



ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

ARCHIVIO ISTITUZIONALE DELLA RICERCA

Alma Mater Studiorum Università di Bologna Archivio istituzionale della ricerca

Determination of free and bound phenolic compounds and their antioxidant activity in buckwheat bread loaf, crust and crumb

This is the final peer-reviewed author's accepted manuscript (postprint) of the following publication:

Published Version:

Determination of free and bound phenolic compounds and their antioxidant activity in buckwheat bread loaf, crust and crumb / Verardo, Vito; Glicerina, Virginia; Cocci, Emiliano; Frenich, Antonia Garrido; Romani, Santina; Caboni, Maria Fiorenza. - In: LEBENSMITTEL-WISSENSCHAFT + TECHNOLOGIE. - ISSN 0023-6438. - ELETTRONICO. - 87:(2018), pp. 217-224. [10.1016/j.lwt.2017.08.063]

Availability:

This version is available at: <https://hdl.handle.net/11585/620822> since: 2018-02-08

Published:

DOI: <http://doi.org/10.1016/j.lwt.2017.08.063>

Terms of use:

Some rights reserved. The terms and conditions for the reuse of this version of the manuscript are specified in the publishing policy. For all terms of use and more information see the publisher's website.

This item was downloaded from IRIS Università di Bologna (<https://cris.unibo.it/>).
When citing, please refer to the published version.

(Article begins on next page)

This is the final peer-reviewed accepted manuscript of:

Vito Verardo, Virginia Glicerina, Emiliano Cocci, Antonia Garrido Frenich, Santina Romani, Maria Fiorenza Caboni, *Determination of free and bound phenolic compounds and their antioxidant activity in buckwheat bread loaf, crust and crumb*, LWT, Volume 87, 2018, Pages 217-224, ISSN 0023-6438,

<https://www.sciencedirect.com/science/article/pii/S0023643817306333>

The final published version is available online at:

<https://doi.org/10.1016/j.lwt.2017.08.063>

Rights / License:

The terms and conditions for the reuse of this version of the manuscript are specified in the publishing policy. For all terms of use and more information see the publisher's website.

This item was downloaded from IRIS Università di Bologna (<https://cris.unibo.it/>)

When citing, please refer to the published version.

Accepted Manuscript

Determination of free and bound phenolic compounds and their antioxidant activity in buckwheat bread loaf, crust and crumb

Vito Verardo, Virginia Glicerina, Emiliano Cocci, Antonia Garrido Frenich, Santina Romani, Maria Fiorenza Caboni



PII: S0023-6438(17)30633-3

DOI: [10.1016/j.lwt.2017.08.063](https://doi.org/10.1016/j.lwt.2017.08.063)

Reference: YFSTL 6485

To appear in: *LWT - Food Science and Technology*

Received Date: 7 April 2017

Revised Date: 18 August 2017

Accepted Date: 20 August 2017

Please cite this article as: Verardo, V., Glicerina, V., Cocci, E., Frenich, A.G., Romani, S., Caboni, M.F., Determination of free and bound phenolic compounds and their antioxidant activity in buckwheat bread loaf, crust and crumb, *LWT - Food Science and Technology* (2017), doi: 10.1016/j.lwt.2017.08.063.

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

1 **Determination of free and bound phenolic compounds and their antioxidant activity in**
2 **buckwheat bread loaf, crust and crumb**

3

4 Vito Verardo ^{1*}, Virginia Glicerina ², Emiliano Cocci ³, Antonia Garrido Frenich ⁴, Santina
5 Romani ^{2,5}, Maria Fiorenza Caboni ^{2,5}

6

7 ¹ *Department of Nutrition and Food Science, University of Granada, Campus of Cartuja,*
8 *18071 Granada, Spain.*

9 ² *Interdepartmental Centre of Agri-food Industrial Research (CIRI Agroalimentare), Alma*
10 *Mater Studiorum - University of Bologna, Quinto Bucci 336, 47521 Cesena (FC), Italy*

11 ³ *Agribologna Consortium, via Canali 1, 40127 Bologna, Italy*

12 ⁴ *Department of Chemistry and Physics (Analytical Chemistry Area) and Research Centre for*
13 *Agricultural and Food Biotechnology (BITAL), Agrifood Campus of International Excellence,*
14 *ceiA3, University of Almería, Carretera de Sacramento s/n, 04120 Almería, Spain.*

15 ⁵ *Department of Agricultural and Food Sciences, Alma Mater Studiorum - University of*
16 *Bologna, Piazza Goidanich 60, 47521 Cesena (FC), Italy*

17

18

19 * Corresponding author: Vito Verardo, Department of Nutrition and Food Science, University
20 of Granada, Campus of Cartuja, 18071 Granada, Spain. E-mail: vitoverardo@ugr.es

21

22

23

24

25 **Abstract**

26 This study demonstrated the role of buckwheat flour in improving phenolic compounds in
27 white wheat bread. Three bread samples were obtained by using different buckwheat levels
28 (10, 20 and 30%) in formulations. HPLC-ESI-MS was used to detect the presence of free and
29 bound phenolic compounds in bread loaf, crust and crumb. The phenolic profile changed
30 thanks to the addition of buckwheat flour; in fact, flavan-3-ols and flavonols compounds (i.e.
31 rutin, catechin, etc.) were identified in enriched buckwheat. As expected, the phenolic content
32 increased proportionally to buckwheat flour quantity in bread formulations. The total free
33 phenolic amounts ranged from 109 to 235 mg/kg d.w. in control bread and 30 % enriched
34 buckwheat bread, respectively. Bread crusts showed the highest total free and bound phenolic
35 content; however, flavan-3-ols, flavonols and flavones are more concentrated in crumb than
36 crust. Moreover, enriched breads showed higher *in vitro* antioxidant properties (evaluated by
37 DPPH and ABTS assays) than control one.

38

39

40

41 **Keyword:** *Fagopyrum esculentum* Moench, bread, phenolic compounds, radical scavenging
42 activity

43

44 **1. Introduction**

45 Wheat bread is considered to be a good source of energy for the human body. It is known that
46 bread obtained with natural raw ingredients such as cereals and seeds, spices, herbs and parts
47 of green plants, fruit or vegetable products and waste products from the food industry can be
48 enriched in antioxidant compounds (Blandino et al., 2013; Dziki, Rozyło, Gawlik-Dziki &
49 Swieca, 2014, Balestra, Cocci, Pinnavaia & Romani, 2011).

50 Foods based on wholegrain cereals, including bread, play an important role in human health
51 and well-being. It has been demonstrated that the regular consumption of wholegrain cereals
52 can contribute to reduce the risk of cardiovascular disease (CVD), type 2 diabetes mellitus
53 and certain types of cancer, as well as several gastrointestinal pathologies (Gil, Ortega &
54 Maldonado, 2011). The healthy properties of whole grains are linked to the presence of
55 bioactive compounds such as dietary fiber and phenolic compounds. Phenolic acids and
56 flavonoids represent the most common form of phenolic compounds found in whole grains,
57 and they are among the major and most complex groups of phytochemicals with a number of
58 types that exist as soluble free compounds, soluble conjugates that are esterified to sugars and
59 other low molecular mass compounds, and insoluble, bound forms (Zilic et al., 2011). Among
60 cereals and pseudo-cereals, buckwheat represents a good source of bioactive compounds.
61 These compounds are strictly related to the health benefits attributed to buckwheat including
62 plasma cholesterol level reduction, neuroprotection, anticancer, anti-inflammatory,
63 antidiabetic effects, and improvement of hypertension conditions (Gimenez-Bastida, &
64 Zielinski, 2015). Moreover, buckwheat is a gluten-free pseudocereal, for this reason, it can be
65 used for gluten-free products formulation. As reported by Gimenez-Bastida, Piskula and
66 Zielinski (2015), the buckwheat flour incorporation into a bread gluten-free experimental
67 formula affected positively the technological quality of the product, enriching its protein and
68 microelement contents.

69 Among the microelements, buckwheat is a source of several phenolic compounds such as
70 flavonols, flavan-3-ols, propelargonidins and phenolic acids (Verardo et al., 2010; Inglett,
71 Chen, Berhow & Lee, 2011; Verardo, Gomez-Caravaca, Segura-Carretero, Caboni &
72 Fernández-Gutiérrez, 2011) with antioxidant activity. Recently, Stokić and co-workers
73 (Stokić et al. 2015) stated that buckwheat-enriched wheat bread had higher content of dietary
74 fibers and phenolic compounds than wheat bread; moreover the same authors noticed that the
75 consumption of buckwheat enriched bread caused a significant decrease in total cholesterol,
76 LDL-cholesterol as well as the ratio of LDL/HDL cholesterol in statin treated patients.
77 Several studies have been developed to evaluate the phenolic content in buckwheat bread;
78 however, to our knowledge, literature lacks of information about phenolic distribution in
79 buckwheat bread. Because of that, and due to the health effects attributed to the phenolic
80 compounds of buckwheat, the aim of this study was to study in depth the content of free and
81 bound phenolic compounds in whole, crust and crumb of bread samples formulated with
82 different level of buckwheat flour (10, 20 and 30 %).

83

84 **2. Materials and methods**

85

86 *2.1. Samples*

87 Control bread and three bread samples obtained with wheat and different buckwheat flour (var.
88 Lileja from Umbria, Italy) levels (10, 20 and 30% on wheat flour quantity) were formulated.
89 All used ingredients were supplied by a local bakery company (Cesena, Italy). The list of
90 ingredients and related amount used for each kind of bread are reported in Table 1. In
91 particular, the wheat flour (type 0) used in this research, was a refined flour made from soft
92 wheat (extraction rate ~ 700 g/kg). The physicochemical characteristics of the wheat flour
93 used to develop the dough were: W= 270 10^{-4} J; P/L 0.5; moisture: 140 g/kg; ash: 6.5 g/kg;

94 dry gluten: 96 g/kg; protein content: 129 g/kg. The physicochemical characteristics of the
95 buckwheat flour were instead: moisture: 120 g/kg; ash: 20 g/kg; protein content: 105 g/kg.
96 Moreover, the buckwheat percentages used were chosen after preliminary trials, carried out in
97 order to obtain products with good technological properties, comparable to those of a standard
98 bread formulation (control bread).

99

100 *2.1.1 Sponge Preparation*

101 The sponge was prepared with 775 g of flour, 352 g of water and 7.75 g of brewer's yeast.
102 The main ingredients of the dough were kept constant: sponge (1136 g), salt (37 g), brewer's
103 yeast (39 g), improver (5 g) and water (510 g).

104 All ingredients were mixed in a kneading professional machine (Tauro –Sigma s.r.l, Brescia,
105 Italy). As a first step, refined wheat flour was mixed with water for 3 minutes at minimum
106 speed of 40 rpm, after that, sourdough was added and mixed for other 7 minutes, at the same
107 speed. After mixing, the obtained "sponge dough" was stored in a thermoclimatic chamber
108 (Constant Climate Chambers with Peltier technology, model HPP 108/749, Hemmert,
109 Germany) at 28°C for 24 hours, before to add it into the dough.

110

111 *2.1.2 Bread preparation*

112 Bread enriched with buckwheat was obtained by mixing the sponge previously prepared, with
113 the other ingredients: refined wheat flour, water, sodium chloride (NaCl), alpha-amylase and
114 the different percentages of buckwheat. All ingredients were mixed for 7 minutes at minimum
115 speed by using the same mixer used for the sponge preparation and let to leaven for 1 hour at
116 32°C and 70% of relative humidity in a thermoclimatic chamber (Constant Climate Chambers
117 with Peltier technology, model HPP 108/749, Hemmert, Germany). The baking of bread
118 samples was carried out in a professional oven for 20 minutes at 210°C (FC61, Angelo Po e

119 Grandi Cucine S.p.A, Carpi, Italy). After baking, bread samples were left to cool at room
120 temperature for 2 hours, before performing analysis. The volume of the resulting bread (mL/g)
121 was 3.3 ± 0.9 for the control; 3.2 ± 0.5 for the bread obtained with the addition of 10% of
122 buckwheat flour; 2.9 ± 0.1 for the product obtained with the addition of 20% of buckwheat
123 flour and 2.5 ± 0.2 for the bread with the 30% of buckwheat flour.

124 Each type of bread was produced in triplicate. After baking, crust and crumb were separated
125 from each bread sample, frozen in encoded plastic bags at -20°C and then freeze-dried
126 (Thermo HETO, powerdry LYOLAB 3000; Waltham, USA). Dried samples were ground to a
127 fine powder in a blender mixer (Ika-Werke M20; Staufen, Germany) and used for the analyses.

128

129 *2.2. Reagents and chemicals*

130 HPLC-grade acetonitrile, ethanol and methanol were purchased from Labscan (Dublin,
131 Ireland). Acetic acid analytical grade (assay $> 99.5\%$) was purchased from Fluka (Buchs,
132 Switzerland). Water was purified by using a Milli-Q system (Millipore, Bedford, MA, USA).
133 Other reagents were purchased from VWR (Denver, CO, USA). Analytical standards were
134 from Sigma-Aldrich (St. Louis, MO, USA).

135

136 *2.3. Extraction of free and bound phenolic compounds from control and buckwheat bread*

137 To determine the free and bound phenolic fraction of bread samples, the method developed by
138 Verardo et al. (2011) was applied.

139 Briefly, two grams of bread were extracted twice in an ultrasonic bath with a solution of
140 ethanol/water (4:1 mL/mL). The supernatants were collected, evaporated and reconstituted
141 with 2 mL of methanol/water (1:1 mL/mL). The extracts were stored at -18°C until use.

142 To obtain the bound phenolic fraction, residues of free phenolic extraction were digested with
143 200 mL of 2 mol/L NaOH at room temperature for 4 h by shaking under nitrogen gas. The

144 hydrolyzed solution was acidified to pH 2-3 by adding 10 mol/L hydrochloric acid in a cooling
145 ice bath and extracted with 500 mL of hexane to remove the lipids. The final solution was
146 extracted five times with 100 mL of 1/1 diethyl ether/ethyl acetate (mL/mL). The organic
147 fractions were pooled and evaporated to dryness. The phenolic compounds were reconstituted
148 in 2 mL of methanol/water (1:1 mL/mL).

149

150 *2.4. HPLC-ESI-MS analysis of phenolic compounds*

151 HPLC analysis was performed by an Agilent 1100 series LC system (Agilent Technologies,
152 CA, USA) consisting of a vacuum degasser, autosampler, and a binary pump equipped with a
153 reversed-phase Kinetex™ C18 (100 mm × 4.6 mm, 2.6 μm) column (Phenomenex Inc,
154 Torrance, CA, USA). The mobile phase and gradient program were used as previously
155 described by Gomez-Caravaca, Verardo, Berardinelli, Marconi and Caboni (2014). All
156 solvents were filtered with a 0.45 μm filter disk. The RP-HPLC system was coupled to a HP-
157 Mass Spectrometer Detector (MSD, model G1946A) equipped with an ESI interface peak
158 integration and data elaboration were performed using Chemstation software (Hewlett
159 Packard, Wilmington, DE, USA). Parameters for analysis were set using negative ion mode
160 with spectra acquired over a mass range from m/z 50–1300.

161

162 *2.5. DPPH radical scavenging activity*

163 The free radical scavenging activity of extracts (FRSA) was determined using the DPPH
164 assay according to Parejo, Codina, Petrakis and Kefalas (2000). Briefly, 0.1 mL of extract
165 was added to 2.9 mL of 100 μmol/L DPPH methanol solution. The absorbance was
166 determined at 517 nm after 30 minutes (at 25 °C). To assess the FRSA a Trolox calibration
167 curve was performed and the results were expressed as μmoles of Trolox equivalent/100 g of
168 bread d.w (dry weight).

169 The spectrophotometric analyses were performed using a UV-1601 spectrophotometer from
170 Shimadzu (Duisburg, Germany).

171

172 *2.6. ABTS Radical Cation Decolorization Assay*

173 The ABTS assay, was performed by using the method previously described by Re et al. (1999)
174 where the radical monocation $ABTS^{*+}$ is generated by oxidation of ABTS with potassium
175 persulfate and is reduced in the presence of hydrogen-donating antioxidants or with a standard.
176 Briefly, $ABTS^{*+}$ was obtained by reaction of 7.0 mmol/L ABTS and 2.45 mmol/L potassium
177 persulfate (stand in the dark at room temperature for 16 h). The $ABTS^{*+}$ stock solution was
178 diluted with water in order to obtain an absorbance of 0.700 ± 0.02 ($\lambda = 734$ nm). After that,
179 0.01 mL of sample extract was added to 1 mL of $ABTS^{*+}$ and stored in a dark room for 10
180 minutes. The absorbance was measured at 734 nm (at 30 °C). A Trolox calibration curve was
181 performed and the results were expressed as μ moles of Trolox equivalent/100 g of bread d.w.

182

183 *2.7. Statistical analysis*

184 All analyses were carried out in triplicate (n=3) for each sample. Tukey's honest significant
185 difference multiple comparison (one-way ANOVA) at a $p < 0.05$ level, and Pearson
186 correlations were evaluated using Statistica 8.0 software (2007, StatSoft, Tulsa, OK, USA).

187

188 **3. Results and discussion**

189 HPLC-ESI-MS has been used to identify and quantify the single phenolic compounds in
190 refined wheat and buckwheat flours (Supplementary table), and bread loaf, crust and crumb of
191 both control and buckwheat enriched bread samples.

192

193 *3.1. Determination of free phenolic compounds in control and buckwheat breads*

194 **Table 2** reports the free phenolic contents of control and buckwheat enriched bread loaf
195 samples. A total of twenty-seven phenolic compounds were identified in the analyzed samples;
196 however, control bread loaf showed the presence of only twelve phenolic compounds.

197 Among them, three hydroxybenzoic and seven hydroxycinnamic acid derivatives and two
198 flavones isomers were identified.

199 The total amount of phenolic acids and flavonoids increased from 37 to 97 mg/kg bread d.w.
200 and from 72 to 139 mg/kg bread d.w. from control to 30 % enriched buckwheat bread,
201 respectively.

202 As expected, control bread formulated with refined wheat flour showed the apigenin-6-C-
203 arabinoside-8-C-hexoside ((iso)-shaftoside) as principal free phenolic compound followed by
204 *trans*-ferulic acid. These data agreed with those reported by Gianotti et al. (2011). The content
205 of ferulic acid and other phenolic acids was in the same order of magnitude of that reported
206 by several authors (Abdel-Aal & Rabalski, 2013; Lu et al., 2014; Yu & Beta, 2015).

207 Buckwheat enriched breads, as control sample, showed the apigenin-6-C-arabinoside-8-C-
208 hexoside isomers, however their content decreased when buckwheat flour ratio increased.
209 This trend is justified by the presence of these compounds in wheat flour but not in buckwheat
210 flour. Similar trend has been observed for the ferulic acid isomers (*cis* and *trans*).

211 Contrary to control sample, buckwheat breads showed the presence of other phenolic
212 bioactive compounds (Verardo, et al. 2010; Inglett et al. 2011; Verardo et al. 2011) such as
213 flavan-3-ols, propelargonidins, flavonols among others.

214 The flavan-3-ols content increased from 10.4 to 18.3 % according to the increase of
215 buckwheat flour amount used in the bread formulations. In particular, catechin and
216 epicatechin epimers, and their mono- and di-galloylated derivatives are the main flavan-3-ols
217 detected in buckwheat bread.

218 Propelargonidins, such as afzelchin-catechin and afzelchin-catechin-dimethylgallate were
219 detected only in bread samples enriched with 20 and 30 % of buckwheat flour. Their content
220 represented the 1.4 % of total free phenolic compounds in both samples; however, their
221 amounts in bread were very low if compared with their content in buckwheat flours. This
222 suggested that this kind of compounds is thermally labile.

223 As expected, flavonols content increased from 8.4 to 12.1 % of total phenolic compounds in
224 enriched buckwheat breads; rutin was the main flavonol followed by isoquercitrin, quercetin
225 and hyperin. Rutin content was in the same order of magnitude of those reported by Lin, Liu,
226 Yu, Lin and Mau (2009) for buckwheat bread; however, the present results showed quercetin
227 amounts that were ten times higher than the data reported by Lin and co-workers (Lin et al.
228 2009); this could be justified by the different origin of the buckwheat flours. These results
229 encourage the use of buckwheat flour in bread formulation because, as reported by several
230 authors (Szawara-Nowak, Koutsidis, Wiczowski & Zielinski, 2014; Giménez-Bastida,
231 Zielinski, Piskula, Zielinska, & Szawara-Nowak, 2017), rutin and other buckwheat phenolic
232 compounds could be involved in the possible beneficial roles on the prevention of glycation-
233 associated diseases.

234 Flavones content decreased when buckwheat flour content increased; nevertheless, this trend
235 is due to the lower content of apigenin-6-C-arabinoside-8-C-hexoside, which is the principal
236 flavone in control bread. However, if the buckwheat flavone contribution has been considered,
237 it is very clear that orientin, isorientin, vitexin and isovitexin were determined only in
238 buckwheat breads and their content reached the high level when higher amounts of buckwheat
239 were used in bread formulation.

240 Finally, phenolic acid derivatives increased from 34% (control bread) to 41 % in bread
241 enriched with the highest amount of buckwheat flours. The total phenolic amounts improved
242 from 1.9 to 2.6 times in enriched breads compared with control. The main phenolic acid

243 derivatives that contributed to this improvement were syringic acid, *p*-hydroxybenzaldehyde
244 and swertiamacroside. Vanillic, syringic, *p*-coumaric, sinapic, dehydroferulic and sinapoyl-
245 hexose acid derivatives were detected in free form in formulated breads, but they are present
246 only in bound form in refined wheat and buckwheat flours. This confirmed the hypothesis of
247 other authors that mixing, sourdough fermentation and baking process facilitate the release of
248 bound phenolic compounds to its free form (Angeloni & Collar, 2011; Yu & Beta, 2015)

249 To better evaluate the distribution of phenolic compounds in control and buckwheat enriched
250 breads, the crumb was separated from the crust in each loaf samples; free phenolic fraction of
251 the two section of loaf is reported in **Table 3**.

252 Control and enriched samples showed that crust has the higher phenolic content compared to
253 the crumb. These data totally fitted with the results reported in other works (Balestra et al.,
254 2011; Lu et al. 2014; Yu & Beta, 2015). According to Vitali, Dragojevic, and Sebecic (2009)
255 the high content of phenolic compounds in crust should be due to the effect of baking
256 temperature that probably hydrolyzes some complex phenols resulting in an increase of
257 extractable phenolic content. Anyway, Gélinas and McKinnon (2006) hypothesized that also
258 Maillard reactions are involved to some extent in the content of phenolic compounds in bread
259 crust.

260 Only four phenolic compounds were determined in control crumb; basically, apigenin-6-C-
261 arabinoside-8-C-hexoside isomers represented more than 95 % of its total phenolic content;
262 minor phenolics were *trans* ferulic acid and *p*-hydroxybenzaldehyde. Twelve phenolic
263 compounds were quantified in control crust. Apigenin-6-C-arabinoside-8-C-hexoside was the
264 principal phenolic compound followed by the *trans* ferulic acid and their sum corresponds to
265 81.9% of total phenolic compounds.

266 To our knowledge, no studies on the distribution of phenolic compounds in buckwheat crumb
267 and crust was published; because of that, the comparison with literature is difficult.

268 The total phenolic content in the two loaf sections increased when higher buckwheat flour
269 ratio were used for formulation.

270 The first phenolic class in bread crumbs was the flavone; it represented the 69, 46 and 39 %
271 of total phenolic compounds in 10, 20 and 30 % buckwheat enriched bread, respectively. It is
272 important to underline that swertiamacroside was determined only in buckwheat bread
273 crumbs; probably, the high temperature in crust caused its degradation. Flavan-3-ols and
274 flavonols were the second and third phenolic fraction, respectively, and their content
275 increased when high amounts of buckwheat were used. Rutin amounts in the enriched breads
276 increased from 5 to 11 mg/kg of crumbs (corresponding to 4.2 and 9.6 % of total phenolic
277 compounds, respectively) when the buckwheat ratio reached the 30 % of flour formulation.

278 Higher amounts of flavonols such as rutin, quercetin, hyperin and isoquercitrin were
279 determined in crumb than in crust. This trend could result from the low thermal stability of
280 flavonol compounds as reported by several authors (Cho and Lee, 2015). Moreover, as
281 reported by Buchner, Krumbein, Rohn, & Kroh (2006), the presence of oxygen accelerates
282 the degradation of rutin and quercetin, because of that we could suppose that, due to the
283 structure of the crumb, the concentration of oxygen in crust is higher than in crumb thus low
284 amounts of rutin and quercetin were detected in the upper section of loaf. However further
285 analyses are needed to corroborate this aspect.

286 The main phenolic class in crust was the phenolic acid group that increased with the increase
287 of buckwheat flour quantity. The same trend was reported by flavan-3-ols that was the second
288 phenolic class ranged from 4.7 to 11.2 % of total phenolic fraction.

289

290 *3.2. Determination of bound phenolic compounds in control and buckwheat breads*

291 Twenty-four bound phenolic compounds were identified in the loaf of control and buckwheat
292 breads (**Table 4**). Flavonoids were the most abundant phenolic compounds in bread samples

293 ranging from 70.5 (control bread) to 97.4 (30 % buckwheat bread) mg/kg bread d.w.; phenolic
294 acid derivatives increased from 31 (in control bread) to 89 mg/kg bread d.w. (30 %
295 buckwheat bread).

296 As expected, the increase of the level of substitution of buckwheat flour was followed by the
297 increase of bound flavonols and flavan-3-ols content. Contrary, flavones decrease from 10.9
298 to 20 % compared to control according to the buckwheat level of substitution; however, as
299 reported for the free phenolic fraction, increased isovitexin, vitexin, orientin and isorientin
300 contents resulted proportionally to the quantity of buckwheat flour used in bread formulations;
301 in fact, these flavones are not characteristic of wheat flours.

302 With regards to individual bound phenolic compounds, apigenin-6-C-arabinoside-8-C-
303 hexoside resulted as the most abundant compounds in control and buckwheat breads, and their
304 content decreased when buckwheat flour levels increased. Syringic and *trans* ferulic acids,
305 and *p*-hydroxybenzaldehyde were other main bound phenolic compounds.

306 Ferulic acid content in control bread was in agreement with the data found by Yu, Nanguet
307 and Beta (2013) in bread made from refined flour.

308 It is important to underline that some compounds, such as quercetin and propylgallates,
309 were not detected in bound form, probably due to their degradation and/or hydrolysis.

310 The results of the bound phenolic compounds determined in crumb and crust are given in

311 **Table 5.**

312 The substitution of wheat flour with buckwheat one caused, in general, significant increase of
313 phenolic acids content in bread crust; contrary, flavonoids content decreased.

314 Apigenin-6-C-arabinoside-8-C-hexoside was the main phenolic compounds in crust and
315 crumb, and its content decreased when higher amounts of buckwheat flour have been added in
316 the formulation.

317 *Trans* ferulic acid was the second phenolic compound in bread crust; its content in crumb was
318 from 16 to 25 times lower than in crust. Moreover, the ferulic content in buckwheat breads
319 was lower than control bread. Similar trend has been showed by *p*-hydroxybenzaldehyde.

320 Crumbs of breads formulated with buckwheat flours contained increasing amounts of flavan-
321 3-ols (from 12 to 29 mg/kg bread d.w.) according to the buckwheat flour ratio added during
322 bread formulation.

323 Rutin was also detected in bound form and its content was higher in buckwheat bread crumb
324 than crusts confirming the low thermal stability of this compound as previously reported for
325 its free form.

326

327 3.3. Antioxidant activity of bread samples

328 The results of antioxidant activity measured by DPPH and ABTS radicals, and total phenolic
329 content, expressed as sum of each phenolic compound determined by HPLC-ESI-MS, are
330 reported in **Table 6**.

331 Total free phenolic content in bread loaf varied between 109 and 235 mg/kg bread d.w.,
332 buckwheat bread samples showed higher amounts of these compounds compared to control.

333 These data confirm the results showed in previous works (Angioloni, & Collar, 2011;
334 Szawara-Nowak, Bączek & Zieliński, 2016) that demonstrate as the multigrain bread
335 exhibited increased polyphenol content, higher polyphenol bioaccessibility and higher
336 antioxidant power than bread obtained with single grains.

337 Significant correlations have been found between total phenolic content and DPPH and ABTS
338 assay results. Briefly, DPPH assay showed a positive correlation ($r = 0.9354$, $p < 0.001$) with
339 total phenolic amounts, and according to Yu et al. (2013) and Yu and Beta (2015), crusts
340 showed the highest scavenging activity due to the high phenolic content and probably to the
341 high presence of Maillard reaction products that could react with DPPH radical.

342 Significant differences ($p < 0.05$) were found among the buckwheat bread samples; in fact high
343 ratio of buckwheat flour correspond to high phenolic content and radical scavenging activity.
344 Similarly, ABTS assay reported a positive correlation ($r = 0.9338$, $p < 0.001$) with free total
345 phenolic content in breads. ABTS scavenging capacity was comprised between 118 and 899
346 $\mu\text{moles TEAC}/100 \text{ g bread d.w.}$; according to results obtained by Yu et al. (2013) and Yu and
347 Beta (2015), crust samples showed the highest antioxidant capacity, and buckwheat breads
348 scavenging capacity increased when high buckwheat ratio was used during the bread
349 formulation.

350 High correlation was found between DPPH and ABTS assay results ($r = 0.9950$, $p < 0.001$).
351 Total bound phenolic compounds content ranged between 77 and 213 $\text{mg}/\text{kg bread d.w.}$ These
352 values are apparently in contrast with the data of other authors (Abdel-Aal & Rabalski, 2013;
353 Yu & Beta, 2015) which showed that bound phenolic content was higher than free phenolic
354 content in bread obtained with wheat flour; according to Yu et al. (2013), the bound phenolic
355 content in refined flour could be more than ten times lower than in whole wheat flours.

356 Antioxidant activity, measured by DPPH and ABTS assays, decreased with the diminution of
357 buckwheat flour quantity. As noticed for free phenolic fraction, in each kind of bread crust
358 samples showed higher antioxidant activity than in loaf, and the last one presented higher
359 antioxidant activity than crumb. These results could be justified by a strong Maillard reaction
360 development in crust than in crumb.

361 Positive correlations were found between total bound phenolic content and DPPH ($r = 0.7765$,
362 $p < 0.05$) and between total bound phenolic content and ABTS ($r = 0.8361$, $p < 0.05$).

363

364 **4. Conclusions**

365 The phenolic composition of bread samples enriched with buckwheat flour was compared
366 with refined wheat flour bread. The addition of buckwheat flour allowed the introduction of

367 flavan-3-ols, propelargonidins and flavonols (i.e. rutin among others) in bread. In this way,
368 the buckwheat breads could represent “functional” breads, permitting to introduce these
369 bioactive phenolic classes in the diet.

370 Bread crust contains higher amounts of phenolic compounds and higher antioxidant activity
371 than bread crumb; however, the phenolic classes distribution varied between the two zone of
372 bread loaf. In fact, flavonoids were more concentrated in crumb than crust probably due to
373 their low thermal stability.

374 Finally, this work improves the information about the phenolic content of buckwheat
375 enhanced wheat bread and, to our knowledge, the phenolic composition of crust and crumb of
376 buckwheat breads has been showed for the first time. However, further researches are needed
377 to explore the neo-formation/degradation/hydrolysis reactions of phenolic compounds during
378 baking process in order to clarify the effect of temperature on single phenolic compound.

379

380 **Acknowledgments**

381 Vito Verardo thanks the Spanish Ministry of Economy and Competitiveness (MINECO) for
382 “Juan de la Cierva” and “Ramon y Cajal” contracts.

383

384

385 **References**

386 Abdel-Aal, E.S.M., & Rabalski, I. (2013). Effect of baking on free and bound phenolic acids
387 in wholegrain bakery products. *Journal of Cereal Science*, 57, 312-318.

388 Angioloni, A., & Collar, C. (2011). Polyphenol composition and “in vitro” antiradical activity
389 of single and multigrain breads. *Journal of Cereal Science*, 53, 90-96.

390 Balestra, F., Cocci, E., Pinnavaia, G. & Romani, S. (2011). Evaluation of antioxidant,
391 rheological and sensorial properties of wheat flour dough and bread containing ginger powder.
392 *LWT - Food Science and Technology*, 44, 700–705.

393 Blandino, M., Sovrani, V. Marinaccio, F., Reyneri, A., Rolle, L., Giacosa, S., ... & Arlorio, M.
394 (2013). Nutritional and technological quality of bread enriched with an intermediated pearled
395 wheat fraction. *Food Chemistry*, 141, 2549–2557.

396 Buchner, N., Krumbein, A., Rohn, S., & Kroh, L.W. (2006). Effect of thermal processing on
397 the flavonols rutin and quercetin. *Rapid Communications in Mass Spectrometry*, 20, 3229–
398 3235.

399 Cho, Y.J., & Lee, S. (2015). Extraction of rutin from Tartary buckwheat milling fractions and
400 evaluation of its thermal stability in an instant fried noodle system. *Food Chemistry*, 176, 40–
401 44

402 Dziki, D., Rozyło, R., Gawlik-Dziki, U., & Swieca, M. (2014). Current trends in the
403 enhancement of antioxidant activity of wheat bread by the addition of plant materials rich in
404 phenolic compounds. *Trends in Food Science & Technology*, 40, 48-61.

- 405 Gélinas, P., & McKinnon, C.M. (2006). Effect of wheat variety, farming site, and bread-
406 baking on total phenolics. *International Journal of Food Science and Technology*, *41*, 329–
407 332.
- 408 Gil, A., Ortega, R. M., & Maldonado, J. (2011). Wholegrain cereals and bread: a duet of the
409 Mediterranean diet for the prevention of chronic diseases. *Public Health Nutrition*, *14*(12A),
410 2316–2322.
- 411 Gianotti, A., Danesi, F., Verardo, V., Serrazanetti, D.I., Valli, V., Russo, ... & Bordoni, A.
412 (2011). Role of cereal type and processing in whole grain *in vivo* protection from oxidative
413 stress. *Frontiers in Bioscience*, *16*, 1609-1618.
- 414 Giménez-Bastida, J. A., & Zieliński, H. (2015). Buckwheat as a functional food and its effects
415 on health. *Journal of Agricultural and Food Chemistry*, *63*, 7896–7913.
- 416 Giménez-Bastida, J.A., Piskula, M., & Zieliński, H. (2015). Recent advances in development
417 of gluten-free buckwheat products. *Trends in Food Science & Technology*, *44*, 58-65.
- 418 Giménez-Bastida, J.A., Zieliński, H., Piskula, M., Zielinska, D., & Szawara-Nowak, D.
419 (2017). Buckwheat bioactive compounds, their derived phenolic metabolites and their health
420 benefits. *Molecular Nutrition & Food Research*, *61*, 1600475.
- 421 Gómez-Caravaca, A.M., Verardo, V., Berardinelli, A., Marconi, E., & Caboni, M. F. (2014).
422 A chemometric approach to determine the phenolic compounds indifferent barley samples by
423 two different stationary phases: A comparison between C18 and pentafluorophenyl core shell
424 columns. *Journal of Chromatography A*, *1355*, 134–142.
- 425 Inglett, G.E., Chen, D., Berhow, M., & Lee, S. (2011). Antioxidant activity of commercial
426 buckwheat flours and their free and bound phenolic compositions. *Food Chemistry*, *125*, 923–
427 929.
- 428 Lin, L.Y., Liu, H.M., Yu, Y.W., Lin, S.D., & Mau, J.L. (2009). Quality and antioxidant
429 property of buckwheat enhanced wheat bread. *Food Chemistry*, *112*, 987–991.

- 430 Lu, Y., Luthria, D., Fuerst, E.P., Koszonas, A.M., Yu, L., & Morris, C.F. (2014). Effect of
431 processing on phenolic composition of dough and bread fractions made from refined and
432 whole wheat flour of three wheat varieties. *Journal of Agricultural and Food Chemistry* 62,
433 10431–10436.
- 434 Parejo, I., Codina, C., Petrakis, C., & Kefalas, P. (2000). Evaluation of scavenging activity
435 assessed by Co(II)/EDTA-induced luminol chemiluminescence and DPPH (2,2-diphenyl-1-
436 picrylhydrazyl) free radical assay. *Journal of Pharmacological and Toxicological Methods*,
437 44, 507-512.
- 438 Re, R., Pellegrini, N., Proteggente, A., Pannala, A., Yang, M., & Rice-Evans, C. (1999).
439 Antioxidant activity applying an improved ABTS radical cation decolorization assay. *Free*
440 *Radical Biology & Medicine*, 26, 1231–1237.
- 441 Stokic, E., Mandic, A., Sakac, M., Misan, A., Pestoric, M., Simurina, O., ... & Sedej, I.
442 (2015). Quality of buckwheat-enriched wheat bread and its antihyperlipidemic effect in statin
443 treated patients. *LWT - Food Science and Technology*, 63, 556-561.
- 444 Szawara-Nowak, D., Bączek, N., & Zieliński, H. (2016). Antioxidant capacity and
445 bioaccessibility of buckwheat-enhanced wheat bread phenolics. *Journal of Food Science and*
446 *Technology*, 53(1), 621–630.
- 447 Szawara-Nowak, D., Koutsidis, G., Wiczowski, W., & Zielinski, H. (2014). Evaluation of
448 the in vitro inhibitory effects of buckwheat enhanced wheat bread extracts on the formation of
449 advanced glycation end-products (AGEs). *LWT - Food Science and Technology*, 58, 327-334.
- 450 Verardo, V., Arráez-Román, D., Segura-Carretero, A., Marconi, E., Fernández-Gutiérrez, A.,
451 & Caboni, M.F. (2010). Identification of buckwheat phenolic compounds by reverse phase
452 high performance liquid chromatography-electrospray ionization-time of flight-mass
453 spectrometry (RP-HPLC-ESI-TOF-MS). *Journal of Cereal Science*, 52, 170-176.

- 454 Verardo, V., Gomez-Caravaca, A.M., Segura-Carretero, A., Caboni, M.F., & Fernandez-
455 Gutierrez, A. (2011). Development of a CE-ESI-microTOF-MS method for a rapid
456 identification of phenolic compounds in buckwheat. *Electrophoresis*, 32, (6-7), 669-673.
- 457 Verardo, V., Arráez-Román, D., Segura-Carretero, A., Marconi, E., Fernández-Gutiérrez, A.,
458 & Caboni, M.F. (2011). Determination of free and bound phenolic compounds in buckwheat
459 spaghetti by RP-HPLC-ESI-TOF-MS: effect of thermal processing from farm to fork. *Journal*
460 *of Agricultural and Food Chemistry*, 59, 7700–7707.
- 461 Vitali, D., Dragojevic, B., & Sebecic, B. (2009). Effects of incorporation of integral raw
462 materials and dietary fibre on the selected nutritional and functional properties of biscuits.
463 *Food Chemistry*, 114, 1462-1469.
- 464 Yu, L., Nanguet, A.L., & Beta, T. (2013). Comparison of antioxidant properties of refined and
465 whole wheat flour and bread. *Antioxidants* 2, 370-383.
- 466 Yu, L., & Beta, T. (2015). Identification and antioxidant properties of phenolic compounds
467 during production of bread from purple wheat grains. *Molecules*, 20, 15525-15549.
- 468 Zilic, S., Sukalovic, V. H. T., Dodig, D., Maksimovi, V., Maksimovi, M., & Basic, Z. (2011).
469 Antioxidant activity of small grain cereals caused by phenolics and lipid soluble antioxidants.
470 *Journal of Cereal Science*, 54, 417-424.

Table 1. Amounts (kg) of the different ingredients used for bread formulation

Ingredients	Control	BB 10%	BB 20%	BB 30%
Wheat flour (Type 0)	1.25	1.125	1.00	0.875
Buckwheat flour	-	0.125	0.25	0.375
Water	0.83	0.83	0.83	0.83
Brewer's Sourdough	0.06	0.06	0.06	0.06
NaCl	0.06	0.06	0.06	0.06
Alpha-amylase	0.01	0.01	0.01	0.01
Sponge	1.84	1.84	1.84	1.84

Table 2. Content of single free phenolic compounds and relative classes in control (white bread) and buckwheat enriched bread loaf samples expressed as mg/kg d.w.

Compound	Control	BB 10%	BB 20%	BB 30%
Vanillic acid	0.9±0.1 ab	0.8±0.05 a	1.5± 0.1c	1.9±0.2 d
Syringic acid	0.9±0.1 a	26.5±1.3 b	24.7±1.1 b	31.6±1.0 c
<i>p</i> -hydroxy-benzaldehyde	4.1±0.3 a	15.8±0.7 b	21.6±0.9 c	32.0±1.1 d
<i>p</i> -coumaric acid	2.2±0.2 a	2.3±0.3 a	3.8±0.6 b	5.2±0.5 c
Sinapic acid	4.7±0.6 d	3.6±0.2 c	2.0±0.2 b	1.9±0.1 a
<i>trans</i> ferulic acid	20.1±0.3 d	17.7±0.8 bc	16.4±0.5 b	14.8±0.4 a
<i>cis</i> ferulic acid	2.5±0.2 b	2.2±0.3 b	1.7±0.1 a	1.5 ±0.2a
Dihydroferulic acid Isomer I	0.3±0.03 c	0.2±0.01 b	0.1±0.02 a	0.1±0.01 a
Sinapoyl hexose	0.9±0.05 b	1.3±0.2 c	1.2±0.2 c	0.6±0.1 a
Dihydroferulic acid Isomer II	0.5±0.1 b	0.1±0.02 a	0.1±0.01 a	0.1±0.01 a
Apigenin-6-C-arabinoside-8-C-hexoside Isomer I	68.5±1.2 d	60.5±1.4 c	49.5±1.1 b	43.3±0.8 a
Apigenin-6-C-arabinoside-8-C-hexoside Isomer II	3.4±0.1 b	2.9±0.2 a	2.7±0.1 a	2.5±0.2 a
Catechin	-	3.7±0.2 a	12.8±0.9 b	15.7±1.0 c
Epicatechin	-	6.4±0.5 a	8.2±0.3 b	10.3±0.7 c
Afzelchin-catechin	-	-	2.2±0.3 a	1.8±0.1 ab
Swertiamacroside	-	2.3±0.4 a	7.9±0.2 b	8.9±0.5 c
Orientin	-	1.6±0.2 a	2.5±0.1 b	2.8±0.05 c
Isorientin	-	0.9±0.04 a	1.3±0.1 b	1.7±0.1 c
Rutin	-	5.0±0.1 a	6.3±0.6 b	9.7±0.4 c
Isoquercitrin	-	3.9±0.4 a	5.6±0.2 b	6.9±0.6 c
Vitexin	-	2.9±0.3 a	7.1±0.6 b	9.2±0.8 c
Epigallocatechin	-	5.4±0.3 a	7.1±0.1 b	8.1±0.4 c
Isovitexin	-	1.3±0.2 a	3.5±0.3 b	4.4±0.1 c
Hyperin	-	2.5±0.03 a	2.9±0.1 b	3.6±0.3 c
Afzelchin-catechin-dimethylgallate	-	-	0.7±0.2 a	1.5±0.4 b
Epicatechin-dimethylgallate	-	2.6±0.6 a	6.9±0.9 b	9.0±0.5 c
Quercetin	-	3.5±0.2 a	5.9±0.4 b	8.2±0.7 c
Sum phenolic acids	37.1±0.3 a	72.8±0.8 b	81.1±0.6 c	98.5±0.5 d
Sum flavones	71.9±0.6 d	70.0±0.7 c	66.6±0.7 b	63.9±0.5 a
Sum flavan-3-ols	-	18.2±0.5 a	37.9±1.2 b	46.3±1.1 c
Sum flavonols	-	14.8±0.6 a	20.7±0.9 b	28.4±1.3 c

BB= buckwheat enriched bread

Analyses were carried out in triplicate (n=3). Different letters in the same line indicate significantly different values ($p < 0.05$).

Table 3. Content of single free phenolic compounds and relative classes in crust and crumb of formulated breads expressed as mg/kg d.w.

Compound	Control		BB 10%		BB 20%		BB 30%	
	Crumb	Crust	Crumb	Crust	Crumb	Crust	Crumb	Crust
Vanillic acid	-	0.8±0.1 b	0.6±0.05 a	0.9±0.1 b	0.6±0.03 a	1.4±0.1 d	1.1±0.1 c	2.9±0.3 e
Syringic acid	-	0.9±0.1 a	-	25.0±0.9 d	1.9±0.1 b	45.6±1.3 e	2.3±0.1 c	58.8±1.6 f
<i>p</i> -hydroxy-benzaldehyde	1.5±0.1 a	6.7±0.4 e	1.7±0.05 b	30.0±1.4 f	2.7±0.2 c	40.6±1.6 g	3.1±0.1 d	61.5±1.8 h
<i>p</i> -Coumaric acid	-	2.0±0.6 d	0.1±0.03 a	4.6±0.8 e	0.5±0.05 b	7.1±0.4 f	0.7±0.1 b,c	9.7±0.3 g
Sinapic acid	-	4.6±0.3 c	-	3.4±0.1 b	-	2.9±0.2 a	-	2.4±0.4 a
<i>trans</i> Ferulic acid	2.1±0.04 b	38.0± e	1.9±0.05 a	33.5±0.8 d	2.4±0.1 b	30.1±1.4 c	2.5±0.1 b	28.6±1.3 c
<i>cis</i> Ferulic acid	-	2.3±0.1 d	-	1.8±0.04 c	-	1.5±0.02 b	-	1.4±0.03 a
Dihydroferulic acid Isomer I	-	0.1±0.01 a,b	-	0.04±0.001 a	-	0.1±0.01 a,b	-	0.1±0.01 a,b
Sinapoyl hexose	-	0.8±0.02 b	-	1.0±0.05 c	-	1.1 ±0.1 c,d	-	0.7±0.03 a
Dihydroferulic acid Isomer II	-	0.5±0.05 c	-	0.03±0.005 a	-	0.04±0.001 a	-	0.1±0.03 b
Apigenin-6-C-arabinoside-8-C-hexoside Isomer I	74.1±1.2 h	62.8±1.3 f	66.7±0.9 g	54.3±1.0 e	46.3±0.8 c	50.0±0.6 d	42.6±0.4 b	40.4±0.6 a
Apigenin-6-C-arabinoside-8-C-hexoside Isomer II	3.2±0.2 c	3.7±0.2 d	2.6±0.1 a	3.2±0.1 c	2.5±0.1 a	2.9±0.04 b	2.6±0.1 a	2.4±0.2 a
Catechin	-	-	0.4±0.03 a	3.1±0.2 b	8.7±0.6 c	14.9±0.4 e	12.2±0.8 d	17.2±0.9 f
Epicatechin	-	-	5.1±0.2 a	-	11.7±0.6 b	4.8±0.2 a	15.8±0.4 c	4.8±0.3 a
Afzelchin-Catechin	-	-	-	-	-	2.0±0.1 b	1.1±0.1 a	2.5±0.1 c
Swertiamacroside	-	-	2.7±0.2 a	-	7.5±0.1 b	-	8.1±0.3 c	-
Orientin	-	-	1.4±0.1 b	-	4.1±0.2 c	0.9±0.1 a	4.5±0.2 c	1.0±0.05 a
Isorientin	-	-	0.7±0.1 a	-	1.9±0.2 b	0.8±0.1 a	2.5±0.1 c	0.9±0.1 a
Rutin	-	-	4.7±0.4 c	-	11.1±1.0 d	1.5±0.2 a	17.2±0.7 e	2.2±0.1 b
Isoquercitrin	-	-	2.7±0.2 b	1.1±0.1 a	6.1±0.04 e	4.6±0.2 c	7.6±0.4 f	5.9±0.1 d
Vitexin	-	-	3.2±0.1 b	2.5±0.1 a	8.9±0.4 e	5.3±0.3 c	11.1±0.8 f	7.3±0.6 d
Epigallocatechin	-	-	5.9±0.2 b	5.0±0.2 a	7.2±0.1 c	7.0±0.3 c	8.9±0.3 d	7.2±0.2 c
Isovitexin	-	-	1.8±0.2 b	0.8±0.1 a	5.0±0.5 d	2.0±0.03 b	6.6±0.3 e	2.2±0.1 c
Hyperin	-	-	2.3±0.1 a	-	2.4±0.3 a	-	3.1±0.2 b	-
Afzelchin-catechin-dimethylgallate	-	-	-	-	0.5±0.04 a	-	1.2±0.1 b	-
Epicatechin-dimethylgallate	-	-	2.4±0.1 a	-	6.5±0.2 b	-	7.8±0.1 c	-
Quercetin	-	-	3.3±0.4 b	-	11.2±0.7 c	0.7±0.1 a	15.5±0.6 d	0.7±0.1 a
Sum phenolic acids	3.6±0.4 a	56.6±1.1 e	7.0±0.8 b	100.4±0.9 f	15.7±0.7 c	130.5±1.2 g	17.8±0.9 d	166.0±1.2 h
Sum flavones	77.3±0.5 h	66.4±0.5 d	76.3±0.2 g	60.8±0.2 b	68.7±0.2 e	61.8±0.5 c	69.8±0.2 f	54.3±0.6 a
Sum flavan-3-ols	-	-	13.8±0.4 b	8.1±0.2 a	34.5±0.6 e	28.7±0.3 c	47.0±0.4 f	31.7±0.4 d

Sum flavonols	-	-	13.0±0.4 d	1.1±0.1 a	30.8±0.6 e	6.7±0.2 b	43.4±0.7 f	8.8±0.4 c
---------------	---	---	------------	-----------	------------	-----------	------------	-----------

BB= buckwheat enriched bread

Analyses were carried out in triplicate (n=3). Different letters in the same line indicate significantly different values ($p < 0.05$).

ACCEPTED MANUSCRIPT

Table 4. Content of single bound phenolic compounds and relative classes in control (white bread) and enriched bread loaf expressed as mg/kg d.w.

Compound	Control	BB 10%	BB 20%	BB 30%
Vanillic acid	0.6±0.04 a	0.8±0.1 b	0.9±0.1 b	1.5±0.2 c
Syringic acid	0.6±0.1 a	10.0±0.3 b	18.3±0.4 c	29.7±0.7 d
<i>p</i> -hydroxy-benzaldehyde	4.9±0.5 a	12.8±0.4 b	21.7±0.9 c	28.1±1.3 d
<i>p</i> -coumaric acid	1.7±0.2 a,b	1.5±0.1 a	2.6±0.3 c	4.3±0.3 d
Sinapic acid	2.6±0.2	-	-	-
<i>trans</i> ferulic acid	18.9±0.2 d	17.1±0.3 c	16.5±0.2 b	15.7±0.2 a
<i>cis</i> ferulic acid	1.7±0.1 c	1.5±0.1 b	1.3±0.1 a	1.3±0.1 a
Sinapoyl hexose	1.3±0.1 c	1.3±0.1 c	1.0±0.1 b	0.8±0.04 a
Dihydroferulic acid	0.1±0.02 a	0.1±0.01 a	0.1±0.02 a	0.1±0.02 a
Apigenin-6-C-arabinoside-8-C-hexoside Isomer I	67.4±0.7 d	56.5±1.3 c	49.1±0.8 b	41.1±0.5 a
Apigenin-6-C-arabinoside-8-C-hexoside Isomer II	3.2±0.2 d	2.7±0.3 b,c	2.3±0.2 a,b	2.0±0.2 a
Catechin-glucoside Isomer I	-	1.2±0.1 a	1.9±0.2 b	2.7±0.4 c
Catechin-glucoside Isomer II	-	1.3±0.3 a	2.6±0.1 b	3.6±0.1 c
Catechin	-	3.2±0.2 a	5.6±0.3 b	8.7±0.2 c
Epicatechin	-	3.9±0.3 a	6.9±0.5 b	11.0±0.2 c
Swertiamacroside	-	2.3±0.2 a	5.0±0.1 b	8.0±0.4 c
Orientin	-	0.6±0.1 a	1.3±0.2 b	1.8±0.1 c
Isorientin	-	0.5±0.1 a	0.7±0.1 b	1.1±0.2 c
Rutin	-	4.2±0.1 a	4.7±0.1 b	5.7±0.3 c
Isoquercitrin	-	0.1±0.03 a	0.9±0.1 b	1.0±0.1 b
Vitexin	-	1.9±0.2 a	3.9±0.1 b	7.0±0.6 c
Epigallocatechin	-	3.4±0.2 a	3.8±0.3 a	4.3±0.1 b
Isovitexin	-	0.5±0.1 a	2.4±0.3 b	3.4±0.2 c
Hyperin	-	2.1±0.3 a	2.3±0.2 a,b	3.9±0.4 c
Sum phenolic acids	32.7±0.3 a	47.3±0.2 b	67.3±0.5 c	89.4±0.4 d
Sum flavones	70.5±0.4 d	62.8±0.3 c	59.7±0.5 b	56.4±0.4 a
Sum flavan-3-ols	-	13.0±0.3 a	20.7±0.2 b	30.3±0.2 c
Sum flavonols	-	6.4±0.1 a	8.0±0.1 b	10.6±0.3 c

BB= buckwheat enriched bread

Analyses were carried out in triplicate (n=3). Different letters in the same line indicate significantly different values ($p < 0.05$).

Table 5. Content of single and bound phenolic compounds and relative classes in crust and crumb of formulated breads expressed as mg/kg d.w.

Compound	Control		BB 10%		BB 20%		BB 30%	
	Crumb	Crust	Crumb	Crust	Crumb	Crust	Crumb	Crust
Vanillic acid	0.6±0.1 a	0.6±0.1 a	0.8±0.1 b	0.8±0.1 b	0.8±0.1 b	0.9±0.05 c	1.0±0.1 d	2.0±0.3 e
Syringic acid	-	0.7±0.1 a	0.7±0.1 a	19.3±0.4 d	1.8±0.2 b	34.8±0.8 e	2.8±0.1 c	56.7±0.4 f
<i>p</i> -hydroxy-benzaldehyde	2.0±0.2 a	7.8±0.2 d	2.5±0.1 b	23.0±0.4 e	2.6±0.1 b	40.9±0.5 f	3.5±0.3 c	52.7±0.9 g
<i>p</i> -coumaric acid	-	1.7±0.2 d	0.1±0.01 a	3.0±0.4 e	0.2±0.03 b	4.9±0.5 f	0.6±0.05 c	8.0±0.4 g
Sinapic acid	-	2.3±0.3 a	-	3.2±0.1 b	-	3.5±0.1 c	-	4.3±0.2 d
<i>trans</i> ferulic acid	1.9±0.3 c,d	35.9±0.5 h	1.3±0.05 a	32.9±0.2 g	1.5±0.1 a,b	31.6±0.4 f	1.8±0.2 c	29.6±0.6 e
<i>cis</i> ferulic acid	-	1.6±0.1 c	-	1.3±0.03 b	-	1.2±0.1 a	-	1.1±0.1 a
Sinapoyl hexose	-	1.2±0.1 c	-	1.2±0.1 c	-	0.9±0.02 b	-	0.7±0.04 a
Dihydroferulic acid	0.03±0.005 a	-	0.03±0.004 a	-	0.03±0.005 a	-	0.04±0.003 a	-
Apigenin-6-C-arabinoside-8-C-hexoside Isomer I	69.2±0.4 g	65.5±0.8 f	58.9±0.5 e	54.2±0.7 d	49.5±0.4 c	48.8±0.4 c	43.1±0.1 b	39.1±0.3 a
Apigenin-6-C-arabinoside-8-C-hexoside Isomer II	3.0±0.1 d	3.3±0.1 e	2.6± b	2.8±0.1 c	1.9±0.2 a	2.8±0.1 c	1.7±0.1 a	2.3±0.2 b
Catechin-glucoside Isomer I	-	-	1.1±0.04 a	-	1.7±0.1 b	-	2.6±0.3 c	-
Catechin-glucoside Isomer II	-	-	1.1±0.1 a	-	2.5±0.3 b	-	3.5±0.2 c	-
Catechin	-	-	3.1±0.3 a	-	5.5±0.1 b	-	8.2±0.1 c	-
Epicatechin	-	-	3.6±0.2 a	-	6.8±0.5 b	-	10.0±0.3 c	-
Swertiamacroside	-	-	2.2±0.1 a	-	4.8±0.1 b	-	7.3±0.2 c	-
Orientin	-	-	0.5±0.05 a	-	2.1±0.3 c	0.4±0.1 b	3.0±0.2 d	0.5±0.1 a
Isorientin	-	-	0.4±0.04 b	-	1.1±0.1 c	0.2±0.04 a	2.0±0.3 d	0.3±0.03 a
Rutin	-	-	4.2±0.3 c	-	6.8±0.5 d	0.3±0.04 a	9.7±0.4 e	0.7±0.1 b
Isoquercitrin	-	-	-	0.1±0.02 a	-	0.9±0.1 b	0.8±0.1 b	1.1±0.1 c
Vitexin	-	-	2.1±0.1 b	1.7±0.2 a	5.0±0.3 d	2.8±0.04 c	8.2±0.2 e	5.9±0.3 d
Epigallocatechin	-	-	3.2±0.1 a	-	3.5±0.2 a	4.0±0.2 b	4.5±0.1 c	4.2±0.04 b
Isovitexin	-	-	1.3±0.04 c	0.4±0.02 a	3.7±0.1 e	1.1±0.1 b	4.8±0.1 f	2.0±0.2 d
Hyperin	-	-	2.0±0.2 b	-	3.2±0.3 c	1.5±0.2 a	6.3±0.2 d	1.6±0.1 a
Sum phenolic acids	4.6±0.2 a	51.8± 0.8 e	7.6±0.1 b	84.6±0.4 f	11.8±0.3 c	118.7±1.2 g	16.9±0.4 d	155.2±0.8 h
Sum flavones	72.2±0.5 g	68.9±0.8 f	65.9±0.5 e	59.1±0.4 c	63.3±0.8 d	56.1±0.7 b	62.9±0.6 d	50.0±0.5 a
Sum flavan-3-ols	-	-	12.0±0.3 b	-	20.0±0.2 c	4.0±0.2 a	28.8±0.2 d	4.2±0.3 a
Sum flavonols	-	-	6.2±0.2 d	0.1±0.001 a	10.0±0.2 e	2.6±0.1 b	16.8±0.1 f	3.4±0.1 c

BB= buckwheat enriched bread. Analyses were carried out in triplicate (n=3). Different letters in the same line indicate significantly different values ($p < 0.05$).

Table 6. Total free and bound phenolic content (by HPLC-ESI-MS) and antioxidant activity of bread samples

		Total phenolic content by HPLC-ESI-MS (mg/kg d.w.)	DPPH (μ moles Trolox equivalent/100 g d.w.)	ABTS (μ moles Trolox equivalent/100 g d.w.)
Free phenolic compounds				
Control	Loaf	109 \pm 1	296 \pm 1	222 \pm 1
	Crust	123.1 \pm 0.9	443 \pm 2	317 \pm 2
	Crumb	81.0 \pm 0.7	146.1 \pm 0.9	118 \pm 1
BB 10%	Loaf	172 \pm 1	476 \pm 3	402 \pm 2
	Crust	170.3 \pm 0.9	579 \pm 3	498 \pm 2
	Crumb	110 \pm 1	368 \pm 2	302 \pm 2
BB 20%	Loaf	204 \pm 1	679 \pm 3	607 \pm 3
	Crust	228 \pm 1	763 \pm 3	711 \pm 3
	Crumb	150 \pm 2	589 \pm 3	503 \pm 3
BB 30 %	Loaf	235 \pm 1	889 \pm 3	845 \pm 4
	Crust	261 \pm 2	949 \pm 3	899 \pm 4
	Crumb	178 \pm 2	823 \pm 2	787 \pm 3
Bound phenolic compounds				
Control	Loaf	103.2 \pm 0.5	166 \pm 1	115 \pm 1
	Crust	120.6 \pm 0.7	200 \pm 1	118 \pm 1
	Crumb	76.8 \pm 0.5	128 \pm 2	109 \pm 1
BB 10%	Loaf	129.5 \pm 0.8	239 \pm 2	213 \pm 2
	Crust	143.8 \pm 0.4	382 \pm 2	301 \pm 2
	Crumb	91.7 \pm 0.6	183 \pm 1	121 \pm 2
BB 20%	Loaf	155.7 \pm 0.6	396 \pm 2	356 \pm 3
	Crust	181.3 \pm 0.9	452 \pm 2	403 \pm 2
	Crumb	105.1 \pm 0.9	418 \pm 3	306 \pm 2
BB 30 %	Loaf	187 \pm 1	485 \pm 3	555 \pm 3
	Crust	213 \pm 1	632 \pm 3	602 \pm 3
	Crumb	125 \pm 1	571 \pm 3	501 \pm 3

BB= buckwheat enriched bread. Analyses were carried out in triplicate (n=3).

Highlights

- Enrichment of bread with buckwheat flour increase its flavonols and flavan-3-ols content
- This study highlighted differences between phenolic composition of crust and crumb
- Rutin is more concentrated in crumb than crust