1 **Enrichment of bread with fruits and vegetables: trends and strategies to increase**
2 **functionality.**

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8 **Abstract**

9 Background and objectives: Functional foods have become a reality that can complete the nutritional
10 needs of a specific segment of the population. Cereals products have been traditionally the election foodstuff
11 for enrichment campaigns however the food matrix and processing can have a significant influence on the
12 bioactivity of the key compounds. The aim of this review is to present an overview on the trends followed
13 during the last years in the enrichment of bread, deepening on the enrichment with fruits and vegetables.

14 Findings: Ingredients incorporation form has an influence on the water interactions and influence the
15 retention of bioactive compounds. The negative effects related to the application of high temperature in
16 baking operation can be minimized by selecting the source of origin, managing the technological properties
17 of the final products or incorporating ingredients that create protective structures. The incorporation of fruits
18 and vegetables increased significantly the total phenolic compounds and antioxidant activity of enriched
19 breads.

20 Conclusions: Increasing the knowledge on the effect of process conditions and the interactions
21 established among bioactive compounds can contribute clearly to increase the functionality of enriched
22 bread.

23 Significance and novelty: The effect of bread processing on bioactive compounds is analyzed
24 emphasizing the effect on the structure and the interactions established in order to identify strategies that
25 could increase the functionality of the final products developed.

26

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1. Trends in enrichment during last years.

Bread is a good source of functional food as it is a staple and affordable food product eaten daily and consumed all over the world. The manufacturing process is relatively cheap, well known and it is not difficult to implement. In fact, cereals and cereal based products have been the election foodstuff for enrichment campaigns when vitamin or mineral deficiencies were detected (Rosell, 2016). Generally, bread has good taste allowing a great possibility of variations that ensure a broad acceptance by the consumer. Consequently, it still represents the election carrier for any other healthy component leading to functional foods. In bread products, enrichment trends have changed over the years in parallel to the improvement of production and analytical techniques and the better knowledge of bioactive compounds impact on health benefits. Initially, enrichment was focused on the specific compounds. Enrichment with folates (Rader, Weaver & Angyal, 2000), fiber (Fendri et al., 2016; Foschia, Peressini, Sensidoni & Brennan, 2013; Ktenioudaki & Gallagher, 2012), vitamins and minerals (Rosell, 2016) were the most studied examples. Then, the legumes were considered as a good alternative because of their nutritional profiles (Table 1). They are rich in protein, fiber and also present vitamins and minerals. It has been described that the addition of legumes enhanced the protein content and nutritional status of cereal-based diets (Bojňanská, Francaková, Lisková & Tokár, 2012; Iqbal, Khalil, Ateeq & Khan, 2006). Some examples described the enrichment of bread with flaxseed and lupine (Wandersleben et al., 2018), lentils (Turfani, Narducci, Durazzo, Galli & Carcea, 2017), soybean (Silgadze et al., 2017) and fava bean (Coda, Varis, Verni, Rizzello & Katina 2017) (Table 1). Together with this tendency, the enrichment of bread with pseudo cereals such as chia (Fernandes & Salas-Mellado, 2017), amaranth (Singh & Singh, 2011), quinoa and buckwheat (Verardo et al., 2018) was carried out.

As defined by European Commission (2010) functional food is a food that beneficially affects one or more target functions in the body beyond adequate nutritional effects in a way that is relevant to either an improved state of health and wellbeing and/or reduction of risk of disease, and

54 it is consumed as a part of a normal food pattern (not a pill, a capsule or any form of dietary
55 supplement)”. Currently, functional foods have become a reality that can complete the nutritional
56 needs of a specific segment of the population. The needs of an increasingly aging population,
57 changes in lifestyle, the rising cost of health care, the attention of the media to food innovations and
58 medical discoveries have increased consumer engagement in their health and wellbeing. There is no
59 doubt that functional food development has a great interest from consumers, industries,
60 governments and universities. From the research and development point of view functional foods
61 represent an opportunity to obtain innovative products that satisfy considerably this demand that
62 already exists (Betoret, Betoret, Vidal & Fito 2011).

63 The protective role of fruits and vegetables consumption against various chronic diseases has
64 been shown in several epidemiological studies (Oliviero & Fogliano, 2016). Fibers, minerals and
65 many other compounds such as vitamins, polyphenols, carotenoids and glucosinolates present in
66 fruits and vegetables are the responsible of their healthiness.

67 Nevertheless, the functional effect of a food or food component depends on the bioactive
68 component gaining access to the functional target site. The viability of a bioactive compound
69 should be kept during manufacture, storage and the passage to the gastrointestinal tract in order to
70 have a healthy effect. Foods are mostly complex mixtures of macro- and micro-components,
71 organized in a structure that can trap bioactive compounds, modulating their release or inhibiting
72 their bioactivity (Chen, Remondetto & Subirade, 2006). Thus, the food matrix can have a
73 significant influence on the bioactivity or release on the key components. The selection and
74 development of both appropriate food vehicle and technological process, able to maintain the
75 bioactive molecular form until the time of consumption and deliver this form to the physiological
76 target within the organism, are the key steps for the success of a specific functional food (Betoret,
77 Betoret, Rocculi & Dalla Rosa, 2015). For instance, in the particular case of fruits and vegetables, it
78 is necessary the selection of the most appropriate matrix to stabilize phytochemicals that otherwise,

79 in fresh fruits and vegetables, are easily degraded during storage and transportation (Jin et al.,
80 2014).

81 The aim of this review was to present an overview on the trends followed during the last years
82 in the enrichment of bread, considering it as a possible functional food, deepening on the
83 enrichment with fruits and vegetables powders or ingredients, but emphasizing the effect of
84 processing and structure on the interactions established between compounds as well as on the
85 properties of the final products obtained.

86

87 **2. Bread enrichment with fruits and vegetables.**

88 In the last years, there was an increase in the tendency to incorporate fruits and vegetables into
89 bread (Tables 2.1 and 2.2). Among the fruits used, citrus and berries were distinguished due to their
90 high content in ascorbic acid, flavonoids and anthocyanins respectively (Reshmi, Sudha &
91 Shashirekha, 2017; Rodriguez-Mateos, Cifuentes-Gómez, George & Spencer, 2014). Other fruits
92 used were pear, guava, apple, banana, apricot and baobab. For vegetable enrichment stood out algae
93 because of their fatty acid profile and pumpkin, yellow pepper and tomato due to their high content
94 in carotenoids (Graça, Fradinho, Sousa & Raymundo, 2018; Danza et al., 2014). Other vegetables
95 used were beetroot and carrot due to their high content in glycosylates and carotenoids (Hobbs et
96 al., 2014), spinach and chard because of folic acid and pea due to its high fiber content (López-
97 Nicolás et al., 2014). Even in some cases, herbs and spices extracts were used to increase the total
98 polyphenol content in bread (Coe & Ryan, 2016). The quantities of fruit and vegetable incorporated
99 into bread varied considerably, from 0.5% of algae to 50% of pumpkin (Graça et al., 2018;
100 Ptitchkina, Novokreschonova, Piskunova & Norris, 1998). The incorporated quantity depended on
101 final product, ingredient and form of incorporation. No pattern or trend was identified, although an
102 ingredient incorporation amount of 10% or similar was mostly applied. Most of the ingredients
103 were incorporated as powder, but also in fresh form as puree and the rest in liquids form such as
104 juice or hydrated powder (Mastromatteo, Danza, Guida & Del Nobile, 2012b; Hobbs, Ashouri,

George, Lovegrove & Methven, 2014; López-Nicolás et al., 2014). Wheat based products have been the predominant target, but also on gluten-free products (O'Shea, Roble, Arendt & Gallagher, 2015). Generally, research goal in the studies was product development, and they tested the addition of one ingredient at different levels and studied its impact on the technological quality attributes of the final product (Mastromatteo, Danza, Guida & Del Nobile, 2012a; Fendri et al., 2016). Nevertheless, the impact of the process conditions on the functionality of bioactive compounds has also been scarcely considered (Lin & Zhou, 2018). Lately, studies have been focused on the total phenolic content together with total antioxidant activity, mostly using *in vitro* measurements to study bioavailability, and only in some cases *in vivo* studies were performed (Coe & Ryan, 2016). The analysis carried out with the published research (Table 2) reflected that even many alternatives have been reported for enriching breads with fruits and vegetables, generally studies analyzed the bioactive compounds in the final product and less information is provided about the different stages during processing on the impact of bioactives compounds and their bioavailability. Breadmaking process is a very demanding process with biochemical and physical constraints; therefore, even using ingredients rich in bioactive compounds, their presence in the recipe cannot ensure their functionality in the end-product. Because of that, a revision of the state of the art seems necessary.

121

122 **3. Impact of breadmaking on bioactive compounds**

123 The enrichment of bread with fruits and vegetables means the incorporation of a large number of
124 bioactive compounds that can improve directly the functional properties of the developed bread.
125 One good reason to focus on this tendency is that the consumption of whole foods can provide
126 higher benefits than the consumption of one specific bioactive compound. For instance, hesperidin
127 is more effective when administered in combination with vitamin C (Garg, Garg, Zaneveld &
128 Singla, 2001). In addition, the combination of all bioactive compounds present in fruits and
129 vegetables is responsible for their high antioxidant activity. For example, vitamin C of apple with
130 skin represents 0.4% of all antioxidant activity (Eberhardt, Lee & Liu, 2000).

131 In addition, considering the mechanical, biochemical and thermal constraints of the
132 breadmaking process, it is necessary to study the effects of the processing conditions to maximize
133 the amount of a bioactive compound in the final product. The degradation/transformation of a
134 specific bioactive compound from its incorporation into bread formulation can be influenced by
135 source of origin, addition of water and air during mixing and kneading, pH decrease during
136 fermentation and temperature increase during baking. Ingredients are usually added during mixing,
137 but the ingredients form can affect the structural and functional properties of the final product. A
138 nice illustration of this effect is the comparison of adding dehydrated powder versus previously
139 hydrated one or fresh pulp versus dehydrated one. Danza et al. (2014) evaluated the main
140 carotenoids (zeaxanthin, capsanthin, lutein and β -carotene) from yellow pepper incorporated into
141 bread as powder or partially hydrated and they found no significant losses in the content of
142 carotenoids in doughs and in breads. Reshmi et al (2017) studied the fortification of white and
143 brown bread with dry and fresh pomelo segments, finding better retention (from 15 % to 60 %
144 depending on the bread type and added quantity) of flavonoids on both types of breads when dry
145 segments were added, particularly the retention of naringin. The high retention of bioactive
146 compounds added in dry form might be explained based on their lower interaction with the oxygen
147 incorporated within dough during mixing due to its harder structure. Nevertheless, some further
148 research will be needed to confirm the impact of ingredients form in the bioactive compounds'
149 retention.

150 During proofing or leavening, the pH reduction due to the release of lactic or acetic acid has
151 been used to explain the good retention of bioactive compounds. For example, Rodriguez-Mateos,
152 Cifuentes-Gomez, George & Spencer (2013) observed high retention of blueberry anthocyanins,
153 procyanidins, flavonols and phenolic acids with an increase in chlorogenic acid levels after dough
154 fermentation (from 18 to 31 %). Same findings were reported by Wang, Zhou, Yu & Chow, 2006,
155 that observed better retention of green tea catechins in yeast leavened breads enriched with green
156 tea extract (83 – 91 %). Nevertheless, Han & Koh (2011) pointed out the role of yeasts breaking

157 down the bonds within dough constituents and antioxidants, releasing them. It should be
158 emphasized that when making whole wheat bread or bran added wheat, the action of cell-wall-
159 degrading enzymes combined with yeast fermentation, increases the bioavailability of phenolic
160 acids (Delcour, Rouau, Courtin, Poutanen, & Ranieri, 2012).

161 Large divergences have been encountered when studying the performance of bioactive
162 compounds during baking. Seetal (2011) observed that phenols present in flour retain most of their
163 activity after baking. However, Peng et al. (2010) showed that thermal processing decreased the
164 antioxidant activity of grape seed extract in bread (30 – 40 %). Similarly, Vogrincic, Timoracka,
165 Melichacova, Vollmannova & Kreft (2010) observed a decrease in polyphenol concentrations
166 during baking. However, the enrichment provided a significant increase in the antioxidant activity
167 (from 1.20 to 15.27 mg GAE/g), rutin (from nd to 0.91 mg/g) and quercetin (from nd to 9.83 mg/g).
168 Same decrease was observed in the levels of anthocyanin (21 %), procyanidins (9 %) and
169 chlorogenic acid (17 %) from blueberry during baking (Rodriguez-Mateos et al., 2013).
170 Presumably, the thermal stability of the different bioactive compounds is responsible of the
171 discrepancies. In fact, López-Nicolás et al. (2014) observed that the addition of 20 and 40% of
172 spinach and swiss chard provided folate enriched breads, but the initial levels were reduced after
173 baking. However, no significant effect was observed on the content of H4-folate from wheat flour,
174 probably due to its high stability in cereals compared to leafy vegetables. There are studies on
175 wheat bread reporting that the baking process did not reduce the level of these H4-folate, but rather
176 increased due to the folate synthesis by the yeast during the fermentation (Hjortmo, Patring,
177 Jastrebova, & Andlid, 2008).

178 It must also be considered the distribution of bioactive compounds through the bread structure.
179 For instance, Alves & Perrone (2015) found an increase in the total amount of phenolic compounds
180 incorporated into crust melanoidins (from 3.3 to 13.3 fold), influenced by baking time, when wheat
181 bread was enriched with 10 or 20% guava flour. Even within the crust melanoidins, phenolic

182 compounds were differently distributed between high or intermediate molecular weight
183 melanoidins, with the exception of quercetin in 20% guava enriched bread.

184 In order to prevent the degradation of bioactive compounds thermally sensitive, Ezhilarasi,
185 Indrani, Jena & Anandharamakrishnan (2013), enriched wheat bread with encapsulated *Garcinia*
186 *cowa* extract, which is rich in hydroxycitric acid, a hygroscopic and thermally sensitive compound
187 claimed to be anti-obesity agent (Preuss et al., 2005). The coating material was either whey protein
188 isolate or maltodextrin, or their combination, although whey protein encapsulates had significantly
189 higher free hydroxycitric acid content likely due to the protection of *Garcinia* fruit extract induced
190 by denatured protein aggregates. In enriched breads the quantities of hydroxycitric acid reached
191 from 275 to 381 mg/100 g depending on the encapsulating material.

192

193 **4. Other considerations: Ingredients interactions**

194 Bread is a very complex system in which different ingredients are mixed thus interaction within
195 them cannot be ignored. Sun Waterhouse et al. (2011) investigated the extractability of polyphenols
196 and proteins in breads enriched with kiwifruit, blackcurrant or apple extract in the absence or the
197 presence of apple high methoxyl pectin. Authors reported that the oxidation of myricetin or
198 quercetin occurred to some extent during baking, and the polar oxidation products enhanced the
199 hydrophilic bonding and weakened the hydrophobic interactions with the rest of the constituents.
200 The presence of added apple extract and pectin decreased the percentage of the unextractable high
201 molecular weight proteins, owing to the decrease in the S–H group concentration and the formation
202 of S-S bonds during the breadmaking, leading to a reduced extractability of gluten proteins (Koh &
203 Ng, 2009). Other finding related to apple extract was the increase in the stability of p-coumaric acid
204 during breadmaking maybe through binding to flour polysaccharides (Adams, Kroon, Williamson
205 & Morris, 2003). Similarly, Sivam, Sun-Waterhouse, Perera & Waterhouse (2012) explored the
206 interactions between added blackcurrant polyphenols and pectin, as well as different bread
207 components in model bread systems. Results showed that addition of polyphenols and pectin

208 increased the total extractable polyphenol content and decreased the proportion of unextractable
209 high molecular weight proteins.

210 Anthocyanins are also affected by the interactions between bread ingredients, especially
211 delphinidin-3-o-glucoside and delphinidin-3-o-rutinoside (Sivam et al., 2012). In fact, research
212 conducted by Swieca, Gawlik-Dziki, Dziki, Baraniak & Czyz (2013) confirmed that the decrease in
213 the antioxidant potential of phenol-enriched breads was not related with the thermal deactivation of
214 bioactive supplements, but with the formation of indigestible complexes with bread proteins.
215 Therefore, enrichment of wheat bread with phenolics-rich materials is an effective technique to
216 improve the antioxidant potential of the bread, but the quality and biological effect of fortified bread
217 are affected by multiple factors, like the phenolic and protein interactions (Swieca, Secyk, Gawlik-
218 Dziki & Dziki 2014). These interactions between added phenolics and flour proteins and starch,
219 influence the antioxidant capacity, protein and starch digestibility or functional properties of
220 fortified bread (Swieca et al., 2013; Reshmi et al., 2017).

221

222 **Conclusions**

223 Bread can be used successfully as a vehicle for enrichment of bioactive compounds from fruits
224 and vegetables. The incorporation of fruits and vegetables increased significantly the total phenolic
225 compounds and antioxidant activity of all enriched breads. However, breadmaking is a very
226 complex process with many physical and biochemical constraints that can affect the bioavailability
227 of bioactive compounds. Increasing the knowledge on the effect of process conditions and the
228 interactions established among bioactive compounds can contribute clearly to increase the
229 functionality of enriched bread.

230

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Table 1. Enrichment of bread

Ingredient	Form of addition	Quantity	Results of selected ingredients in enriched breads	Reference
Kinako (new soybean), chia	Kinako flour and chia seed	10 and 2 %	Polyunsaturated fatty acids (mg/100 g total lipids): - Wheat bread: 54.59 - Enriched bread: 57.77	Giaretta, Lima & Carpes 2018
Flaxseed and lupine	Flour	88% wheat 10% lupine grit 2% flaxseed expeller	Total polyphenols (GAE/100 g dm): - Wheat bread: 53.5 - Enriched bread: 89.3	Wandersleben et al 2018
Lentils and carob	Carob seed and green lentil flour	5-6, 10-12, 24 %	Total polyphenols (mg/ 100 g): - Wheat bread: 471.2 - Enriched bread with carob: 371.5 – 487.7 - Enriched bread with raw carob: 505.6 – 653.1 - Enriched bread with germ carob: 457.2 – 645.8 - Enriched bread with lentils: 773.5 – 1212.2	Turfani et al 2017
Faba bean	Flour	30 % faba bean flour or sourdough	Protein efficiency ratio: - Wheat bread: 18.5 - Enriched bread with faba bean: 24.7 - Enriched bread with faba sourdough: 26.8	Coda et al., 2017
Amaranth Buckwheat Corn Chickpea Millet Quinoa Rice	Flour	30-50-70 g/100g		Buresova et al., 2017
Quinoa Buckwheat Rice	Flour	12.5, 25, 37.5, 50 %	Protein content (g/100 g dm): - Control bread: 7.6 - Enriched breads: 7.81 – 8.18	Turkut, Cakmat, Kumcuogly & Tavman, 2016
Lupine	Flour	10 % lupine	Protein content (g/100 g): - Wheat bread: 8.46 - Enriched bread: 13.97	López & Goldner, 2015
Buckwheat	Wholegrain buckwheat flour	50 %	Increase in wheat bread and enriched bread: - Total phenolic content: 3.33 – 143 mg GAE/100 g dm - Rutin and quercetin: nd – 7.73 mg/100 g dm - Antioxidant activity: 25.2 – 3.23 IC50 mg/ml	Stokic et al 2015
Buckwheat	Flour	10, 20, 30 %	Total phenolic content (mg/kg dw): - Wheat bread: 613.6 - Enriched bread: 817.3 – 1199 Antioxidant activity DPPH (umol Trolox equivalent/100 g dw): - Wheat bread: 1312.1 - Enriched bread: 2227 – 4349 Antioxidant activity ABTS (umol Trolox equivalent/100 g dw): - Wheat bread: 999 - Enriched bread: 1837 – 4189	Verardo et al., 2018
Folate	Swiss chard and spinach	20 – 40 g/100g	Folate content (ug/100g)	López-Nicolás et al., 2014

	Fresh vegetable		<ul style="list-style-type: none"> - White bread: 19.90 - Swiss chard enriched bread: 36.17 – 57.87 - Spinach enriched bread: 47.47 – 53.53 - Whole grain bread: 37.35 - Swiss chard enriched bread: 31.10 – 75.47 - Spinach enriched bread: 33.05 – 49.52 	
Flaxseed	Flour	5 – 10 – 15 % flaxseed	Protein content (g/100 g): <ul style="list-style-type: none"> - Wheat bread: 10.55 - Enriched bread: 12.01 – 21.61 	Marpalle, Sonawane & Arya, 2014
Amaranth	Whole amaranth flour	10 – 20 – 30 – 40 %	Protein content (g/100 g): <ul style="list-style-type: none"> - Wheat bread: 14.29 - Enriched bread: 14.66 – 16.30 Microelements content (ug/g): <ul style="list-style-type: none"> - Wheat bread: 39.14 - Enriched bread: 50.98 – 92.27 Macroelements content (mg/g): <ul style="list-style-type: none"> - Wheat bread: 3.75 - Enriched bread: 5.04 – 8.57 	Sanz-Penella, Wronkowska, Soral-Smietana & Haros, 2013
Soybean	flours	10.92 soybean flours and 3% soybean protein isolates	Total isoflavones content (nmol/g dm): <ul style="list-style-type: none"> - Enriched low isoflavone soy breads: 2782.7 - Enriched intermediate isoflavone soy breads: 4081.4 - Enriched high isoflavone soy breads: 5590.3 	Shao et al 2009
Folate	Bioproduction by yeast strain		Folate content (ug/100 g dm): <ul style="list-style-type: none"> - White bread fermented with commercial yeast: 30 – 50 - Enriched bread fermented with specific yeast strain: 135 - 140 	Hjortmo et al., 2008
Folate	Wheat, quinoa, Buckwheat, Amaranth Flour	40 % of the formulation	Folate content (ug/100 g dm): <ul style="list-style-type: none"> - Quinoa enriched bread: 41.1 - Buckwheat enriched bread: 26.1 - Amaranth enriched bread: 35.5 	Schoenlechner, Wendner, Siebenhandl-Ehn & Berghofer, 2010
Folate	Powder	Not specified	Folate content (ug/100 g): <ul style="list-style-type: none"> - Wheat bread: 55 – 81 - Enriched bread: 131 - 191 	Rader et al 2000

Table 2.1. Enrichment of bread and bakery products with fruits.

Ingredient	Form of addition	Quantity	Final Product	Determinations	Reference
Pear and navel	Fresh fruit not peeled	200g of fruit + 500 g of water + 40 g sugar --- 300g of liquid with 300 g of flour to form the sourdough	White pan breads	Sourdough: ph, acidity, leavening properties, LAB and yeast identification Bread: volume, texture, free amino acid content	Yu, Wang, Qian, Zhang & Qi, 2018
Quercetin	Powder	0, 0.05, 0.10, and 0.20%	Bread	Specific volume, texture, colour, moisture content, and pH HPLC quercetin ABTS, DPPH, total phenolic content, antiglycation capacity	Lin & Zhou 2018
Apricot kernels	Flour	4, 8, 12, 24 %	Wheat bread	Bread composition, hydration and textural properties, colour and consumer acceptance	Dhen, Rejeb, Boukhris, Damergi & Gargouri, 2018
Grapefruit	Fresh segments Dried segments	0, 10, 20, 30 % 0, 2.5, 5, 7.5 %	White bread Brown bread	Sensory evaluation Estimation of sugars Estimation of reducing sugars Total phenolic content Estimation of carotenoids Estimation of flavonoids Naringin content Total starch Resistant starch Predicted glycemic index	Reshmi, Sudha & Shashirekha, 2017
Baobab fruit, green tea, grape seed, resveratrol	Extract	0.2-3.75 %	White bread and enriched bread	<i>In vitro</i> digestion Release of reducing sugars <i>In vivo</i> study Test meals Glycemic response Insulin response Satiety	Coe & Ryan, 2016
Banana peels	Powder	5 – 10%	Wheat flat bread and enriched bread	Physicochemical, composition, minerals, water holding capacity, oil holding capacity, sensory evaluation	Eshak, 2016
Sea-buckthorn (<i>Hippophae rhamnoides</i> L.) Elderberry (<i>Sambucus nigra</i> L.) Hawthorn (<i>Crataegus</i> L.) Rowan (<i>Sorbus aucuparia</i> L.)	Freeze-dried fruits	5 %	Wheat Bread	Dry matter, protein, fat, ash Total dietary fiber Starch digestibility Total polyphenols ABTS FRAP	Borczak et al., 2016
Guava	Flour	10 -20 %	Wheat bread	Free and bound phenolic compounds in wheat and guava flours Bread crust melanoidins Antioxidant activity	Alves & Perrone, 2015

Banana pseudo stem	Flour	10 %	Wheat bread	Mineral content, Sugars, Water soluble pentosan, total pentosan, total starch, resistant and digestible starch, in vitro starch hydrolysis and glycemic index	Ho, Tan, Aziz & Bhat, 2015
Orange pomace	Flour	0, 2, 4, 8 %	Gluten free bread	Moisture, texture, specific volume, image analysis, crumb moisture Fibre analysis	O'Shea et al 2015
Garcinia cowa fruits	Garcinia Extract microencapsulated powders	100:2 (flour: fruit powder)	Wheat bread	Bread quality characteristic, hydroxycitric acid in bread	Ezhilarasi et al 2013
Blackcurrant	Powder	3 %	Model bread	Total extractable polyphenol content, antioxidant activity and anthocyanin analyses, HPLC, FTIR,	Sivam et al 2012
apple pectin and kiwifruit, blackcurrant or apple polyphenol extract	Powders	replacing the (6%w/w) of flour with a combination of pectin and a fruit extract ingredient in a 1:1 ratio.	Wheat bread	Bread volume, firmness, sensory. Polyphenols analysis, total extractable polyphenols, free thiols groups	Sun Waterhouse et al 2011
Blueberry	Freeze-dried powder	12.4 % dough 31.8 % filling	Baked product	HPLC Analysis of Anthocyanidins, Procyanidins, Phenolic Acids, and Quercetin.	Rodriguez-Mateos et al., 2014

Table 2.2. Enrichment of bread with vegetables.

Ingredient	Form of addition	Quantity	Final Product	Determinations	Reference
Algae (<i>Chlorella vulgaris</i>)	Powder	1, 2, 3, 4, 5 %	Bread	Dough rheological characteristics Bread texture	Graça et al., 2018
Pumpkin	Powder	2.5, 5, 7.5, 10 %	Baked rolls	Powder: Water holding capacity Water retention capacity Swelling capacity Fat absorption capacity Dough reology Baked rolls: Volume Baking loss Firmness Sensory analysis	Minarovicová, Lauková, Karovicová & Kohajdová, 2018
Pumpkin	Pumpkin powder swollen in water (200 ml)	0, 5, 10, 25, 50 g/kg flour	Bread	Moisture content Acidity Maximum overpressure Extensibility Loaf volume Porosity Sensorial analysis	Ptitchkina et al., 1998
Yellow pepper	Dehydrated flour Flour previously hydrated with 0.4, 0.7, 1 L hot water	25 %	Durum wheat bread	Dough texture Crumb texture Tomographic analysis Sensory analysis Carotenoids HPLC In vitro digestion Analysis of starch digestion	Danza et al., 2014
Screening of vegetables flour and application with yellow pepper flour	Yellow pepper flour	10, 15, 20, 25 %	Durum wheat Bread	Sensorial analysis	Mastromatteo et al., 2012a
Yellow pepper	Yellow pepper flour hydrated	0.9, 1.2, 1.5 L	Bread	Dough rheological properties Texture Sensory analysis	Mastromatteo et al., 2012b
Orange fleshed sweet potato	Flour	10, 20, 30 %	Bread	Colour Carotenoids Estimation of the contribution of bread to vitamin A	Nzambita, Duodu & Minnaar, 2017
Ascorbic acid and tomato	Powder, incorporated in films	Aa: 0.8-2.20% Tp: 5-11 %	Wheat bread	Dough expansion, bread colour, volume, porosity	Galvao, Zambelli, Araújo & Bastos, 2018

Red beetroot, carrot with coriander, red pepper with tomato or white beetroot	Puree	40 %	Bread	Sensorial analysis	Hobbs et al., 2014
Swiss chard or spinach	Fresh vegetable	20, 40 %	Bread	Folates HPLC Sensory evaluation	López-Nicolás et al., 2014
Moringa Oleifera	Powder	2.5, 5, 7.5, 10 %	Gluten free bread	Physical properties (volume, textural properties, colour), total phenolic content antioxidant activity sensory evaluation	Bourekoua et al 2018
Pea and broad bean pods fibers	Flours of extracted fibers	0, 0.25, 0.5, 0.75 and 1 g/100 g of flour	Wheat white bread and enriched bread	Composition of fibers aw, WRC, ORC of fibers alveo dough, Texture of dough Volume, weight of breads Texture of bread Crust and crumb color Sensory analysis	Fendri et al 2016