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Development of edible spoons using non-traditional flours

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ABSTRACT

This work aimed to develop edible spoons from non-traditional types of flour that could help reduce pollution related to the use of plastic cutlery. Moreover, the experimentally produced edible spoons were fortified with health-enhancing bioactive compounds from non-traditional flours. Edible spoons were made by blending different types of flours, including acorn, pumpkin seeds, poppy seeds, and wheat, with the addition of water to form a homogenous, formable dough. The spoons were baked at 180 °C for 10 min and subjected to a dryer to achieve an even firmer texture. Next, the following parameters were determined: total polyphenol content, composition of phenolic compounds, antioxidant activity, and the textural profile. The highest total polyphenol content was recorded in acorn flour samples, with a value of 14.0 mg GAE/g in the sample containing 30 % acorn flour. This sample also showed the highest antioxidant activity with a value of 127.3 μmol TE/g and the highest concentrations of rutin, myricetin, catechin, and naringenin. The highest hardness was recorded in the sample with the addition of 10 % acorn flour. Our study highlighted a simple and effective method of producing edible and biodegradable spoons, offering a sustainable alternative to single-use plastic cutlery.

1. Introduction

Plastics are durable and stable, but their decomposition can take from several decades to hundreds of years. Commercial plastic production began in the 1950s and led to improvements and facilitation of human life. However, due to improper disposal and the increasing accumulation of plastic in the environment, all organisms, including humans are threatened. Disposable plastic makes up approximately 50 % of the total plastic waste, contributing considerably to pollution and harming ecosystems worldwide. Most plastics are not easily biodegradable in the environment, and due to their low volume weight, they take up a large amount of space in landfills (Lebreton and Andrady, 2019; Prata et al., 2020; Ren, 2003; Hale & Song, 2020). Only 2 % of plastic packaging is recycled back into packaging (Defruyt, 2019). On 1 October 2022, Directive (EU) 2019/904 on reducing the impact of certain plastic products on the environment came into effect. This prohibition applies only to selected single-use plastic products, such as plastic plates, cutlery, straws, balloon sticks, and expanded polystyrene containers. However, the Directive does not completely ban the use of plastic. Starting in 2025, the percentage of recycled plastic to be used in the manufacture of single-use plastic products will be set at least at 25 %, calculated as an average for all PET bottles placed on the market in a member state. By 2030, this percentage will increase to at least 30 % (EU Directive 2019/904). The use of these plastics and the difficulties in their disposal represent a significant problem currently observed in the world. Some entrepreneurs are attempting to find a solution for disposable plastic by introducing options that can be biodegradable or eaten (Siddiqui et al., 2023; Manivel and Paramasivam, 2024). Edible cutlery not only has to be good in terms of biodegradability and eco-friendliness, but through fortification with different ingredients, it can transform into a nutritionally enriching food (Patil and Sinhal, 2018). By choosing edible cutlery, consumers can simultaneously support environmental sustainability and enhance their dining experience.

The primary aim of this study was to develop edible spoons and fortify them with unconventional types of flour, specifically pumpkin and poppy seed flours and acorn flour. These flours were chosen due to

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their nutritional benefits, including the high content of bioactive phenolic compounds. Additionally, their unique functional properties, such as binding capacity and texture enhancement, make them suitable for creating durable and palatable edible cutlery (Czerwonka and Białek, 2023; Levent and Aktaş, 2023). The second aim was to develop a product that meets the necessary physical and textural properties, making it practical for customers to use during the consumption of certain food commodities.

2. Material and methods

2.1. Spoon preparation

The edible spoons were developed from three different types of flours in varying proportions using water as a binding agent. For the production process, the following ingredients were used: fine wheat flour „Babiččina volba“ sourced from GoodMills Česko s.r.o, pumpkin and poppy seed flours from „Zdraví z přírody“ s.r.o. Zlín, Czech Republic, and acorn flour from „Dary Natury“ s.p., Poland. The basic nutritional composition of the flours used was summarized in Supplementary Table S1. Data are taken from the producers listed above. Ingredients following their respective percentages (5, 10, 15, 20, 30 %) were accurately weighted and mixed to create a homogenous dough (50 g of flour with 23 g of water). By using a pasta machine, uniform thickness of dough was ensured, which was afterward moulded into the silicone forms. The prepared spoons were baked at 180 °C for 10 min in a Unox Elena convection oven (Unox, Cadoneghe, Italy). In total, 15 distinct samples were prepared. The composition of each spoon is shown in Supplementary Table S2. After texture measurements, all samples were vacuum-packed and frozen before further analyses.

2.2. Determination of the texture profile

Texture attributes were measured using the TA.XT plus Texture Analyzer. A three-point stand was used for the measurement, on which the spoons were placed. The analyzer was calibrated to the specified matrix, specifically the “Comparison of the hardness and fracturability of shortbread and ginger nut biscuits by penetration with a cylinder probe”.

2.3. Determination of total polyphenol content

The total polyphenol content was determined on the Cecil Instruments CECIL CE 7210 spectrophotometer (Cecil Instruments, CE7210 DIET-QUEST, Cambridge, UK) at a wavelength of 765 nm. The concentration was measured using the Folin-Ciocalteu test, during which the oxidation of phenols changed the colour of the solution from yellow to blue. This method is commonly used as an indicator of the overall concentration of polyphenols in natural products (Cicco et al., 2009).

For the extract, 0.1 g of the sample was mixed with 20 mL of ethanol: water. The mixture was extracted for 30 min in an ultrasound water bath, then filtered, and 1 mL of sample was transferred to a 25 mL volumetric flask. Subsequently, 5 mL of a 1:10 diluted FC reagent and 4 mL of sodium carbonate were added. The samples were incubated in the dark at room temperature for 30 min. After the incubation, the samples were supplemented with distilled water. Absorbance was measured on a UV spectrophotometer at a wavelength of 765 nm against a blank sample (Abdullah et al., 2022). Results are presented as gallic acid equivalents (GAE) in mg/g.

2.4. Determination of antioxidant activity by the FRAP method (Ferric reducing antioxidant power assay)

The method is based on the principle of reducing ferric ions to ferrous ions. The method relies on the reduction of a colorless ferric-tripyridyltriazine complex (Fe^{3+}-TPTZ) to the intensely blue-colored ferrous form (Fe^{2+}-TPTZ) by antioxidants in the sample. The reduction leads to a measurable change in absorbance at 593 nm using a spectrophotometer. The intensity of the color correlates with the antioxidant power of the sample (Paulová et al., 2004).

Homogenized samples (0.1 g) were weighed and extracted with 20 mL of ethanol and water (1:1). The extraction was performed in an ultrasonic bath in the dark, followed by filtration. Sample preparation then involved combining 180 μL of the extract with 300 μL of H2O and 3.6 mL of the working solution. Following an 8-minute incubation period in the absence of light, the absorbance was measured at 593 nm (Abdullah et al., 2022). Results are presented as Trolox equivalents (TE) in μmol/g.

2.5. Determination of phenolic acids and flavonoids

For the quantification of phenolic compounds, homogenized samples (10 mg) were mixed with 1 mL of 80 % methanol and placed in an ultrasonic bath for 10 min. Subsequently, it was centrifuged at 14,500 g. After centrifugation, the supernatant was transferred to a new vial and stored at − 20 °C until the analysis. The samples were injected into a reverse phase column (Acquity BEH C18, 1.7 μm, 3.0 $m \times 150$ mm, Waters, Milford, MA, USA), where the mobile phase used was (A) 0.1 % formic acid in water and (B) 0.1 % formic acid in methanol at a flow rate of 0.4 mL/min and a linear gradient 5 % B for 3 min, 5–25 B % for 4 min, 25–3 % B for 6 min, 30–35 % B for 4 min, 35–60 % B for 6 min and 60–100 % B for 4 min with isocratic phase for 1.5 min followed by a return to 5 % B 10 s. The column temperature was maintained at 40 °C, and the backpressure ranged between 45 and 50 MPa throughout the entire chromatographic measurements (Cavar Zeljkovic et al., 2021). Levels of quantified compounds are presented as μg/kg.

2.6. Sensory analysis

The samples used for sensory analysis were prepared in the technological room at the Department of Plant Origin Food Sciences. In total, 4 different batches of experimentally produced edible spoon samples for each type of flour were prepared. Spoons were baked with relevant flour content, which was 5, 10, 15, and 20 %. Then they were dried in a food dehydrator (Ezidri Snackmaker FD500). To perform the sensory analysis a 9-point hedonic scale was used. The samples were evaluated by a group of 6 trained panelists. The assessment included the pleasantness of appearance, color intensity, fragrance intensity, surface characteristics, texture pleasantness, and overall acceptability.

2.7. Statistical analyses

Statistical analyses were conducted with SPSS software (version 23.0, SPSS, Chicago, IL, USA). The Levene test was used, followed by *t*-tests and one-way analysis ANOVA. Based on the results of Levene’s test, the homogeneity of variances was determined, with the help of which we chose the Games–Howell test at a value of Levene’s test of $p\langle$ 0.05 or the Tukey test at a value of $p\rangle$ 0.05. All data are presented as the mean ± standard deviation. Correlation matrix was performed in RStudio (Version 1.1.463 – © 2009–2018 RStudio, Inc.) using the *factoextra, FactoMineR*, and *corrplot* packages.

3. Results and discussion

Incorporation of the three flour samples at all examined concentrations yielded numerically higher hardness values relative to the control sample, but significant differences were observed only with the addition of pumpkin flour (Table 1). The concentration of 10 % acorn flour had the greatest effect on improving hardness. As the concentration of acorn flour increased further, hardness gradually decreased. This suggests that the addition of acorn flour improves hardness only up to a certain

Table 1
The texture profile of the spoons with varying percentages of pumpkin seed, poppy seed, and acorn flour.

Sample	Hardness (g)	Sample	Hardness (g)	Sample	Hardness (g)
C	1134.6 ± 623.5	C	1134.6 ± 623.5	C	1134.6^{ad} ± 623.5
5P	6856.8 ± 963.3	5PS	6097.1 ± 571.3	5A	8836.7^{ad} ± 2471.5
10P	5907.9 ± 1066.8	10PS	7991.0 ± 1168.2	10A	10,330.4^{c} ± 1808.7
15P	5478.3 ± 1821.9	15PS	6267.0 ± 1875.3	15A	6995.1^{bd} ± 2374.6
20P	5178.7 ± 2549.3	20PS	5731.9 ± 1348. 5	20A	6607.7^{bd} ± 1346.5
30P	5297.7 ± 984.3	30PS	5939.1 ± 571.3	30A	4000.4^{b} ± 1489.7

C – control sample (wheat flour); P – pumpkin flour; PS – poppy seeds flour; A – acorn flour; lowercase letters in the superscript indicate a statistically significant difference ($p < 0.05$) within the column, where significance was observed.

threshold, with the optimal concentration for enhancing this property being around 10 %. An increase in hardness following the addition of pumpkin flour to biscuits was also observed by Kulkarni and Joshi (2013). Specifically, they recorded a hardness of 3300 g with the inclusion of 10 % pumpkin flour, whereas the control sample exhibited a hardness of 2500 g.

Based on previous experiments, a temperature of 180 °C was chosen for the production of edible spoons, which showed a better effect on hardness compared to the higher temperature of 240 °C (Dordevic et al., 2021). In that study, the hardness of plastic spoons was also measured with values of 4006.3 ± 228.7 g and 9941.5 ± 82.3 g. These values were comparable with our present results on edible spoons. In the case of acorn flour with a concentration of 10 %, the measured hardness values were even higher than those of plastic spoons. The incorporation of acorn flour was previously observed to enhance the textural firmness of bread and various baked goods (Szabłowska and Tańska, 2020; Park al., 2017). In these studies, higher concentrations of acorn flour yielded progressively harder textures. Our findings indicate that the incorporation of acorn flour yields a statistically significant improvement in hardness compared to alternative flour types evaluated. This property can be attributed to the unique compositional characteristics of acorn flour.

Table 2 demonstrates how the total polyphenol content of experimentally produced spoons is affected by the substitution of pumpkin (P), poppy seed (PS), or acorn (A) flour. Among the spoons with the addition of pumpkin flour, a linear increase in the total content of polyphenols was recorded in samples from concentrations 10 to 30 %, with the highest total phenolic content (1.119 mg GAE/g) among spoons produced with the addition of pumpkin flour. Hussain et al. (2022) observed the effect of the addition of different types of pumpkin flour on the total polyphenol content of biscuits, where they showed that pumpkin seed flour contained the highest values of total polyphenols compared to pumpkin flour made from peel or flesh. When compared to our samples with pumpkin flour with concentrations of 5, 10, and 15 %, they recorded slightly higher values of 0.844, 0.925, and 1.018 mg GAE/g. Significantly higher values of total polyphenols were measured in a study by Wahyono et al. (2020), where they recorded values in bread samples with the addition of pumpkin flour from 4.16 mg GAE/g (control without pumpkin flour) to 16.16 mg GAE/g in bread with 20 % of pumpkin flour.

An increase in total polyphenol content was also noted with increasing concentrations of poppy flour, with the highest values when using 20 and 30 % concentrations (1.02 and 1.03 mg GAE/g). Wójcik et al. (2022) showed slightly higher values when they partially replaced a blend of flours with poppy seed flour in a sample with 15 %, where the content of total polyphenols was 1.05 mg GAE/g. The highest content of total polyphenols was recorded in samples with the addition of acorn flour, with an increase with increasing concentration, with the highest measured value of 14.04 mg GAE/g at a concentration of 30 %. Interestingly, already in the sample with a 5 % addition of this flour, the values were several times higher compared to poppy seed and pumpkin flour, even at the highest concentration of 30 %. The increase in total polyphenol content after the addition of acorn flour is also confirmed by other studies (Skendi et al., 2018; Martins et al., 2020), in which they observed the addition of this flour to gluten-free bread. Phenolic acids are also commonly present in the whole grain; however, in the production of flours, they are lost in the refining process (Rocchetti et al., 2017). For comparison, gluten-free non-traditional flours such as acorn or pumpkin are made only by grinding without refining processes (Silva et al., 2016; Ahmed et al., 2014), which may result in the preservation of bioactive substances in these flours.

The addition of all tested flours, including pumpkin seed, poppy seed, and acorn flours, resulted in a significant concentration-dependent increase in antioxidant activity, as determined by the FRAP assay (Table 3). Notably, acorn flour exhibited the most substantial effect on increasing antioxidant activity compared to pumpkin and poppy flours, which show more modest increases. In a study by Rana et al. (2022), the highest antioxidant activity was measured in pumpkin seeds compared to their pulp and skin, which points to the appropriate use of pumpkin seed flour to increase this property in foods as well as in edible spoons. Chmelová et al. (2018) suggested that bioactive compounds from poppy seeds can be used in food to increase the shelf life of the food and ensure health benefits. Different genotypes of selected poppy seed (*Papaver somniferum* L.) species contain varying levels of bioactive compounds. In a study on antioxidant activity and proteinase inhibition, the major genotype exhibited the highest antioxidant activity, with 31.61 mg Trolox/L, as measured by the FRAP method (Krošlák et al., 2017). Muhammad et al. (2021) also showed that different poppy species appear to be suitable for different potential uses of poppy, as an herbal medicine or food ingredient.

A spoon with an addition of acorn flour had the highest antioxidant activity from 24.559 to 127.304 μmol TE/g. According to Beltrao et al. (2020), antioxidant activity in gluten-free bread with 35 % of acorn

Table 2
Content of total polyphenols, presented as gallic acid equivalents mg GAE/g in the spoons with varying percentages of pumpkin seed, poppy seed, and acorn flour.

Sample	GAE (mg/g)	Sample	GAE (mg/g)	Sample	GAE (mg/g)
C	0.67^{a} ± 0.04	C	0.67^{a} ± 0.04	C	0.68^{a} ± 0.04
5P	0.73^{cd} ± 0.00	5PS	0.84^{c} ± 0.03	5A	3.25^{c} ± 0.08
10P	0.71^{d} ± 0.01	10PS	0.96^{d} ± 0.02	10A	6.26^{b} ± 1.28
15P	0.77^{bc} ± 0.03	15PS	0.88^{ce} ± 0.01	15A	8.66^{be} ± 1.20
20P	0.95^{c} ± 0.41	20PS	1.02^{b} ± 0.02	20A	9.69^{de} ± 0.20
30P	1.12^{c} ± 0.11	30PS	1.03^{b} ± 0.01	30A	14.04^{f} ± 0.25

C – control sample (wheat flour); P – pumpkin flour; PS – poppy seeds flour; A – acorn flour; lowercase letters in the superscript indicate a statistically significant difference ($p < 0.05$) within the column.

Table 3
Antioxidant activity determined via FRAP assay (expressed as Trolox equivalent (TE), μmol/g) in the spoons with varying percentages of pumpkin seed, poppy seed, and acorn flour.

Sample	TE	Sample	TE	Sample	TE
C	0.55^{a} ± 0.00	C	0.55^{a} ± 0.00	C	0.55^{a} ± 0.00
5P	4.16^{c} ± 0.18	5PS	4.16^{c} ± 0.07	5A	24.56^{b} ± 1.09
10P	4.14^{c} ± 0.20	10PS	4.17^{c} ± 0.03	10A	43.11^{c} ± 0.37
15P	4.25^{c} ± 0.23	15PS	4.09^{c} ± 0.10	15A	64.59^{d} ± 4.77
20P	4.87^{cd} ± 0.72	20PS	5.06^{d} ± 0.08	20A	81.25^{e} ± 5.27
30P	4.93^{bd} ± 0.15	30PS	6.42^{b} ± 0.16	30A	127.30^{f} ± 2.31

C – control sample (wheat flour); P – pumpkin flour; PS – poppy seeds flour; A – acorn flour; lowercase letters in the superscript indicate a statistically significant difference ($p < 0.05$) within the column.

flour was 0.064 μmol TE/g. In our study, a similar activity was observed with 15 % acorn flour. Gkountenoudi-Eskitz et al. (2023) demonstrated that adding acorn flour to gluten-free bread recipes enhanced both bioactive compound content and antioxidant activity, as measured by the FRAP method. This improvement was observed even at low levels of acorn flour fortification. It should be emphasised that while low levels of acorn flour fortification were beneficial, higher levels could potentially have negative effects on the bread's sensory properties (Levent and Aktaş, 2023; Beltrao et al., 2020).

Comprehensive LC-MS/MS analysis of free phenolic acids and flavonoids in designed spoons confirmed the findings presented above, i.e., phenolic content and antioxidant activity increase by boosting of content of pumpkin (P), poppy seeds (PS), and acorn (A) flours in prepared spoons. Fig. 1A and Fig. 1B represent the phenolic acid and flavonoid content in prepared spoons, respectively. The levels of each compound quantified are summarized in Supplementary Table S3.

The prepared spoons significantly differ in both the content and composition of phenolic acids and flavonoids. The major compounds in the spoons prepared using pumpkin (P) and wheat flour were salicylic acid glucoside (SaAG), free salicylic acid (SaA), and ferulic acid (FA). Their levels varied from 895.25 to 2959.43 μg/kg for SaAG, from 163.65 to 363.10 μg/kg for SaA, and from 179.60 to 377.92 μg/kg for FA. Spoons supplemented with poppy seeds (PS) flour were also rich in phenolic acids, with 4-hydroxybenzoic acid (4HBA), vanillic acid (VA), and FA. Their levels ranged from 92.29 to 334.92 μg/kg for 4HBA, from 242.21 to 576.88 μg/kg for VA, and from 156.76 to 280.91 μg/kg for FA.

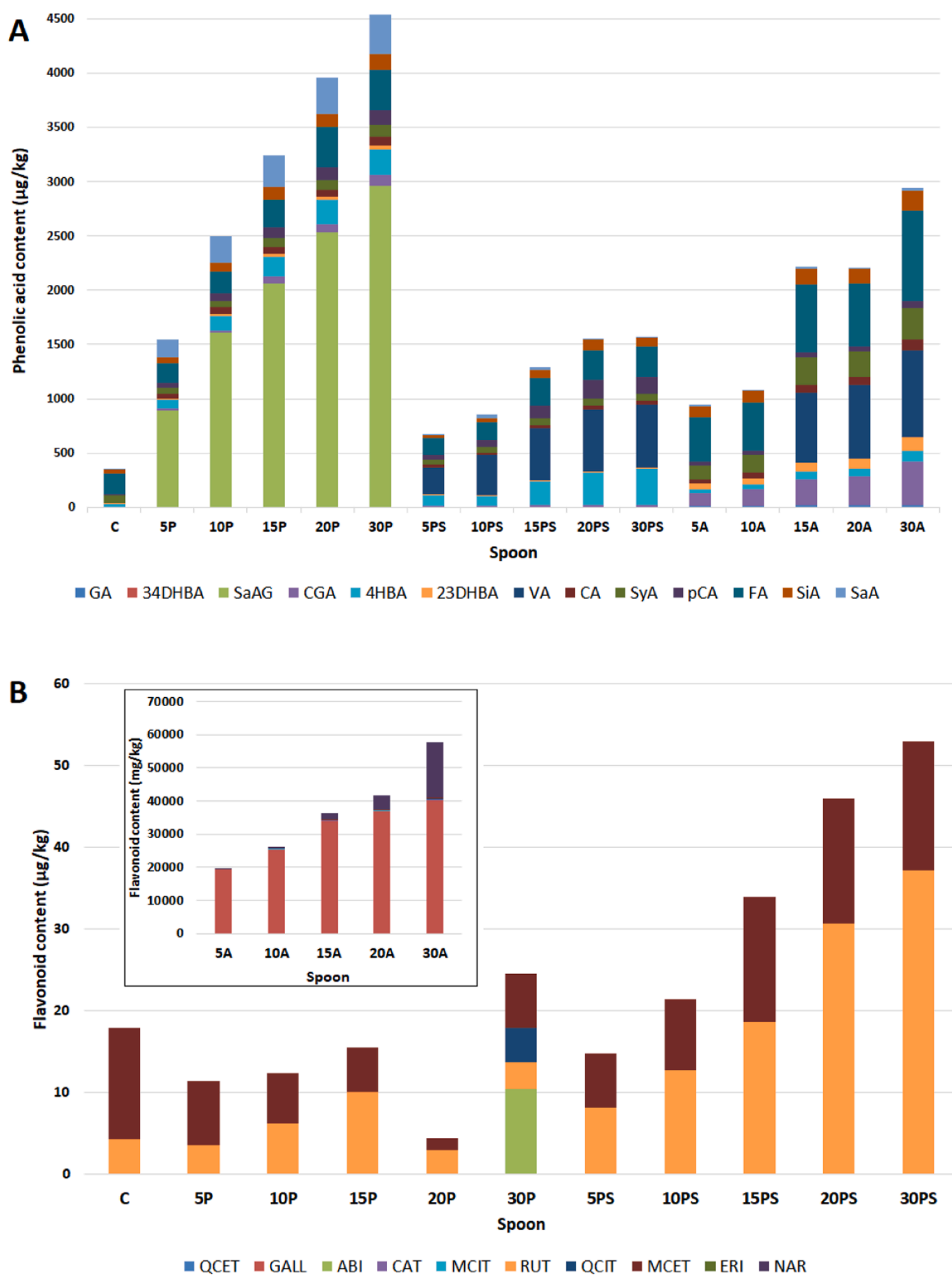

Fig. 1. Content of phenolic acids (A) and flavonoids (B) in prepared spoons.
GA – Gallic acid; 34DHBA – 3,4-Dihydroxybenzoic acid; SaAG – Salicylic acid glucoside; CGA – Chlorogenic acid; 4HBA – 4-Hydroxybenzoic acid; 23DHBA – 2,3-Dihydroxybenzoic acid; VA – Vanillic acid; CA – Caffeic acid; SyA – Syringic acid; pCA – p-Coumaric acid; FA –Ferulic acid; SiA –Sinapic acid; SaA – Salicylic acid; QCET – Quercetin; GALL –Gallocatechin; ABI –Abietin; CAT – Catechin; MCIT – Myricitrin; RUT – Rutin; QCIT – Quercitrin; MCET – Myricetin; ERI – Eriodictyiol; NAR – Naringenin.

Similarly, the spoons enriched with acorn (A) flour have a heterogeneous composition of phenolic acids, with FA, VA, and chlorogenic acid (CGA) as the main representatives. Their levels ranged from 408.08 to 829.76 μg/kg for FA, from 647.15 to 805.04 μg/kg for VA, and from 118.69 to 396.79 μg/kg for CGA. In addition, spoons prepared with acorn (A) flour were extremely rich in flavonoids gallocatechin (GALL) and naringenin (NAR), whose levels ranged from 19,330.12 to 40,033.55 μg/kg for GALL and from 95.396 to 16,620.85 μg/kg for NAR. Other samples of spoons, namely P and PS, contained small amounts of rutin (RUT) and myricetin (MYR), which were again higher in acorn (A0 spoons.

In addition, the correlation matrix presented in Fig. 2 illustrates the relationships between the total phenolic content, antioxidant activity, and hardness of prepared spoons, and the levels of the phenolic compounds present. Remarkably, the majority of the phenolic compounds, except for 3,4-dihydroxybenzoic acid (34DHBA), SaAG, 4HBA, *p*-coumaric acid (pCA), and SaA, exhibited notably high correlations with both the total phenolic content (TCA) and antioxidant activity (FRAP). This suggests that flavonoids are primarily responsible for the samples' ability to reduce stable cations, which was already shown in the literature (Ullah et al., 2020). Considering hardness, the correlation matrix shows just a slightly positive correlation with gallic acid (GA) and GALL, which is in agreement with the literature data (Oguz Ahmet et al., 2019; Zhu et al., 2022).

Table 4 shows the results of sensory analysis of experimentally produced edible spoons with the addition of pumpkin, acorn, and poppy seed flours. For most of the monitored parameters, the obtained score increased with increasing percentage of pumpkin flour, from which we can conclude its positive effect on the sensory properties of edible spoons, with the highest total acceptability score of 6.33 in samples with 20 % concentration of pumpkin flour. The best rating in overall acceptability among edible spoons with acorn flour was obtained by a sample with a 15 % addition. This sample also represents the best-rated sample compared to other types of edible spoons, with the addition of pumpkin and poppy seed flour. With a gradual increase in the concentration of acorn flour, an increase in acceptability was recorded in relation to the color of the spoons, but without a statistically significant difference. Similar to pumpkin flour, the addition of poppy seed flour recorded the best overall rating when using concentrations of 20 %, with the values of 6.5. With an increase in the concentration of poppy seed flour, an increase in the evaluation of almost all monitored parameters was also recorded. About color, a statistically significant difference was noted when comparing the samples with 5 % and other concentrations. On the results of sensory analysis in the tested samples, we observed that the addition of these non-traditional flours had a positive effect on the increase in overall acceptability, up to a concentration of 20 % in the case of poppy seed and pumpkin flour and up to a concentration of 15 in the case of acorn flour, but without a statistically significant differences ($p > 0.05$). It should be added that experimentally produced edible spoons were described as fully functional by trained panelists.

4. Conclusion

The incorporation of alternative flours—pumpkin seed, poppy seed,

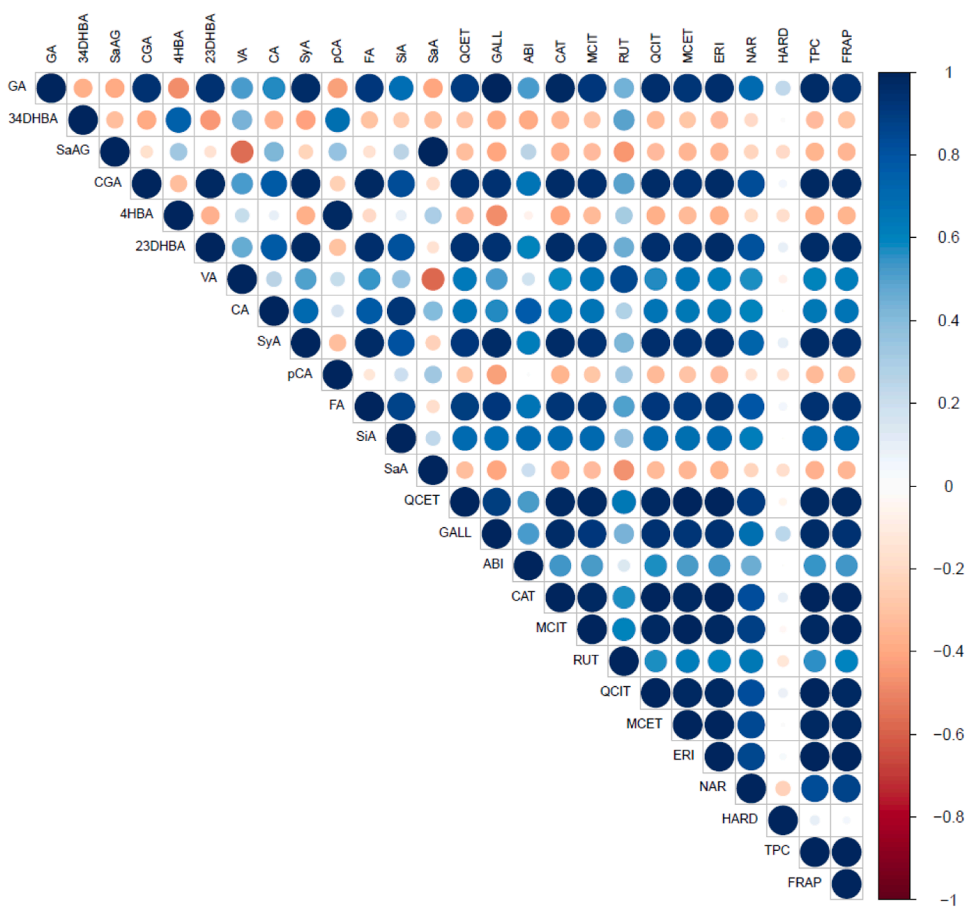

Fig. 2. Correlation matrix between total phenolic content, antioxidant activity, hardness, and the phenolic compounds in the prepared spoons.
GA – Gallic acid; 34DHBA – 3,4-Dihydroxybenzoic acid; SaAG – Salicylic acid glucoside; CGA – Chlorogenic acid; 4HBA – 4-Hydroxybenzoic acid; 23DHBA – 2,3-Dihydroxybenzoic acid; VA – Vanillic acid; CA – Caffeic acid; SyA – Syringic acid; pCA – p-Coumaric acid; FA –Ferulic acid; SiA –Sinapic acid; SaA – Salicylic acid; QCET – Quercetin; GALL –Gallocatechin; ABI –Abietin; CAT – Catechin; MCIT – Myricitrin; RUT – Rutin; QCIT – Quercitrin; MCET – Myricetin; ERI – Eriodictyiol; NAR – Naringenin; HARD – hardness; TPC – total phenolic content; FRAP – ferric reducing antioxidant power.

Table 4
Sensory evaluation of spoons with the addition of pumpkin flour.

Samples	appearance	color	scent	surface	texture	overall acceptability
5P	5.33 ± 2.25	5.00 ± 2.53	7.67 ± 0.81	4.83 ± 2.31	5.67 ± 1.97	5.33 ± 1.63
10P	5.83 ± 2.48	5.67 ± 2.50	8.33 ± 0.82	5.33 ± 1.75	6.17 ± 2.32	6.17 ± 1.94
15P	5.33 ± 2.88	6.00 ± 2.61	8.00 ± 0.00	4.83 ± 1.72	5.5 ± 2.43	5.67 ± 1.75
20P	6.00 ± 3.22	7.00 ± 2.09	7.83 ± 0.41	6.17 ± 3.21	6.33 ± 2.34	6.33 ± 1.97
5A	5.17 ± 1.94	4.5 ± 1.22	6.67 ± 1.51	5.67 ± 2.06	5.33 ± 2.16	5.5 ± 1.64
10A	5.17 ± 1.94	5.33 ± 1.21	7.33 ± 1.21	5.67 ± 2.06	6.17 ± 2.79	6.17 ± 2.40
15A	5.50 ± 2.73	6.00 ± 1.26	8.17 ± 0.75	6.5 ± 1.64	7.00 ± 1.67	7.33 ± 1.63
20A	5.67 ± 1.86	6.00 ± 1.67	7.17 ± 0.98	6.17 ± 1.72	6.33 ± 1.86	6.83 ± 1.47
5PS	4.50 ± 2.16	5.00 ± 1.54^a	7.17 ± 1.16	4.17 ± 1.64	5.33 ± 2.16	6.00 ± 1.41
10PS	4.50 ± 1.37	5.83 ± 0.75^b	7.67 ± 1.03	4.5 ± 2.13	5.5 ± 2.07	5.5 ± 1.87
15PS	4.83 ± 2.13	6.67 ± 1.21^b	7.33 ± 0.51	4.67 ± 1.96	6.33 ± 1.36	6.33 ± 1.36
20PS	6.00 ± 1.78	5.83 ± 1.47^b	8 ± 1.26	6.33 ± 1.21	6.67 ± 1.75	6.5 ± 1.51

C – control sample (wheat flour); P – pumpkin flour; PS – poppy seeds flour; A – acorn flour; lowercase letters in the superscript indicate a statistically significant difference ($p < 0.05$) within the same flour addition.

and acorn flour—into edible spoons significantly influenced their mechanical and functional properties. Among the tested flours, acorn flour consistently demonstrated superior performance in enhancing both textural and bioactive properties. In terms of hardness, all flour types resulted in increased values relative to the control, with acorn flour at 10 % yielding the greatest improvement. However, this effect plateaued or declined at higher concentrations, indicating an optimal threshold for acorn flour incorporation regarding mechanical strength. The phenolic content and antioxidant activity increased in a concentration-dependent manner across all flour types, with acorn flour showing the most significant enhancement. Notably, the total polyphenol content and FRAP values in acorn flour-enriched spoons were several-fold higher than those of pumpkin and poppy seed flours, even at the lowest substitution levels. These findings were corroborated by LC-MS/MS analysis, which revealed a rich profile of phenolic acids and flavonoids, particularly gallocatechin and naringenin, in spoons enriched with acorn flour. Furthermore, correlation analysis confirmed strong relationships between total phenolic content, antioxidant activity, and specific bioactive compounds, highlighting the critical role of flavonoids in contributing to the spoons' antioxidant capacity. The mechanical properties of hardness showed only a modest correlation with individual phenolic compounds, suggesting that factors beyond phenolic content, such as flour structure and composition, also influence textural attributes. The sensory acceptance of experimentally produced edible spoons was high, and the spoons were evaluated as fully functional. Overall, these results demonstrate that acorn flour is a highly promising ingredient for the development of functional, antioxidant-rich edible utensils with desirable mechanical properties. Its application could contribute to both enhanced sustainability in packaging and improved nutritional profiles of food-contact products. The purpose of using edible cutlery is to help reduce plastic pollution, which poses significant environmental challenges. Our study highlighted a simple and effective method of producing edible and biodegradable spoons, offering a sustainable alternative to single-use plastic cutlery.

CRediT authorship contribution statement

Dani Dordevic: Writing – review & editing, Supervision, Methodology, Data curation, Conceptualization. **Tomas Pencak:** Writing – review & editing, Writing – original draft, Visualization, Methodology. **Daniela Slamova:** Writing – review & editing, Visualization, Methodology, Formal analysis, Conceptualization. **Sanja Cavar Zeljkovic:** Writing – review & editing, Resources, Methodology, Funding acquisition, Formal analysis. **Bohuslava Tremlova:** Writing – review & editing, Supervision, Funding acquisition. **Galia Zamaratskaia:** Writing – review & editing, Data curation.

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.

Ethics statement

This study did not involve human participants or animal subjects.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.afres.2025.100995.

Data availability

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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