evaluated as the most effective in descending order: bread with the addition of quercetin extract of 2.5% > bread with the addition of curcumin extract of 5% > bread with the addition of Maitake extract of 7.5 % > sweet biscuit with the addition of quercetin extract of 2.5% > sweet biscuit with the addition of curcumin extract of 2.5% > salty crackers with the addition of Maitake extract of 10% > salty crackers with the addition of Shiitake extract of 10% > bread with the addition of Shitake extract of 7.5 %.

After a comprehensive evaluation of the sensory quality of the designed products, the following products can be recommended: muffins with the addition of 5% of curcumin, sweet biscuits with the addition of 2.5% of curcumin, experimental breads with the addition of 7.5% of Shiitake and Maitake, and salty crackers with the addition of 10% of Shiitake and Maitake. In conclusion, these non-bakery raw materials can be recommended for a production of new, innovative designed cereal-based products.

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