Physical and Sensory Properties of Bread Enriched with Phenolic Aqueous Extracts from Vegetable Wastes

Antonietta BAIANO, Ilaria VIGGIANI, Carmela TERRACONE, Roberto ROMANIELLO and Matteo Alessandro DEL NOBILE

Department of the Sciences of Agriculture, Food and Environment, University of Foggia, Foggia, Italy

Abstract

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The water of the breads was replaced with phenolic aqueous extracts from chicory, cabbage, celery, fennel, olive leaf, or grape marc wastes obtained through microwave-assisted extraction. The highest phenolic concentrations were found in the grape marc and in the bread enriched with it. The highest antioxidant activity values were measured in the crust of bread produced with the grape marc extract and in the crumb of bread with olive leaf extract. Generally, the replacement of water caused significant decreases of the specific volume, the shift of the crumb colour towards redder and yellower tones, and modification of gustatory and tactile attributes.

Keywords: antioxidant activity; functional food; phenolic compounds; sensory properties

In the traditional bread-making process, cereal flour, water, salt, and yeasts are mixed to make a viscoelastic dough that is then submitted to fermentation and baking (Sivam *et al.* 2010) operations. Since bread is an important component in the daily diet of most people around the world, it may be used to deliver fibre polysaccharides, prebiotics, polyunsaturated fatty acids, and phenolic compounds.

A simple way to fortify bread and other products whose processing includes the formation of dough consists in using an aqueous extract of antioxidants as water substitute. Many extracts of plants potentially usable in the food industry have been described (Bucić-Kojić *et al.* 2011; Radojkovic *et al.* 2012). The proposed extraction methods differ from each other although all of them include the use of hydroalcoholic solutions that are not suitable to be incorporated into foods. The microwave-assisted extraction using water as a solvent shows several advantages, including rapidity and reduction of environmental hazards.

By-products derived from the production of minimally processed vegetables could be a rich and cheap source of antioxidants. In fact, the increasing demand for processed plant products has led to a substantial increase of solid wastes.

The work described in the present study was aimed at waste valorisation and production of functional bread by replacing water with aqueous extracts of solid wastes from celery, chicory, cabbage, fennel, olive leaves, and grape marc.

MATERIAL AND METHODS

Plant material. The solid wastes derived from industries producing ready-to-use vegetables and located in the south of Italy. They were represented by external leaves and stems of chicory, celery, cabbage, and fennel, olive leaves, and grape marc.

Microwave-assisted extraction of the antioxidant fraction. The solid waste, finely chopped in an electric cutter, was added to tap water (solid-to-water ratio 1 : 1, w/w) to a final mass of 300 g, treated in a domestic microwave oven (JT 366, 6th sense; Whirlpool Europe, Comerio, Italy) at 750 W for 4 min, and filtered on a common filter paper. The liquid phase was used to replace water in bread-making.

Bread production. Seven types of bread were produced: a control and six breads in which the water was replaced by the aqueous extracts. The raw materials used to produce the bread samples were a soft wheat flour of type 0 (535.0 ± 2.1 g), tap water or aqueous extracts (300.2 ± 1.2 ml), sucrose (14.2 ± 0.5 g), salt (14.3 ± 0.3 g), and active dried *Saccharomyces cerevisiae* (7.2 ± 0.3 g).

The baking procedure was carried out in a loaf pan (17 cm in length, 13 cm in width) put in a bread-making machine PaneExpress (Ariete, Prato, Italy). It included the following steps: 1st kneading 5 min; break 5 min; 2nd kneading 20 min; 1st leavening 39 min; 1st fast stirring 10 s; 2nd leavening 30 min; 2nd fast stirring 10 s; further leavening 59 min; cooking 52 minutes.

After baking, the bread loaves were cooled and weighed. Subsequently, crust and crumb were separated and analysed.

Extraction of phenolic compounds. The phenolic fraction of crust or crumb was extracted according to the method reported in Zielinski *et al.* (2008) and analysed to determine the total phenolic content and the antioxidant activity.

Total phenolic content. It was determined according to the Folin-Ciocalteu method (Gorinstein *et al.* 2000) and expressed as mg of gallic acid equivalents per 100 ml of solid waste extract or as mg/kg of wet or dry crust and crumb.

Evaluation of the antioxidant activity. The antioxidant activity of the phenolic extracts was evaluated according to the ABTS [2,2'-azino-bis(3-ethyl-benzothiazoline-6-sulfonic acid)] (Re *et al.* 1999) and DPPH (2,2-diphenyl-1-picrylhydrazyl) (Brand-Williams *et al.* 1995) assays.

Results were expressed as mmol of Trolox equivalent per 100 ml of solid waste extract or as mmol of Trolox equivalent per kilogram of wet or dry crust and crumb.

Physical analyses of vegetable waste extracts and bread samples. The pH values of the vegetable waste extracts were measured using an Ion/pH/mV/Temperature bench meter (Oakton Instruments, Vernon Hills, USA). Moisture was measured on crust and crumb according to the AACC method (2003). The loaf volume was measured by the rapeseed displacement method and then divided by loaf weight to obtain specific volume (g/cm^3).

Image analysis of bread slices. A computer vision system (CVS) was used for 24 bit image acquisition of bread slices. The CVS was equipped with a Canon EOS 00D digital colour camera (Canon, USA) located vertically over the matte black background at a distance of 0.45 m. As standard setting conditions, the viewing/illuminating geometry was about 0/45. The images were acquired with the resolution of 3888 × 2592 pixels and stored in TIFF format. The image processing software was performed using the MATLAB v. 7.12 (MathWorks, Natick, USA) image processing toolbox.

The fields of view of the RGB images were segmented by principal components method (Gonzalez *et al.* 2004) in order to individuate the crumb cell region and calculate some morphological parameters such as mean cell area and eccentricity. The eccentricity is the ratio of the distance between the foci of the ellipse and its major axis length. The value is between 0 and 1, with 0 (circle) and 1 (line segment) being degenerated cases.

The colour of the bread crumb were calculated in L^*, a^*, and b^* units using the function of the MATLAB v. 7.12 image processing toolbox.

Sensory evaluation. The bread samples were analysed by conventional sensory profiling using seven trained panellists. The judges were selected and trained according to the guidelines in ISO/DIS 8586-1:1989 (Draft International Standard. Sensory analysis–Methodology–General guidance for the selection, training and monitoring of assessors. Part 1: Selected assessors) and the method for sensory profiling according to ISO 6564:1985 (International Standard. Sensory analysis–Methodology–Flavor profile methods).

The trained judges used a consensus list of 22 sensory attributes. A continuous non-structured scale was used for the evaluation. The left side of the scale corresponded to the lowest intensity (value 0) while the right side corresponded to the highest intensity (value 9). Breads were cut into slices (1.5 cm thick) that were served after two hours from preparation in a randomised order. Three samples were served in each session (one session per day). Between two tastings, panellists cleaned their mouth with tap water (20°C).

Statistical analysis. The extractions of the phenolic compounds were carried out at least three times and each type of bread was produced in triplicate. Analyses were performed at least in triplicate. The averages and the standard deviations were calculated using Excel software v. 11.5.1 (Microsoft, Redmond, USA). The analysis of variance (ANOVA) at $P < 0.05$ followed by the Fisher test was applied to highlight significant differences between samples. All the statistical analyses were done through the Statistica v. 7 software (Statsoft Inc., Tulsa, USA).

Table 1. Folin-Ciocalteu reaction applied to breads (crust and crumb) enriched with vegetable waste extracts

Types of bread	Wet crust	Dry crust	Wet crumb	Dry crumb
	(mg gallic acid eq/kg)			
Control	554.96 ± 75.55[a]	799.65 ± 108.87[a]	270.24 ± 48.57[b]	489.67 ± 88.00[b]
With chicory extract	574.91 ± 80.09[a]	777.87 ± 108.36[a]	347.00 ± 56.86[c]	592.99 ± 97.16[c]
With celery extract	556.03 ± 35.84[a]	729.07 ± 47.00[a]	239.65 ± 9.75[a]	405.25 ± 16.49[a]
With cabbage extract	647.64 ± 98.93[b]	892.38 ± 136.31[b]	629.47 ± 68.21[e]	1053.60 ± 223.68[f]
With fennel extract	750.86 ± 66.35[c]	1034.78 ± 91.45[c]	373.22 ± 32.08[d]	687.23 ± 59.06[d]
With olive leaf extract	530.89 ± 65.98[a]	777.79 ± 74.52[a]	731.51 ± 90.91[f]	820.14 ± 102.53[e]
With grape marc extract	790.67 ± 67.53[c]	1115.56 ± 95.28[d]	618.45 ± 90.35[e]	951.56 ± 152.59[f]

In columns, for each sample, different lowercase letters indicate significant differences ($P < 0.05$) between control bread and breads with phenolic extracts of the waste vegetable

RESULTS AND DISCUSSION

Determination of total phenolic content. The phenolic concentrations of the waste extracts, expressed as mg/100 ml, were in a descending order: grape marc 142.84 ± 8.20, olive leaves 88.96 ± 1.30, cabbage 27.41 ± 1.62, chicory 23.58 ± 1.24, fennel 18.70 ± 0.58, and celery 8.16 ± 0.19. The total phenolic contents of the breads are reported in Table 1. The first interesting evidence is the higher results of the Folin-Ciocalteu reaction applied to crust with respect to those referred to crumb in 5 (control, and with chicory, celery, fennel, or grape marc extracts) of the 7 types of breads. This difference was due to the contribution of the Maillard reaction products to the overall antioxidant contents of crust. In fact, the antioxidant properties are among the most interesting biological activities associated with such newly formed compounds (Delgado-Andrade & Morales 2005). Other bread components can

Table 2. Antioxidant activity of breads (crust and crumb) enriched with vegetable waste extracts, as measured by the DPPH (2,2-diphenyl-1-picrylhydrazyl) assay and ABTS [2,2'-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid)]

Types of bread	Trolox (mmol/eq/kg)			
	wet crust	dry crust	wet crumb	dry crumb
DPPH				
Control	0.09 ± 0.02[b]	0.13 ± 0.02[c]	0.04 ± 0.01[b]	0.07 ± 0.01[b]
With chicory extract	0.13 ± 0.02[c]	0.18 ± 0.03[d]	0.05 ± 0.01[b]	0.09 ± 0.01[b]
With celery extract	0.05 ± 0.02[ab]	0.09 ± 0.02[b]	0.02 ± 0.01[a]	0.01 ± 0.01[a]
With cabbage extract	nd[a]	nd[a]	nd[a]	nd[a]
With fennel extract	nd[a]	nd[a]	nd[a]	nd[a]
With olive leaf extract	0.16 ± 0.03[d]	0.22 ± 0.04[e]	0.48 ± 0.06[d]	0.64 ± 0.08[d]
With grape marc extract	0.23 ± 0.04[e]	0.32 ± 0.06[f]	0.18 ± 0.03[c]	0.32 ± 0.05[c]
ABTS				
Control	1.60 ± 0.30[bc]	2.30 ± 0.44[b]	0.84 ± 0.01[d]	1.51 ± 0.02[d]
With chicory extract	1.29 ± 0.23[a]	1.75 ± 0.30[a]	0.65 ± 0.04[b]	1.11 ± 0.07[b]
With celery extract	1.32 ± 0.12[ab]	1.73 ± 0.16[a]	0.55 ± 0.06[a]	0.93 ± 0.10[a]
With cabbage extract	1.71 ± 0.28[c]	2.36 ± 0.38[b]	0.75 ± 0.11[c]	1.27 ± 0.17[c]
With fennel extract	1.24 ± 0.22[a]	1.70 ± 0.30[a]	0.54 ± 0.10[a]	1.00 ± 0.18[ab]
With olive leaf extract	1.43 ± 0.27[b]	1.93 ± 0.37[ab]	0.87 ± 0.17[d]	1.35 ± 0.25[c]
With grape marc extract	1.87 ± 0.33[c]	3.15 ± 0.56[c]	1.39 ± 0.13[e]	2.34 ± 0.23[e]

In columns, for each sample, different letters indicate significant differences ($P < 0.05$) between control bread and breads with phenolic extracts of the waste vegetable; nd – not detected

Table 3. Physical characteristics of breads enriched with vegetable waste extracts

Types of bread	Moisture (%)		Volume (cm^3)	Weight (g)	Specific volume (cm^3/g)
	crust	crumb			
Control	30.6 ± 4.0^c	44.8 ± 6.2^{abc}	2320.5 ± 15.0^c	715.7 ± 10.5^a	3.24 ± 0.02^e
With chicory extract	26.15 ± 0.8^b	41.55 ± 0.3^a	2231.2 ± 10.2^b	769.9 ± 5.5^b	2.90 ± 0.03^b
With celery extract	23.75 ± 0.3^a	40.95 ± 0.8^a	2244.0 ± 5.0^b	775.4 ± 9.5^c	2.89 ± 0.05^b
With cabbage extract	27.42 ± 2.70^b	44.45 ± 0.33^c	2016.0 ± 10.3^a	788.9 ± 3.5^d	2.56 ± 0.05^a
With fennel extract	27.44 ±2.33^b	45.69 ± 1.36^c	2371.8 ± 5.6^d	765.2 ± 5.4^b	3.10 ± 0.04^d
With olive leaf extract	26.06 ± 2.39^b	44.39 ± 0.35^c	2016.0 ± 8.7^a	777.7 ± 6.6^c	2.59 ± 0.07^a
With grape marc extract	29.12 ± 2.07^c	42.16 ± 0.18^b	2392.0 ± 6.5^e	785.3 ± 7.0^d	3.05 ± 0.08^c

In columns, for each sample, different lowercase letters indicate significant differences ($P < 0.05$) between control bread and breads with phenolic extracts of the waste vegetable

contribute to the total antioxidant content. An example is represented by the phenolic compounds present in wheat flour or added, although they can be degraded by heat (Del Castillo *et al.* 2002). The highest results of the Folin-Ciocalteu reaction were obtained on the crust of bread enriched with grape marc and fennel extracts, while control bread, and bread enriched with chicory, celery, and olive leaf extracts showed the lowest values. Concerning crumbs, the lowest values were detected in the bread enriched with celery extract, while the breads with cabbage and grape marc extracts showed the highest concentrations on a dry basis.

The values of the ratio between phenolic concentration in crumb and phenolic concentration in crust, referred to the wet weight, were in a descending order as follows: olive leaf (1.38), cabbage (0.97), grape marc (0.78), chicory (0.60), fennel (0.50), control (0.49), and celery (0.43). The values of this ratio, on dry matter basis, followed a similar order, with the exception of the inversion between olive leaf and cabbage: cabbage

(1.18), olive leaf (1.05), grape marc (0.85), chicory (0.76), fennel (0.66), control (0.61), and celery (0.56). These peculiar distributions of phenolics between crust and crumb are related to the nature of the baking process and of the type of phenolic compounds. Since the temperature of the crumb never exceeds 100°C while the crust reaches temperatures higher than 205°C, heating may alter the phenolic antioxidants to different extents and in different ways in the inner and outer part of the loaf (Sivam *et al.* 2010). Furthermore, different stability is detected among the individual phenolics (Wang & Zhou 2004). According to Horszwald *et al.* (2009), the same Maillard reaction products, able to react with the Folin-Ciocalteu reagent, can bind polyphenols to their protein backbones. The reduction of phenolic content could be just associated with the interactions between phenolic antioxidants and wheat proteins via hydrogen bonding during dough preparation (Wang & Zhou 2004).

Determination of bread antioxidant capacity. The DPPH assay measures the overall radical-

Table 4. Image analysis of control bread and breads enriched with vegetable waste extracts

Descriptors	Control	With chicory extract	With celery extract	With cabbage extract	With fennel extract	With olive leaf extract	With grape marc extract
Morphological parameters							
Cell area (mm^2)	0.98 ± 0.09^a	1.35 ± 0.43^a	0.90 ± 0.43^a	1.28 ± 0.35^a	1.37 ± 0.65^a	1.27 ± 0.31^a	1.58 ± 0.76^a
Cell eccentricity	0.78 ± 0.02^a	0.76 ± 0.04^a	0.77 ± 003^a	0.76 ± 0.03^a	0.78 ± 0.04^a	0.80 ± 0.04^a	0.80 ± 0.03^a
Chromatic parameters of crumb							
*L**	64.53 ± 0.89^e	38.78 ± 1.44^b	64.07 ± 1.32^e	56.74 ± 1.24^d	56.75 ± 1.89^d	54.94 ± 1.61^d	27.88 ± 1.72^a
*a**	1.33 ± 0.32^a	4.21 ± 0.55^c	0.96 ± 0.53^a	3.43 ± 0.25^b	2.58 ± 0.32^b	3.27 ± 0.72^{bc}	7.51 ± 0.63^d
*b**	21.07 ± 0.28^b	23.59 ± 0.72^c	20.82 ± 0.42^b	27.29 ± 0.22^d	26.73 ± 0.22^d	26.34 ± 0.69^d	4.99 ± 0.67^a

In lines, for each sample, different lowercase letters indicate significant differences ($P < 0.05$) between control bread and breads with phenolic extracts of the waste vegetable

scavenging activity of a sample whereas the ABTS assay is generally used to screen the relative radical-scavenging abilities of flavonoids and phenolics. According to the DPPH assay, the antioxidant activity of the vegetable extracts, expressed as mmol Trolox eq/100 ml, was in a descending order as follows: grape marc 239 ± 25, olive leaves 141 ± 11, cabbage 18 ± 3, fennel 19 ± 1, chicory 4 ± 1, and celery 1 ± 0. Based on the ABTS assay, the values were: grape marc 1145 ± 110, olive leaves 383 ± 35, cabbage 65 ± 8, fennel 54 ± 6, chicory 33 ± 3, and celery 15 ± 2. The linear regression between DPPH and ABTS values of the extracts showed a high correlation coefficient (R = 0.99, P < 0.05). Table 2 shows the antioxidant activity of crust and crumb of enriched and control breads. Based on the DPPH results of the bread crust, the antioxidant activity was: grape marc > olive leaves > chicory > control > celery. The DPPH results of the crumb were slightly different: olive leaves > grape marc > control and chicory > celery. When the ABTS assay was applied to the crust, the highest and the lowest antioxidant activity values were shown by the breads with grape marc and chicory/celery/fennel extracts. In the case of crumb, the highest concentrations of Trolox equivalents were detected in the bread with grape marc while the lowest antioxidant values were observed in celery/fennel breads. Low correlation coefficients were obtained by the linear regression between the results of the Folin-Ciocalteu reaction and the antioxidant activity measured by both the assays (the R values were lower than 0.72 at P < 0.05). In fact, although advanced Maillard reaction products and phenolic compounds are good scavengers of peroxyl and ABTS radicals, the antioxidant capacity of a baked product would derive from the synergistic effects of many factors also including thermal-induced degradative products (Rupasinghe *et al.* 2008), and polyphenol-polysaccharide complexes (Sivam *et al.* 2010). For these reasons, the antioxidant activity values of crust were always higher than those of crumb, except for the bread made with olive leaf extract, whose antioxidant activity values were coherent with the higher phenolic content of crumb with respect to crust.

Analyses of bread samples. The bread physical parameters are reported in Table 3. Moisture was the highest in the crust of control bread and bread with grape marc extract, while the lowest value was detected in bread with celery extract. The moisture percentage of crumb was in the following order: cabbage/fennel/olive leaf breads > grape marc extract breads > chicory/celery breads. The crumb moisture

values could be related to the presence of soluble solids in the extracts with a certain water holding capacity that slowed the migration of water from the inside to the outside during baking. This hypothesis would be confirmed by a significant increase of the bread weights followed by the replacement of water with the same volume of vegetable waste extracts. The control bread showed a great moisture variability.

The specific volume showed the following descending order: control > fennel > grape marc > chicory and celery > cabbage and olive leaf. Thus, the enrichment of bread with the extracts significantly lowered the specific volume. A previous study attributed this decrease to the acidifying effect of the adjuncts, which would denature the gluten network (Masoodi & Chauhan 1998). In fact, in the present work, the vegetable waste extracts had significantly lower pH values (between 6.20 and 6.50 for all the extracts with the exception of the grape marc one, whose pH was 3.57) than water (7.40). Nevertheless, it is also well known that the addition of bioactive ingredients may physically modify the development of bread dough (Sivam *et al.* 2011), since antioxidants can form complexes with proteins and/or polysaccharides. Such complexation reactions can occur reversibly via hydrogen bonding between hydroxyl groups of phenolic compounds and the carbonyl group of peptide residues of proteins, and the resultant complexes can be stabilised via covalent and ionic bonds between the phenolate and anion or cationic site of protein molecules. Complexation can also occur through hydrophobic interactions between polyphenols and proteins, or through a cross-link with different protein molecules (Sivam *et al.* 2010).

Morphological and chromatic parameters. As reported in Table 4, the replacement of water with the aqueous extracts left the cell area unchanged, thus leading to the hypothesis that different volumes of the various breads were due to a different number of cells. Eccentricity ranged between 0.72 and 0.84 without significant differences between samples. These values indicate the presence of elongated cells in the crumb cross-sectional area.

With the exception of bread produced with the celery extract, the addition of the extracts caused a significant decrease of crumb lightness and shifted the colour towards a redder tone. Concerning $b*$ values, the enriched breads showed yellower tones, while the bread with celery extract was similar to the control, and that enriched with grape marc showed lower values than the control.

Table 5. Sensory evaluation of bread enriched with vegetable waste extracts

Descriptors	Control	With chicory extract	With cabbage extract	With celery extract	With fennel extract	With olive leaf extract	With grape marc extract
Visual descriptors							
Colour (crumb)	3.60 ± 0.55[b]	6.40 ± 0.89[c]	1.00 ± 0.82[a]	1.33 ± 0.82[a]	1.83 ± 0.75[a]	4.00 ± 0.71[b]	7.00 ± 0.82[c]
Development (crumb)	4.20 ± 2.59[a]	4.33 ± 3.39[a]	3.50 ± 1.29[a]	6.50 ± 0.84[a]	3.83 ± 1.33[a]	2.80 ± 0.84[a]	3.50 ± 2.38[a]
Alveolation (crumb)	3.00 ± 1.41[a]	4.00 ± 2.97[a]	4.00 ± 2.16[a]	4.50 ± 2.07[a]	3.83 ± 1.60[a]	3.60 ± 0.89[a]	4.00 ± 1.41[a]
Visual elasticity (crumb)	7.80 ± 1.10[a]	5.83 ± 1.72[a]	5.25 ± 3.20[a]	6.17 ± 2.48[a]	6.00 ± 2.19[a]	6.60 ± 1.52[a]	6.25 ± 1.26[a]
Olfactory descriptors							
Global smell (crust and crumb)	5.00 ± 1.87[b]	3.83 ± 2.32[a]	3.50 ± 1.29[a]	4.50 ± 1.38[ab]	4.33 ± 2.34[ab]	6.40 ± 1.14[b]	6.25 ± 1.71[b]
Fragrance (crust and crumb)	5.20 ± 2.59[ab]	4.67 ± 1.03[ab]	4.25 ± 1.50[ab]	3.00 ± 1.26[a]	4.00 ± 1.67[a]	6.80 ± 0.45[b]	5.25 ± 2.50[ab]
Yeasty smell (crumb)	3.00 ± 2.00[a]	1.67 ± 1.75[a]	1.00 ± 1.41[a]	2.67 ± 1.51[a]	4.00 ± 2.97[a]	3.00 ± 3.08[a]	2.50 ± 0.58[a]
Toasted smell (crust)	1.40 ± 2.19[a]	0.17 ± 0.41[a]	1.25 ± 0.96[a]	1.33 ± 1.03[a]	1.83 ± 2.23[b]	nd[a]	1.75 ± 1.50[a]
Wheat smell (crust)	2.20 ± 2.59[a]	0.33 ± 0.52[a]	nd[a]	1.33 ± 2.07[a]	1.83 ± 1.60[a]	2.20 ± 1.48[a]	nd[a]
Other smells (crumb)	nd[a]	nd[a]	nd[a]	0.67 ± 1.63[a]	1.50 ± 2.51[a]	2.80 ± 1.64[ab]	4.25 ± 2.06[b]
Tactile, gustatory, and flavour descriptors							
Sweetness (crumb)	3.00 ± 2.92[ab]	1.50 ± 2.26[a]	5.25 ± 2.22[b]	2.67 ± 2.25[ab]	5.67 ± 1.97[b]	4.40 ± 2.07[b]	7.50 ± 0.58[c]
Saltiness (crumb)	2.50 ± 1.66[a]	3.83 ± 2.14[ab]	5.25 ± 2.50[b]	5.50 ± 2.26[b]	3.83 ± 2.04[ab]	3.40 ± 1.14[ab]	3.25 ± 3.20[ab]
Sourness (crumb)	nd[a]	1.17 ± 2.40[a]	1.25 ± 1.89[a]	1.17 ± 1.60[a]	1.50 ± 1.22[a]	2.60 ± 0.55[b]	6.00 ± 0.82[c]
Bitterness (crumb)	nd[a]	2.17 ± 2.71[a]	nd[a]	0.83 ± 1.33[a]	0.33 ± 0.82[a]	4.20 ± 0.84[b]	3.25 ± 3.20[ab]
Astringency (crumb)	0.20 ± 0.45[a]	3.00 ± 2.53[b]	0.25 ± 0.50[a]	0.33 ± 0.82[a]	nd[a]	nd[a]	nd[a]
Global flavour (crust and crumb)	4.00 ± 2.45[a]	5.67 ± 1.03[b]	5.25 ± 2.36[b]	4.83± 2.71[b]	nd[a]	4.40 ± 1.52[b]	0.50 ± 0.58[a]
Wheat flavour (crumb)	2.90 ± 1.75[ab]	1.83 ± 3.06[a]	1.75 ± 2.06[a]	1.67 ± 2.07[a]	2.83 ± 1.72[ab]	4.80 ± 1.79[b]	7.00 ± 0.82[c]
Other flavours (crumb)	nd[a]	1.50 ± 2.35[a]	2.00 ± 2.31[a]	1.33 ± 3.27[a]	0.83 ± 1.17[a]	3.60 ± 2.07[b]	2.25 ± 1.26[b]
Other flavours (crust)	nd[a]	nd[a]	1.50 ± 3.00[a]	nd[a]	1.00 ± 2.45[a]	nd[a]	3.25 ± 3.20[a]
Cohesiveness (crumb)	6.20 ± 1.92[b]	3.83 ± 2.23[a]	6.25 ± 1.26[b]	5.50 ± 2.26[b]	3.67 ± 2.16[a]	1.80 ± 0.84[a]	6.50 ± 1.00[b]
Firmness (crust)	4.00 ± 1.58[b]	3.67 ± 1.51[b]	2.75 ± 1.71[b]	2.83 ± 2.23[a]	3.67 ± 1.51[b]	1.00 ± 0.71[a]	6.00 ± 3.83[c]
Crunchiness (crust)	3.60 ± 2.07[a]	2.83 ± 1.33[a]	2.50 ± 1.29[a]	4.00 ± 2.37[a]	7.00 ± 1.10[b]	6.80 ± 0.84[b]	7.25 ± 1.50[b]

In lines, for each sample, different lowercase letters indicate significant differences ($P < 0.05$) between control bread and breads with phenolic extracts of the waste vegetable; nd – not detected

Sensory analysis. The replacement of water with aqueous phenolic extracts from vegetable wastes substantially changed 15 out of the 22 sensory attributes (Table 5). The addition of chicory and grape marc extracts made the crumb colour darker, while the addition of cabbage and celery extracts increased lightness. No significant differences were observed for the other visual characteristics, i.e. development, alveolation, and visual elasticity.

The global smell was significantly lower in breads made with chicory and cabbage, while the fragrance was less intense in celery and fennel enriched bread.

Concerning gustatory descriptors, the bread produced with grape marc extract was sweeter and more sour than the others, while the bread enriched with cabbage and celery extracts had the highest saltiness, that made with olive leaf extract was judged as the bitterest, and the astringency was higher in bread enriched with chicory extract.

The global flavour was decreased by the addition of fennel and grape marc extracts while the wheat flavour was enhanced by the enrichment with olive leaf and grape marc extracts that also allowed the perception of their proper flavours in the crumb. The bread enriched with grape marc extracts showed the highest firmness and crunchiness while cohesiveness was reduced in bread made with chicory, fennel, and olive leaf extracts.

CONCLUSION

Vegetable wastes are rich in phenolic compounds, and their availability at a null cost makes them potentially promising ingredients for value-added food applications. The vegetable waste extracts derived from grape marc and olive leaves gave the breads with the highest phenolic contents and antioxidant activity. Physical and sensory properties were strongly modified by the addition of all the types of extracts.

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Corresponding author:

Dr Antonietta Baiano, University of Foggia, Dipartimento di Scienze Agrarie, degli Alimenti e dell'Ambiente, Via Napoli, 25-71122 Foggia, Italy; E-mail: a.baiano@unifg.it