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1 **Pulses for bread fortification: a necessity or a choice?**

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19 **Abstract:**

20 ***Background***

21 Pulses are an affordable source of carbohydrates, dietary fiber, vitamins, minerals, phytochemicals, and
22 particularly proteins. These nutritious seeds greatly contribute to food security, sustainable agriculture,
23 biodiversity and environmental changes mitigation. Pulses are, indeed, a protein source with low carbon
24 and water footprints. Interest in the use of pulses and their by-products in bread formulation has been
25 mounting in recent years due to their high nutritional and functional values. Bread is one of the oldest and
26 most consumed food worldwide, but it has an unbalanced amino-acids profile.

27 ***Scope and approach***

28 This review aims to provide up-to-date information on the compositional and nutritional attributes of pulses
29 as well as their impact on bread-making quality. Keeping in mind that forthcoming challenges should be
30 overcome to formulate a high-quality bread based on pulses-wheat blends.

31 ***Key findings and conclusions***

32 Fortifying bread with pulses will secure a better amino-acids profile and a higher protein intake favoring
33 ensurement of a balanced diet to a wide population with low environmental impact. Hence, pulses
34 consumption is a necessity more than a choice for developing and developed countries with no exception.

35 **Keywords:** pulses, legumes, nutrition, fortification, bread.

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41 **1. Preface**

42 Legumes belong to the family *Fabaceae* or *Leguminosae* and are important agricultural crops grown all
43 over the world. The term "legume" refers to the plants whose fruit is enclosed in a pod. Legumes are a very
44 large family which consists of 750 genera and 16,000–19,000 species (Ratnayake, Hoover, Shahidi, Perera,
45 & Jane, 2001). Among these, approximately 60 species have been domesticated, including soybeans, mung
46 beans, chickpeas and lentils. Legumes were declared the theme of the year 2016 by FAO (Food and
47 Agricultural Organization of the United Nations) to acknowledge their important contribution in feeding
48 the world. Such celebration aimed to highlight benefits of these crops for farmers, manufactures and
49 consumers, and to promote their growth and implementation in the diet. After cereals, legumes production
50 ranks the second major agricultural sector worldwide, with peas, chickpeas, lentils, and beans being the
51 most consumed (over 70%) of legumes worldwide (FAO, 2015). Legumes are considered “superfood” for
52 their dense nutritional composition providing a multitude of health benefits due to their good supply of
53 micro - and macronutrients. Also, they are cultivated worldwide covering important geographical area,
54 subsequently, they have an important socio-economic impact on developed and developing countries. Such
55 crops are also characterized by low water and fertilizing requirements, high resistant to diseases and
56 important adaptability to harsh conditions (Brueck & Lammel, 2016). Also, intercropping cereals with
57 pulses greatly contributes in the sustainability of crops systems and soil biodiversity as renewable natural
58 resources (Maikhuri, Dangwal, Negi, & Rawat, 2016).

59 In recent years, great interest was attributed to pulses, “the dry seed of legumes”, as a main ingredient or as
60 a fortifying agent for bread. Bread is one of the most consumed products worldwide, it is made from wheat
61 flour, salt and water, with or without leavening agent (*Saccharomyces cerevisiae* or/and sourdough).
62 Although bread provides carbohydrates and energy, it lacks some essential amino acids and bioactive
63 components. Therefore, fortifying wheat flour with pulses might enhance the protein profile as well as the
64 bioactive content of bread. This review aims to raise awareness toward the spectrum of benefits related to

65 the consumption of pulses as well as to the effects of the implementation of the most widespread pulses’
66 species into bread recipe on product’s nutritional attribute and quality.

67 **2. Importance of pulses**

68 Pulses, also called grain-legumes, belong to the *Fabaceae* (Figure 1), which are grown primarily for their
69 edible seeds. Pulses belong to the legume family, but the term “pulse” is reserved to the dried seed,
70 according to FAO (2016). The most common pulses are dried peas, beans, lentils and chickpeas. Regardless
71 of the geographical regions, pulses are widely cultivated (Table 1).

72 The global contribution of legumes, particularly pulses, to a balanced and sustainable humans-environment
73 relation is summarized in Figure 2. Most plants in this family obtain their own nitrogen through a symbiotic
74 relationship with soil microbiome (Daubech et al., 2017), and, thanks to their ability to fixe atmospheric
75 nitrogen in the soil, they reduce the need for nitrogen fertilizers (Couëdel, Alletto, Tribouillois, & Justes,
76 2018; Moyano, Marco, Knopoff, Torres, & Turner, 2017). Pulses are, consequently, a sustainable
77 production, play an important role in fostering soil fertility, and might be of great importance for farmers
78 with no or limited access to nitrogen fertilizers (Maikhuri et al., 2016). Pulse crops also contribute in
79 mitigating environmental climate changes through reducing carbon and water footprints. Carbon footprints
80 is associated with intensive use of inorganic N fertilizers, responsible for half of all agricultural greenhouse
81 gas emissions (Crews & Peoples, 2004). Durum wheat produced in a pulse-pulse-durum rotation system
82 was shown to have lower carbon footprint (-34 %) than when it was preceded by 2 seasons of cereal crops
83 (Liu et al., 2016). Inter-cropping cereals crops with pulses also increased the biomass, yield stability and
84 protein content of the harvest (Kermah et al., 2017; Naudin, Corre-Hellou, Pineau, Crozat, & Jeuffroy,
85 2010; Zhang et al., 2015). Pulses also have low water footprint as compared to other sources of protein (e.g.
86 milk, egg and chicken meat) (Mekonnen & Hoekstra, 2010). Therefore, pulses are a 100% renewable energy
87 source to feed humans and animals, as well as maintaining/enhancing the diversification of soil (Brueck &
88 Lammel, 2016; Himanen, Mäkinen, Rimhanen, & Savikko, 2016).

89 Nutritionally, the consumption of pulses not only brings important variety of micro - and macro-nutrients
90 in the diet, but several evidences underlined their significant health-beneficial properties such as satiety
91 increase (McCrorry, Hamaker, Lovejoy, & Eichelsdoerfer, 2010) and cholesterol lowering (Finley et al.,
92 2013; Sagratini et al., 2013; Siah, Wood, Agboola, Konczak, & Blanchard, 2014; Vila-Donat, Fernández-
93 Blanco, Sagratini, Font, & Ruiz, 2015), as well as their action in reducing diet-related chronic diseases
94 including diabetes, metabolic syndrome (e.g. blood pressure and abnormal cholesterol), cardiovascular
95 diseases, and cancer (Dhillon et al., 2016; Feregrino-Pe et al., 2008; Marventano et al., 2017; Messina,
96 2014; Mollard, Wong, Luhovyy, Cho, & Anderson, 2014; Rebello, Greenway, & Finley, 2014). Pulses also
97 can greatly contribute in the prevention of undernutrition and malnutrition issues in low income countries.
98 Therefore, there has been a continuous increase of interest in pulses integration in foodstuffs-making due
99 to their dense nutritional composition, environmental contribution and technological aptitude. Pulses are
100 consumed either as an intact seed or can be processed before consumption, split or milled, or fractionated
101 to obtain fiber, starch and protein concentrates or isolates (Roy, Boye, & Simpson, 2010). These different
102 ingredients held different physicochemical, nutritional and technological properties that will define their
103 functionality once integrated in food formulation during processing, storage, and consumption.

104 **3. Background information about pulses**

105 **3.1. Classification**

106 Table 2 summarizes the main characteristics of the 11 primary pulses, which belong to the *Phaseoleae*,
107 *Cicereae* and *Fabeae* tribes (FAO 2017). Some background information about origin and area of cultivation
108 is shown in Table 3.

109 **3.2. Composition**

110 **3.2.1. Nutrients**

111 A massive work has been carried out by FAO to collect information on the nutritional properties of pulses
112 available in the literature. The gathered data were then standardized and included in an open access database
113 online. Table 4 displayed the major macro-components of the most widespread pulses as stated by FAO
114 (2017). The amino acid composition of wheat flour was also included; even though it can be extremely
115 diverse depending on multiple factors, including genetic diversity, effect of processing and environmental
116 conditions similarly to that of pulses.

117 Pulses can be considered low-energy product, as they provide an amount of energy [an average value
118 relative to Table 4, 318 ± 14 (Kcal/100g), range 301-359 (Kcal/100g)] lower than those of wheat flour (348
119 Kcal/100g) (Table 4). The highest energy (359 Kcal/100g) is provided by chickpea, Kabuli variety.
120 Carbohydrates content differed vastly among pulses and fluctuated from 10.8% (Adzuki bean) to 51.3%
121 (lupin). Similarly, fat content was quite dissimilar, and ranged from 0.6 g/100 g (Adzuki bean) to 6.5 g/100g
122 (lupin). Pulses are an excellent source of dietary fiber with high range of variability extending from 13.1
123 g/100g in chickpea, Kabuli to 35.3 g/100g in lupin. For ash content, Pinto bean had the highest value (4.9
124 g/100g), while lentil showed the lowest one (2.7 g/100g). Notably, according to the FAO (2017) database,
125 important amounts of potassium were found, ranging from 219 to 1940 mg/ 100 g, compared to durum (431
126 mg/100 g) and common wheat (435 mg/ 100 g) (USDA 2016). Likewise, high calcium content was found
127 (up to 295 mg/100g, Table 4) (FAO 2017). Pulses are primarily known as a valuable source of proteins
128 [from 18.4 g/100g (Bambara nut) to 34.1 g/100g (lentil)] with a balanced amino acids profile, rich in
129 essential amino acids. The amino acids composition of different pulses is shown in Table 5. Lentil contains
130 the highest amount of alanine (1270), followed by moth bean (1200 mg/100 g), while wheat flour was the
131 poorest (543 mg/100 g). Lupin had the highest concentration of most amino acids (Arg, Asp, Glu, Gly, His,
132 Ile, Leu, Phe, Pro, Ser, Thr, Tyr and Val), while Cys, was slightly higher in chickpea desi (646 mg/100 g)
133 than lupin (610 mg/100 g). Similarly, Lys was high in lentil (1710 mg/100 g), followed by kidney bean
134 (1670 mg/100 g) and lupin (1650 mg/100 g) suggesting that these pulses are an excellent ingredient to be
135 combined in wheat-based flour blends to obtain a balanced and complete amino acids profile. Pulses amino

136 acids composition is characterized by a rich Lys content compared to that of wheat flour (416 mg/100 g,
137 Table 5) (Tuśnio and others 2017). Met and Trp were quite low in pulses ranging from 166 mg/ 100 g
138 (Board bean) to 405 mg/ 100 g (Cowpea) and from 115 mg/100 g (Bambara nut) to 328 mg/100 g (Kidney
139 bean). However, wheat flour showed intermediate contents of Met (251 mg/ 100 g) and Trp (130 mg/ 100
140 g) but high amounts of proline (1594 mg/ 100 g) and Glu (4839 mg/ 100 g). Moreover, pulses have
141 interesting phenolic acids (e.g. folic acid and hydroxycinnaminic acid), vitamin (e.g. ascorbic acid, and
142 vitamin E, B6, B12 and K) and flavonoids (e.g. glycosides, anthocyanins, proanthocyanidins, and
143 isoflavones) (Boschin & Arnoldi, 2011; Boschin, Scigliuolo, Resta, & Arnoldi, 2014b, 2014a; Heiras-
144 Palazuelos et al., 2013). Hence, for consumers and food manufacturers concerned with health and balanced-
145 diet, pulses are naturally rich in a spectrum of bioactive components and are, therefore, a valuable item to
146 be integrated in foodstuff-making. Nevertheless, it should be taken into consideration the presence of some
147 antinutrients in pulses.

148 **3.2.2. Anti-nutrients**

149 Pulses have a dense-nutrient composition but, at the same time, they contain antinutritional compounds,
150 which can negatively affect bioavailability of nutrients and digestibility (Amalraj & Pius, 2015; Moktan &
151 Ojha, 2016), as well as impart bitter or unacceptable taste (Rizzello, Verni, Bordignon, Gramaglia, &
152 Gobbetti, 2017). Antinutrients can be classified in different categories. They can be grouped according to
153 their chemical nature whether proteins (e.g. including lectins, agglutinins, trypsin and chymotrypsin and
154 amylase inhibitors) or non-proteins (e.g. phytic acid, phenolic compounds and saponins) (Dueñas et al.,
155 2016; Martín-Cabrejas et al., 2009). The classification reported in Table 6 was based on antinutrients
156 sensibility to heat treatment since, in some cases, a simple heat treatment may remove the negative effects
157 associated with pulse consumption. Anti-nutrients can be either thermolabile (e.g. protease inhibitors and
158 lectins), or thermostable (e.g. phytic acid, raffinose, tannins and saponins) (Dueñas et al., 2016; Martín-
159 Cabrejas et al., 2009). The presence of high concentrations of trypsin and protease inhibitors reduces the

160 activity of enzymes such as trypsinase, chymotrypsinase, amylase, and lipase (Sathya & Siddhuraju, 2015).
161 Phytic acid inhibitors and lectin may also hamper protein availability and digestibility (Adenekan, Fadimu,
162 Odunmbaku, & Oke, 2018; R. K. Gupta, Gangoliya, & Singh, 2015; Jin et al., 2017; Ohizua et al., 2017).
163 Tannins negatively interfered with the bioavailability of iron (Prasad & Singh, 2015; Sotelo, González-
164 Osnaya, Sánchez-Chinchillas, & Trejo, 2010). Oligosaccharides such as raffinose are responsible for
165 flatulence, bloating and gas formation in the guts (Adeyemo & Onilude, 2013; Winham & Hutchins, 2011).
166 Saponins might be involved in intestinal wall damaging (R. K. Gupta et al., 2015; Prasad & Singh, 2015),
167 while oxalate is reported to be culprit in limiting calcium absorption (Massey & Kynast-Gales, 2001).
168 Considering that pulses are consumed after cooking, antinutrients levels may be decreased or completely
169 hindered. Therefore, processing is needed because these undesirable effects are more correlated to the
170 consumption of raw pulses. Table 6 underlined also some health-beneficial potential of some anti-nutrients.
171 The positive/negative effect on the human health is strictly related to the (i) amount of pulsed consumed,
172 (ii) type of food processing that pulses undergo, and (iii) to individual sensibility.

173 **4. Pulses: a valuable ingredient for bread fortification**

174 Bread is a basic food item that is consumed in variable forms throughout the world. Fortifying a widely
175 consumed food product like bread can, definitely, exert a positive significant impact in term of plant-protein
176 consumption that in turn could contribute to the reduction of water and carbon-foot print associated with
177 the animal-protein consumption (meat/dairy). In a recent report of the International Association of Plant
178 Bakers, (“AIBI Bread Market Report 2013,” 2015), bread average consumption in Europe is about 59
179 kg/person/year, yet different trends are observed across European countries [e.g. Turkey (104 kg) and
180 Bulgaria (95 kg), UK (32 kg). A stable consumption was recorded in several countries (e.g. Finland, Greece
181 and Germany markets), but in others it is slightly decreasing (e.g. Turkey and Ukraine). Per capita
182 consumption in US is around 39.3, but lower values were recorded in Asian countries [e.g. Japan (22kg)
183 and China (5.8kg)].

184 Towards product innovation and given the increasing awareness to health-beneficial trends of the
185 consumers, bread industry is being driven to bread fortification to enhance its quality through the use of
186 natural ingredients with dense-nutrient composition. In this light, pulses might be considered a valuable
187 fortifying agent for increasing the nutritional value of cereal-based foodstuffs, such as bread, due to their
188 well-balanced amino acid composition and fiber content (Gómez, Oliete, Rosell, Pando, & Fernández,
189 2008). Pulses might be integrated in bread formula in different forms: dehulled or hulled flour, hydrolysates
190 or protein isolates, germinated or fermented flour, and single or as multi-pulses blends. The addition of
191 pulses to wheat flour based-bread impact nutritional, chemical, physical and functional properties. The
192 resulting blends-based breads have increased the protein, fat, dietary fiber and mineral contents compared
193 to 100% wheat flour based-bread (Indrani, Swetha, Soumya, Rajiv, & Venkateswara Rao, 2011). Functional
194 properties of pulses are well documented (Adebisi & Aluko, 2011; Aluko, Mofolasayo, & Watts, 2009; M.
195 B. Barac, Pesic, Stanojevic, Kostic, & Bivolarevic, 2015; M. Barac et al., 2010; Hou & Zhao, 2011; Karaca,
196 Low, & Nickerson, 2011). Indeed, pulses flours are recognized for their high water holding capacity,
197 solubility, emulsifying, foaming and gelling properties and emulsifying properties (Adebisi & Aluko, 2011;
198 Aluko et al., 2009; M. Barac et al., 2010; Barac et al., 2015; Foschia, Horstmann, Arendt, & Zannini, 2017;
199 Hou & Zhao, 2011; Karaca et al., 2011). These properties greatly impacted the rheological properties of the
200 dough.

201 **4.1. Bread made with blends of wheat and pulses**

202 **4.1.1. A brief overview on some pre-treatments of pulses**

203 Prior to consumption, pulses might be subjected to preparation step including dehulling, soaking, cooking
204 and extrusion. Pulses out-layers are rich in antinutrients, which might confer a bitter taste or a foaming
205 ability (Stantiall, Dale, Calizo, & Serventi, 2017). Through the removal of the hulls from the rest of the
206 pulses grain, dehulling improves appearance, texture, cooking quality, palatability and digestibility of grain
207 legumes (Egounlety & Aworh, 2003). However, dietary fiber content decreases due to a decrease in

208 insoluble dietary fiber content, and therefore protein and starch contents increase (M. Ma, Wang, Wang,
209 Jane, & Du, 2017; Sakhare & Inamdar, 2014). Likewise, soaking reduced the total amount of saponins in
210 chickpeas and faba beans (8 and 35%, respectively) (Barakat, Reim, & Rohn, 2015). The reduction of
211 saponins can contribute in the improvement of sensory attributes of pulses (e.g. color, odor and taste)
212 thereby increasing their acceptability by consumers (Aremu and others 2016). Cooking methods (boiling,
213 roasting, microwaving, autoclaving and steaming) showed great efficiency in reducing/inactivating the
214 heat-labile antinutrients. Cooked pulses had drop-in tannin, trypsin inhibitor activity and raffinose to
215 negligible concentrations compared to those untreated (T. M. H. Hefnawy, El-Shourbagy, & Ramadan,
216 2012; M. Ma et al., 2017; Martín-Cabrejas et al., 2009). Boiling resulted in decreased trypsin inhibitor
217 activity (-95%), tannins (-36%) and phytic acid (-42%) (Aremu, Ibrahim, & Ekanem, 2016). These
218 treatments also decreased oxidative enzymes activities that might alternate some nutrients content (María
219 Celia Alasino et al., 2008). Steaming also was effective in retaining the integrity, appearance and texture
220 of the cooked pulses, as well shortening process time (Xu & Chang, 2008). Cooking also influenced the
221 functional properties of on pigeon pea, dolichos bean and jack bean flours, as it increased water absorption
222 capacity (73–96%), decreased protein solubility (>80%) and the tendency to retrogradation of amylose (69–
223 85%) (Acevedo, Thompson, González Foutel, Chaves, & Avanza, 2017). In turn, cooking might induce
224 considerable losses in some bioactive components due to their leaching to the cooking medium or
225 denaturation by the high temperature (Siah et al., 2014). Roasting enhanced fat binding capacity, water
226 holding capacity, gelling capacity, and *in vitro* protein digestibility (Khattab, Arntfield, & Nyachoti, 2009;
227 M. Ma et al., 2017). Microwaving also improved the nutritional quality (i.e. *in vitro* protein digestibility)
228 of pulses (Hefnawy, 2011; Khattab et al., 2009). Compared to soaking, microwaving had less efficiency in
229 reducing tannins, phytic acid and trypsin. Extruding pulses resulted in an important decrease in trypsin
230 inhibitor, phytate and total tannin was reported (Adamidou, Nengas, Grigorakis, Nikolopoulou, & Jauncey,
231 2011; Alonso, Oroe, Zabalza, Grant, & Marzo, 2000; Chinma et al., 2016). Extrusion also improved *in vitro*
232 protein digestibility and protein efficiency ratio (Milán-Carrillo et al., 2007).

233 4.1.2. Single pulse flour

234 Regardless of pulses type, the substitution of wheat flour with pulses flour significantly improved the
235 nutritional value (Alomari & Abdul-hussain, 2013; Erukainure et al., 2016; S. Ma et al., 2014) increasing
236 bread protein, minerals and fiber contents (Man, Păucean, Muste, & Pop, 2015; Moneim, Sulieman, Sinada,
237 & Ali, 2013).

238 According to mixolab, the inclusion of Bambara flour resulted in worsening dough consistency, starch
239 gelatinization, amylase activity, and retrogradation, except for stability time (Erukainure et al., 2016). The
240 addition of chickpea flour (0-30%) also increased the optimal amount of water to make the dough [from
241 58.8 % (100% wheat flour) to 62.5 % (30 % chickpea flour)] (Angioloni & Collar, 2012). Likewise, dough
242 enriched with increasing levels of lentil and bean flours (10, 20, and 30 %) showed an increase in water
243 absorption capacity (from 58.50 to 74.9 %) and dough development time (from 3.50 min to 5.50 min), and
244 a decrease in dough stability (from 6.67 to 2.30 min) (Kohajdová et al., 2013). The increased water
245 absorption was attributed to the higher water holding capacity of pulses flour, which is associated with
246 increased total protein and pentosan content (Angioloni & Collar, 2012; Collar, Santos, & Rosell, 2007;
247 Mohammed, Ahmed, & Senge, 2014; Moneim et al., 2013). This likely might result in modifying water
248 distribution and dynamics in the dough.

249 Extensograph results showed that dough resistance decreased gradually from 5% to 15% level of chickpea
250 supplementation, if compared with wheat flour (Moneim et al., 2013). Addition pulses flours (e.g. Bambara
251 groundnut and chickpea) increased total area/energy, resistance to extensibility and dough development
252 time (S. Ma et al., 2014; Mohammed et al., 2014). Stability and extensibility decreased resulting in stiff
253 dough (S. Ma et al., 2014). Otherwise, an addition level of 10 % chickpea flour increased dough stability
254 and resistance as compared to the control. However, beyond 20%, these parameters decreased. The surface
255 of the dough made with 100 % wheat flour or supplemented with 10 % chickpea flour can be described as
256 “normal”, while blends made with higher levels of supplementation (20-30 %) produced a “sticky” dough

257 surface (Mohammed et al., 2014). Also, relevant changes in pasting properties (i.e. peak viscosity and
258 complex modulus) were observed, which are more dependent on flour biopolymers (Angioloni & Collar,
259 2012). The results of rapid visco-analyzer showed that increasing chickpea flour level increased in pasting
260 temperature (from 62.0 to 66.5 °C) and dough viscosity. Such result might be attributed to chickpea flour'
261 gelling and thickening properties related to fibers and proteins (Angioloni & Collar, 2012).

262 Regarding bread properties, the addition of lupin or pea flour at 5% level gave similar loaf height and
263 structure of the 100% wheat flour based-bread (María Celia Alasino et al., 2008; Pollard, Stoddard,
264 Popineau, Wrigley, & MacRitchie, 2002). Pea flour substitution at levels of 10 and 15 % negatively affected
265 specific volume (María Celia Alasino et al., 2008) . Otherwise, 10 % pea flour supplementation enhanced
266 loaf weights and both loaf and specific volume, while these later decreased with the addition of 15 % (Ma
267 et al., 2014) and 20 % (Erukainure et al., 2016). Flour substitution by 15 % cowpea flour resulted in
268 decreasing loaf height and loaf volume and increasing loaf (Olapade & Oluwole, 2013). The volume
269 decreased as chickpea flour substitution (30%) increased, which might be explained by the dilution of
270 gluten content or/and possible interactions among fiber components, water and gluten (Man et al., 2015;
271 Olapade & Oluwole, 2013). Color of crust and crumb of pulses-based bread became darker as the level of
272 supplementation increased due to Maillard reaction (Man et al., 2015). Nevertheless, 10 % chickpea flour
273 addition enabled to obtain a bread with color similar to the control (100% wheat flour) (Mohammed et al.,
274 2014). The sensory analysis revealed that 10% addition of pulses flour (e.g. cowpea, chickpea and bambara
275 nut) to bread was more appreciated than bread made with higher supplementation levels (S. Ma et al., 2014;
276 Man et al., 2015; Olapade & Oluwole, 2013). Furthermore, increasing levels of the lentil flour (around 20%
277 to 25%) induced negative effects on sensorial quality of the bread (Previtali et al., 2014).

278 Although leavened breads are the most studied due to their popularity all over the world, some attention
279 was attributed also to unleavened bread (e.g. flat-bread, steam bread, Thick kmaj and Arabic bread). Flat
280 bread was made with inclusion of different levels (0-20%) of lupin flour (Alomari & Abdul-hussain, 2013):
281 dough properties revealed an increase in water absorption, possibly due the high water-binding capacity of

282 fiber and protein (Güemes-Vera, Peña-Bautista, Jiménez-Martínez, Dávila-Ortiz, & Calderón-Domínguez,
283 2008; Turnbull, Baxter, & Johnson, 2005). Another type of flat bread (Thick kmaj) was prepared with faba
284 bean flour (5, 10 and 15%). Protein content increased significantly from 13 % in bread made with white
285 flour to 20 % in 15 % faba bean flour supplemented bread, while bread fat content increased from 1.06%
286 to 1.23%. Moreover, sensory analysis results showed that the higher overall acceptability scores were
287 attributed to the control and the 5% replacement level (Ajo, 2013).

288 **4.1.3. Blends of pulses' flours**

289 Indrani, Swetha, Soumya, Rajiv, & Venkateswara Rao (2011) replaced whole-wheat flour with a multigrain
290 mix (chickpea, barley, soya bean and fenugreek seeds) at different levels (0-40 %) to make north Indian
291 parotta. As a result, water absorption increased, while dough stability, resistance, extensibility and viscosity
292 decreased. Baik & Han (2012) also reported that the dough made from cooked or roasted pulses flour was
293 less sticky than that with fermented flour. This likely due to the lower water absorption capability that might
294 be attributed to protein denaturation or/and starch gelatinization. Also, the physical parameters of bread
295 were affected and a reduction in volume, specific volume, and cambering were observed (Baik & Han,
296 2012). At higher levels (>20 %), the aspect (shape and crust color) and the texture (crumb elasticity and
297 firmness) of breads were negatively impacted (Kohajdová et al., 2013). Sensory evaluation showed that
298 10% based-bread was the most acceptable (Kohajdová et al., 2013). Furthermore, Baik & Han (2012)
299 observed that roasted flour had a better aroma and loaf volume of bread as compared to flour from cooked
300 legume, indicating the importance of the pretreatment optimization.

301 **4.1.4. Blends of pulses' flours and structuring agents**

302 As previously reported, high level of pulses flours negatively impacted bread texture and volume. Several
303 studies were carried out to find the suitable formulation based on wheat-pulses blends to overcome the
304 drawback of pulses' high substitution level for wheat flour, on technological quality (Man et al., 2015;

305 Mohammed et al., 2014; Yamsaengsung, Schoenlechner, & Berghofer, 2010). The solution was to rely on
306 the addition of vital gluten or structuring agents, which can mimic gluten properties such as emulsifiers,
307 hydrocolloids and enzymes. Baking performance with wheat flour replaced with 10% with pea flour was
308 improved with the use of 1 % sodium stearoyl lactylate with azodicarbonamide (Alasino, Osella, De La
309 Torre, & Sanchez, 2011). Yamsaengsung et al. (2010) developed two formulations of white and whole
310 wheat flour-based bread using 11% of chickpea and 1.0% emulsifier, without altering the technological
311 quality. Furthermore, Indrani, Swetha, Soumya, Rajiv, & Venkateswara Rao (2011) suggested the use of
312 3% of a mixture of additives (dry gluten powder, sodium stearoyl-2-lactylate and
313 hydroxypropylmethylcellulose, and their combinations) to compensate the dilution of gluten associated
314 with addition of pulses. This addition enhanced the overall bread quality up to 30 % pulses addition. Later,
315 (Angioloni & Collar, 2012) assayed the addition of gluten (with a range from 1 to 5% of wheat flour) and
316 carboxymethylcellulose (with a range from 1 to 5% of wheat flour), revealing that the combination of 42%
317 of pulse with 6% structuring agents enabled to obtain acceptable breads with high fiber and proteins
318 fractions, and reduced starch hydrolysis and glycemic index (Angioloni & Collar, 2012).

319 Hydrocolloids were also added to improve organoleptic properties of bread enriched with hydrated and
320 non-hydrated pea flour. As a result, the addition of guar gum (2%) to hydrated pea flour gave bread with
321 comparable overall quality to that of the wheat control. This addition improved dough properties and
322 reduced bread crumb's firmness (Previtali et al., 2014). In another study, fortified-bread (25% lentil flour)
323 showed high acceptability, when 2% of guar seed flour was added to the formulation (Previtali et al., 2014).
324 A mix of enzymes (transglutaminase and glucosidase), emulsifiers (sodium stearoyl-2-lactylate, diacetyl
325 tartaric acid esters of mono and diglycerides, and their combination) and oxidant (ascorbic acid) was
326 assayed to enhance dough and bread supplemented with lupin flour (15%) (Yorgancilar & Bilgiçli, 2014).
327 All additives, except transglutaminase, increased development time and stability of the enriched dough.
328 Combining emulsifiers gave the highest bread volume and the lowest crumb firmness after storage (3 days)
329 (Yorgancilar & Bilgiçli, 2014).

330 4.2. Blends fortified with pulses' aqueous extracts

331 Recently, water/salt-soluble extracts were produced from pulses (pea, lentil, and faba bean flours) flours
332 doughs, which were made using proteolytic enzyme preparation (25 g/100 kg of proteins) and *L. plantarum*
333 *IA7* as starter for fermentation. Antifungal proteins were identified, in particular nine peptides as sequences
334 encrypted in legume vicilins, lectins and chitinases. Also, aqueous extracts of fermented sourdough
335 (*Lactobacillus brevis* AM7 and *Phaseolus vulgaris* cv. Pinto) was characterized by an antifungal property,
336 probably attributed to the activity of Phaseolin alpha-type precursor, phaseolin, and erythroagglutinating
337 phytohemagglutinin precursor (Coda et al., 2008). These extracts were used as an ingredient for making
338 bread in a pilot plant that resulted to have longer shelf-life than control bread (Rizzello et al., 2017). Indeed,
339 with water-soluble extract (27%, v/w), no fungal contamination was recorded in stored bread (14 days, 25
340 °C) (Coda et al., 2008; Rizzello et al., 2015, 2017).

341 4.3. Blends fortified with pulses' protein isolation

342 4.3.1. Protein isolation

343 Protein isolation was achieved generally following a wet extraction, which comprises the following phases:

344 **Defatting:** The process of protein isolation involves a defatting pretreatment to remove fiber and fat using
345 hexane or petroleum ether (Adamantini Paraskevopoulou, Chrysanthou, & Koutidou, 2012; Peyrano,
346 Speroni, & Avanza, 2016).

347 **Solubilization:** Protein separation is generally carried out using an alkaline or acid solution (Boye, Zare,
348 & Pletch, 2010). Defatted flour was solubilized in distilled water (10 g/ 100 mL) and pH was adjusted
349 (alkaline extraction: pH=8-11 using NaOH; acid extraction pH<4 using citric acid) (Pelgrom, Vissers,
350 Boom, & Schutyser, 2013; Peyrano et al., 2016). The mixture was left to stand at the adequate temperature

351 to maximize the solubilization. Proteins can be solubilized using water, salts, methanol, ammonium sulfate,
352 and acetone (Adenekan et al., 2018; Wati, Theppakorn, Benjakul, & Rawdkuen, 2010).

353 **Precipitation:** Following centrifugation, the solubilized proteins are precipitated by isoelectric
354 precipitation (isoelectric point (pH 4.8)), ultrafiltration or membrane separation to recover the protein
355 (Papalamprou, Doxastakis, & Kiosseoglou, 2010)

356 **Drying:** The isolated proteins were dried using a spray-, drum- or freeze-drying method (Johnston,
357 Nickerson, & Low, 2015). Wet extraction enabled the separation of proteins and starch. Fibers also are
358 recovered to be used as a functional ingredient.

359 **4.3.2. Effect of protein isolates/concentrates of bread quality**

360 Besides being highly nutritious, proteins isolates/concentrates have interesting functional properties like
361 solubility, gelation and water binding resulting in significant changes in dough and bread quality
362 (Kiosseoglou & Paraskevopoulou, 2011; Makri, Papalamprou, & Doxastakis, 2005; Mohammed et al.,
363 2014). Nutritionally, the addition of protein isolates/concentrates increased protein amounts particularly
364 essential amino acids (e.g. lysine) (Franco-Miranda, Chel-Guerrero, Gallegos-Tintoré, Castellanos-Ruelas,
365 & Betancur-Ancona, 2017; Mubarak, 2001) and improved *in vitro* protein digestibility (Mubarak, 2001).
366 Regarding rheological properties, dough water absorption increased (Mubarak, 2001), due to proteins high
367 water binding capacity (Turnbull et al., 2005). With respect to the control, the addition of protein
368 hydrolysates (from lima bean or cowpea) decreased tenacity and slightly increased elasticity of the dough
369 (Franco-Miranda et al., 2017). Dough weakening might be explained by the addition of non-gluten proteins
370 inducing a dilution effect of gluten. An increase in stability time was observed followed to a substitution of
371 5 or 10% isolates of proteins, probably resulting from lupin protein entrapment within the gluten network
372 structure (Paraskevopoulou, Provatidou, Tsotsiou, & Kiosseoglou, 2010). At higher levels (beyond 10 %),
373 dough stability decreased (Mubarak 2001; Serventi et al., 2013). Loaf volume of breads made with proteins

374 isolates (up to 9% level) or concentrate (up to 3% level) was comparable to 100% wheat flour based-bread
375 (Mubarak, 2001). Indeed, pulses' proteins are not as elastic as gluten, so they are unable to form an
376 extendable network and, consequently, bread crumb appeared more compact due to limited cell expansion
377 (Paraskevopoulou, Provatidou, Tsotsiou, & Kiosseoglou, 2010). Beyond 10 %, protein concentrate had
378 detrimental effect on bread textural quality (high firmness and chewiness and low loaf volume) (Mubarak,
379 2001; Paraskevopoulou et al., 2010; Serventi et al., 2013; Serventi, Vittadini, & Vodovotz, 2018). Indeed,
380 9 % of chickpea protein concentrate did not show negative effects on bread texture, except of slight increase
381 firmness, possibly because of low fats and saponins (Serventi et al., 2018). As for sensory analysis, no
382 alteration in bread quality was found with addition of proteins isolates (up to 9%) or protein concentrate
383 (up to 6 %) to bread formula (Mubarak, 2001). It was also underlined an anti-staling effect of lupin proteins
384 isolates resulting in delaying bread firming following storage for 24 and 48 h (Paraskevopoulou,
385 Provatidou, Tsotsiou, & Kiosseoglou, 2010). Possibly, an interaction between starch or/and protein might
386 be involved in preserving the moistness by reducing water migration (from the crumb to the crust) or/and
387 amylopectin retrogradation.

388 **4.4. Blends fortified with germinated pulses flours**

389 **4.4.1. Pulses germination**

390 Germination is a solvent free, simple, low-cost and green process resulting in nutrient compositional
391 changes, which are often associated with health benefits. In this light, germination of pulses has been
392 intensively investigated as a mean to enhance their nutritional value by increasing contents and availability
393 of nutrients and reducing antinutrients (Acevedo et al., 2017; Benítez et al., 2013; Dueñas et al., 2016).
394 Indeed; during germination, the excessive enzyme actions result in the hydrolysis of starch, protein and
395 lipid (Benítez et al., 2013; Mamilla & Mishra, 2017). Consequently, the nutrient composition of pulses (e.g.
396 horse gram, chickpea, red lentil, mung bean, kidney bean and soybean) changed (by increasing protein,
397 fiber, total polyphenol content, and antioxidant activity, and decreasing fat, ash and carbohydrate) as well

398 as antinutrients (by decreasing tannin, phytate, and oxalate) as compared to non-germinated flour (Mamilla
399 & Mishra, 2017; Moktan & Ojha, 2016). In particular, phenolic acids (+30%) and DPPH (63%) (2,2-
400 diphenyl-1-picrylhydrazyl) scavenging activity were increased in germinating pigeon pea. Likewise, the
401 inhibitory potential of this extract against α -glucosidase was increased after germination (Uchegbu &
402 Ishiwu, 2016). Such results might be attributed to increasing activity of enzymes of biosynthetic nature,
403 which result in high content of bioactive compounds with improved nutritional quality (Benítez et al., 2013;
404 Dueñas et al., 2016; Khalil, 2001; Mamilla & Mishra, 2017). For instance proteinases are activated during
405 germination, which may lead to the release of some bioactive amino acids and peptides (Devi, Kushwaha,
406 & Kumar, 2015). Germination was also an effective strategy of antinutrients mitigation. Indeed, tannins
407 and phytic acid of pulses (e.g. mung beans, pigeon pea, lentil and chickpea) were significantly reduced after
408 germination (Gupta et al., 2015; Ibrahim, Habiba, Shatta, & Embaby, 2002; Khalil, 2001; López-Martínez,
409 Leyva-López, Gutiérrez-Grijalva, & Heredia, 2017; Martín-Cabrejas et al., 2009). Another factor to be
410 taken into consideration is the condition of germination including germination temperature and duration.
411 For instance, a reduction in tannic acid was of 8-23 and 14-27% in chickpea varieties after 24 and 48 hours
412 (El-Adawy, 2002).

413 **4.4.2. Effect of germinated pulses flours on bread quality**

414 The incorporation of germinated pulses flour in bread is recommended for nutritional enrichment (Ertaş,
415 Bilgiçli, Özcan, & Sarı, 2014; Ouazib, Garzon, Zaidi, & Rosell, 2016). Gram horse flour incorporation
416 (6%) in bread enhanced the polyphenol and antioxidant contents while retaining acceptability of a sensory
417 panel (Moktan & Ojha, 2016). Breads supplemented with 10% germinated pulses flours (lupin and
418 chickpea) showed superior technological (volume, specific volume, symmetry and texture) compared to the
419 control sample (100% wheat flour) (Levent, Bilgiçli, & Ertaş, 2015). Such result might be likely attributed
420 to improving hydrolytic enzymatic activity and soluble components (Ouazib et al., 2016). Beyond 15%
421 addition level of cowpea germinated flour, sticky dough was produced, which caused difficulties for

422 handling. In this case, it could be possible that by adding the germinated flour you are bringing in the dough
423 formulation also proteolytic and amylolytic enzymes compromising the techno-functionality played by
424 gluten and wheat starch in the bread system. Also, the obtained bread had a lower volume and a crumb
425 compact structure (Hallén, Ibanoglu, & Ainsworth, 2004). Furthermore, 20% addition of chickpea flour
426 showed detrimental effect on bread quality (reduction in volume and increase in crumb firmness) (Ouazib
427 et al., 2016). As for color, yellowness and saturation (C*) was not affected after 10% germinated chickpea
428 flour fortification, while color was worsened in the case of 20% replacement (Ouazib et al., 2016).

429 **4.5. Blends fortified with fermented pulses flour**

430 **4.5.1. Pulses fermentation**

431 Fermentation is reported to be safe processing to enhance the nutritional value of pulses (Adeyemo &
432 Onilude, 2013; Bartkiene et al., 2016; Coda et al., 2008; Kapravelou et al., 2015; Osman, 2011; Rizzello,
433 Calasso, Campanella, De Angelis, & Gobbetti, 2014; Xiao, Huang, et al., 2016). Solid state bioconversion
434 is also a microbial bioprocessing, which is a simple alternative technology to improve the nutritional,
435 nutraceutical and palatable properties of legumes and/or cereals (Sánchez-Magaña et al., 2014). A
436 collection of pulses (faba bean; lupine, chickpea; and peas) and their mixture were subjected to solid state
437 fermentation by *Rhizopus oligosporus* (Nassar, Mubarak, & El-Beltagy, 2008). As result, fermentation
438 increased protein and fiber, while decreased fat, ash and carbohydrate contents (Nassar et al., 2008). Solid-
439 state fermentation with *Rhizopus* spp. enhanced isoflavone aglycones, total phenolic content, and
440 antioxidant activity of black soybean (Cheng, Wu, Lin, & Liu, 2013). The product of solid-state black
441 soybean fermentation serves as a functional ingredient for their potential health such as antioxidative and
442 cytotoxic activities (Cheng et al., 2013; Chia et al., 2013). Solid-state fermentation using a mix of fungi
443 (*Aspergillus awamori*, *Aspergillus oryzae*, *Aspergillus sojae*, *Rhizopus azygosporus* and *Rhizopus sp*)
444 enhanced the antioxidant activity, total phenolic and anthocyanin contents of black bean (Lee, Hung, &
445 Chou, 2008). Fermentation using *BCRC 30222*, *Aspergillus awamori*, *Actinomucor taiwanensis* and

446 *Rhizopus* sp. was reported to increase in total phenolic and antioxidative agents in comparison with the non-
447 fermented soybean (Lin, Wei, & Chou, 2006). Likewise, fermented black soybeans with *Aspergillus*
448 *awamori* showed higher amino acids and total phenolics than to those non-fermented (Chen, Lee, & Chou,
449 2011).

450 Recently, Curiel et al., (2015) assayed the impact of sourdough fermentation with selected lactic acid
451 bacteria (*Lactobacillus plantarum* C48 and *Lactobacillus brevis* AM7) on the nutritional and functional
452 properties of some pulses (*Phaseolus vulgaris*, *Cicer arietinum*, *Lathyrus sativus*, *Lens culinaris* and *Pisum*
453 *sativum* species). Pulses sourdough based-dough had higher free amino acids, soluble fiber, g-aminobutyric
454 acid), total phenols, antioxidant and phytase activities than conventional dough (Curiel et al., 2015).
455 Likewise, fermented soybeans (*Bacillus amyloliquefaciens*, *Lactobacillus* spp., and *Saccharomyces*
456 *cerevisiae*. *Bacillus amyloliquefacie* or *Bacillus subtilis*) had increased antioxidant capacity and scavenging
457 ability (Chen et al., 2011; Juan & Chou, 2010) as compared to the control. Similarly, fermented chickpeas
458 (with *Cordyceps militaris*) had enhanced crude protein and essential amino acids as well as antioxidant and
459 scavenging activities, ABTS radical scavenging activities and reducing power (Curiel et al., 2015; Xiao,
460 Huang, et al., 2016). Fermentation also improved the functional properties of pulses flour such as water
461 absorption index, water holding capacity, fat absorption capacity and emulsifying properties (Xiao et al.,
462 2015). Thus, flour deriving from fermented pulses might be considered of great potential as a functional
463 ingredient for foodstuff-making (Xiao et al., 2014, 2015).

464 Regarding antinutrients, fermentation reduced stachyose and raffinose (Nassar et al., 2008). For instance,
465 tannin (from 1.93 to 0.12 mg/g) and phytate contents (from 1.16 to 0.04 mg/g), as well as trypsin and
466 protease inhibitors (from 1.20 to 0.010 and 1.2 to 0.020, respectively) were reduced after fermentation by
467 *Lactobacillus plantarum* (Adeyemo & Onilude, 2013). Similar results were obtained after the fermentation
468 of grass pea and soybean with *Lactobacillus plantarum* (Limón et al., 2015; Starzyńska-Janiszewska &
469 Stodolak, 2011; Wang et al., 2010) and spontaneous fermentation of kidney beans (Granito and others
470 2002). Sourdough fermentation also enabled a up to 64% decrease in raffinose and tannins (Curiel et al.,

471 2015). Besides reducing antinutrients amounts, pulses fermentation (by *Bacillus amyloliquefaciens*,
472 *Lactobacillus* spp., and *Saccharomyces cerevisiae*. *B. amyloliquefaciens*) reduced allergens (Chi & Cho,
473 2016). After 24 h of fermentation, trypsin inhibitors and glycinin were reduced by 50% and 58%,
474 respectively (Seo & Cho, 2016).

475 **4.5.2. Effect of fermented pulses flours on bread quality**

476 Fermented pulse flour incorporation in breads formula improved their nutritional value in terms of total
477 dietary fiber, protein digestibility, mineral, amino acid, fat and antioxidant contents of composite breads
478 (Chinma et al., 2016; Rizzello et al., 2014; Xiao et al., 2014; Xiao, Fan, et al., 2016). Furthermore,
479 antinutrients were reduced such as phytate and tannin compared to non-fermented pulses (Chinma et al.,
480 2016; Rizzello et al., 2014; Shrivastava & Chakraborty, 2018; Xiao et al., 2014; Xiao, Fan, et al., 2016).
481 As for bread quality, fermented chickpea flour addition (50g/Kg) enhanced specific volume and crumb
482 firmness than the wheat 100% flour bread, unlike non-fermented flours. Yellowness index was also
483 enhanced due to the naturel yellow pigment of chickpea, but reduced crumb lightness probably because of
484 Maillard reaction' products (Xiao, Fan, et al., 2016). In addition, bread made with fermented flours were
485 more appreciated by the panel in terms of appearance, texture, color and overall acceptance (Xiao, Fan, et
486 al., 2016).

487 Also, Chinma et al. (2016) studied bread fortified with bambara nut sourdough flour (0, 5, 10 and 15%),
488 and found that up to 10% substitution, bread had better taste, flavor and overall acceptability compared to
489 wheat bread, while color and texture were not affected by the addition (10%). Beyond 15%, the addition of
490 pulses sourdough flour to wheat flour was correlated to dough weakening (Rizzello et al., 2014). As a result,
491 a decrease in specific volume was observed, which might be due to the dilution effect on gluten resulting
492 in less retention of gas (Chinma et al., 2016; Rizzello et al., 2014). At 30%, bread was not acceptable due
493 to the decrease of the volume and crumb cells, while the addition of 15% did not affect the structure
494 (Rizzello et al., 2014). Based on sensory evaluation, Shrivastava & Chakraborty (2018) optimized a bread

495 recipe based on 18% fermented chickpea flour with addition of 2% xanthan gum to compensate gluten
496 dilution.

497 **5. Conclusions and perspectives**

498 Pulses are bio-diverse, highly nutritious and cultivated worldwide. Indeed, pulses are powerful crops to
499 fight undernutrition in low-income regions and malnutrition in high-income regions of the world. Pulses
500 use to be called the “Poor Man's Meat” because they are economically-affordable and highly-nutritional
501 and are nowadays becoming also the “Rich Man’s Meat”. Therefore, fortifying wheat flour with pulses
502 toward developing new healthy food products might be the right trend to follow.

503 Pulse flour incorporation in bread was carried out mainly to improve the nutritional profile to provide a
504 balanced amino acid profile rich in essential amino acids. In the frame of environmental sustainability of
505 farming, they are also a source of proteins with low carbon and water footprints.

506 Bread made with blends containing pulses (10-15%) has an improved nutritional composition as well as
507 appreciated technological and sensorial traits. Beyond 15% supplementation, additives incorporation might
508 be a good alternative to compensate the dilution of gluten, thereby maximizing nutritional advantages and
509 overcoming technological flaws. Pulses flour pre-treatment (e.g. germination and fermentation) may
510 provide additional benefits such as increasing nutrients availability and decreasing antinutrients. More
511 rigorous studies, such as full-factorial studies, are needed to assess the effects of processing, additives and
512 their combination on bread quality and to optimize formulations/processes for high-quality pulses based-
513 bread.

514 **Author Contributions**

515 FB collected the data and compiled and wrote the manuscript. EZ, EC and EV planned, drafted and
516 corrected the manuscript.

517 **Conflict of interest**

518 The authors declare no conflict of interest.

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1064 **Figure caption**

1065 **Figure 1: Classification and botanical description of pulses.** This figure underlined the major species of pulses
1066 belonging to the family of *Faboidae*.

1067 **Figure 2: Importance of pulses.** This figure highlighted the contribution of pulses to a balanced and sustainable
1068 Humans-Environment relation indicating the possible benefits that might be gained from the cultivation of such crop.

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1073 **Table 1: production quantity and area harvested of pulses versus cereals (FAO 2016).**

Area	Pulses		Cereals	
	Production (tones)	Area harvested (Ha)	Production (tones)	Area harvested (Ha)
European Union	628153	245041	402085	164234
Low Income Food Deficit Countries	2647118	4553099	5567552	3578558
Net Food Importing Developing Countries	1663486	2238303	5616160	3637773

1074 <http://www.fao.org/faostat/en/#data/QC>

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1086 **Table 2: Common name and scientific name of pulses**

Common name	Scientific name
Phaseoleae	
<i>Phaseolus</i>	
Common bean	<i>Phaseolus vulgaris</i> L.
Lima bean	<i>Phaseolus lunatus</i> L.
<i>Vigna</i>	
Mungo bean	<i>Vigna mungo</i> L.
Adzuki bean	<i>Vigna angularis</i> Wild.
Mung bean	<i>Vigna radiata</i> L.
Rice bean	<i>Vigna umbellata</i> Thunb.
Moth bean	<i>Vigna aconitifolia</i> Jacq.
Cowpea	<i>Vigna unguiculata</i> L.
Bambara groundnut	<i>Vigna subterranea</i> L.
<i>Cajanus</i>	
Pigeon pea	<i>Cajanus cajan</i> L.
Cicereae	
Chickpea	<i>Cicer arietinum</i> L.
Hyacinth bean	<i>Lablab purpureus</i> L.
Fabeae	
<i>Lens</i>	
Lentil	<i>Lens culinaris</i> Medik.
<i>Vicia</i>	
Broad bean	<i>Vicia faba</i> L.
Vetch	<i>Vicia sativa</i>
<i>Pisium</i>	
Pea	<i>Pisum sativum</i> L.
Other dried pulses	
Lablab, hyacinth bean	<i>Lablab purpureus</i>
Jack bean	<i>Canavalia ensiformis</i>
sword bean	<i>Canavalia gladiata</i>
Winged bean	<i>Psophocarpus tetragonolobus</i>
Velvet bean	<i>Mucuna pruriens</i>
Yam bean	<i>Pachyrhizus erosus</i>
Grass pea	<i>Lathyrus sativus</i>

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Table 3: Background information of pulses.

Species	Characteristics	References
Dry beans	are an important crop worldwide of pulses, which require warm climate to grow.	(Food And Agriculture Organization of the United Nations, 2016).
Dry board beans	are an ancient crop species that originated in the Near East, is mainly grown in Europe, North Africa, the Middle East, and China.	(Li & Yang, 2014).
Dry peas	have been grown commercially in western Europe, mainly as a spring crop.	(Le May, Guibert, Baranger, & Tivoli, 2014).
Chickpea	is a valuable ancient pulse, which grows well in different soils and climates. It is cultivated in the Indian subcontinent, North Africa, the Middle East, Southern Europe, Asia, the Americas and Australia. Desi and kabuli are the most cultivated varieties.	(Thushan Sanjeeva, Wanasundara, Pietrasik, & Shand, 2008).
Dry cowpeas	are among the most popular pulses mentioned throughout Eastern and Southern Africa.	(Keller, Mndiga, & Maass, 2006).
Pigeon peas	also known as red gram, is among the important grain pulses grown and consumed in in south-west Nigeria. It is tolerant to drought and has wide adaptability to different environmental conditions.	(Ohizua et al., 2017).
Lentils	are commonly consumed worldwide, particularly in the Mediterranean area.	(Turfani, Narducci, Durazzo, Galli, & Carcea, 2017).
Bambara beans	are grain indigenous to sub-Saharan Africa. Though an underutilized crop, it is ranked next to cowpea.	(Erukainure et al., 2016).
Lupins	are relatively more tolerant to several abiotic stresses than other pulses, with great potential in poor and contaminated soils reparation.	(Coba de la Peña & Pueyo, 2012).
Vetches	are consumed by humans since the Neolithic Era, but currently they are mainly used as fertilizer or livestock fodder N.	(Food And Agriculture Organization of the United Nations, 2016).
Other minor pulses	<ul style="list-style-type: none"> • Green gram is one of the important pulse crops cultivated in India since ancient times and it is widely cultivated throughout the Asia. • Faba bean (<i>Vicia faba</i> L.) is grown worldwide under different cropping systems, extensively cultivated in West Asia and North African. Faba bean contributes to the sustainability of cropping systems. Faba bean breeding for resistance to different types of diseases including viruses was reviewed. • Grass pea (<i>Lathyrus sativus</i> L.) is an annual pulse crop, which belongs to the Fabaceae family and is mostly cultivated for stock-feed and human consumption in Asian countries. 	(Rubiales, Rojas-Molina, & Sillero, 2016) (Kumar, Nidhi, Prasad, & Sinha, 2015; Sillero et al., 2010). (Tamburino et al., 2012).

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Table 4: Macro-components of mature, whole, dried, raw pulses (expressed per 100 g edible portion on dry matter basis).

Common name	Energy (kcal)	Water (g)	Protein (g)	Carbohydrates (g)	Fiber (g)	Fat (g)	Ash (g)
Bambara groundnuts	325	9	18,4	33,7	28,9	6,4	3,4
Broad bean	309	10,9	25,3	38,3	20,8	1,4	3,3
Adzuki bean	318	11	20,5	51,3	13,1	0,6	3,7
Chickpea, desi	332	10	21,2	40	21,2	5	2,7
Chickpea, kabuli	359	8,5	20,8	48,9	13,1	6,1	2,8
Common bean	305	10,4	20,9	40,7	22,6	1,5	3,8
Cowpea	324	10,6	22,5	46,9	14,6	1,9	3,5
Kidney bean	307	10,9	22,8	39,4	21,7	1,6	3,6
Lentil	324	9,7	24,4	44,8	17	1,5	2,7
Lima bean	316	9,2	20,9	45	19,1	1,5	4,2
Lupin	309	9,4	34,1	10,8	35,3	6,5	3,8
Moth bean	326	9,6	23,9	45,9	14,9	1,9	3,8
Mung bean	325	9,7	20,9	49,6	15,4	1,3	3,1
Mungo bean	316	9,8	23,9	42,2	19,5	1,4	3,4
Pea	310	11,3	23,4	38,4	22,2	2,1	2,7
Pigeon pea	306	11,4	20,6	41	21,4	1,8	3,8
Pinto bean	301	12,4	19,6	43,8	18	1,3	4,9
Wheat flour (control)	341	12,2	12,1	69,4	1,4	1,7	2,7

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1094 (Food And Agriculture Organization of the United Nations, 2016) FAO/INFOODS Global Database for Pulses on Dry Matter Basis – version 1.0 (PulsesDM1.0) - 2017

1095 **Table 5: Amino acid profile of some pulses (expressed in mg/ 100 g edible portion on dry matter basis).**

	Ala	Arg	Asp	Cys	Glu	Gly	His	Ile	Leu	Lys	Met	Phe	Pro	Ser	Thr	Trp	Tyr	Val
Adzuki bean	1190	1320	2430	190	3190	779	540	815	1720	1540	216	1080	900	1000	694	197	609	1050
Bambara groundnuts	856	1270	2130	144	3250	552	394	870	1510	1220	399	946	831	1140	834	115	449	836
Broad bean	1000	2380	2720	303	4240	1050	652	1010	1810	1570	166	1070	1010	1180	870	217	802	1120
Chickpea, desi	922	2170	2370	646	3840	798	600	893	1600	1420	220	1190	1090	1190	773	217	626	908
Chickpea, kabuli	817	1660	2110	267	3900	802	637	817	1470	1220	272	1200	969	1020	831	213	609	824
Common bean	971	1270	2520	104	3380	898	590	760	1480	1300	185	1000	921	1220	881	234	638	961
Cowpea	1050	1580	2540	114	3960	928	766	1040	1760	1510	405	1260	1040	1100	891	253	649	1190
Kidney bean	996	1420	2900	242	3160	1160	602	1110	1970	1670	271	1310	654	1180	1040	328	905	1400
Lentil	1270	1830	3190	229	4710	1020	557	971	1850	1710	200	1110	1210	1100	773	239	694	1220
Lima bean	1070	1280	2700	231	2960	883	639	1100	1800	1400	264	1200	950	1390	903	248	740	1260
Lupin	1120	3610	3380	610	7930	1360	884	1350	2460	1650	215	1330	1350	1640	1160	281	1130	1300
Moth bean	1200	1310	2490	104	3570	965	698	1070	1750	1470	325	1110	1040	1080	924	231	650	1170
Mung bean	1020	1390	2490	161	3750	1440	559	605	1480	1160	224	1010	980	1390	772	208	560	937
Mungo bean	1060	1500	2960	180	4220	952	674	1020	1890	1550	313	1400	1030	1260	757	241	736	1160
Pea	1040	2030	2690	263	4020	1030	568	931	1670	1640	224	1110	967	1130	884	206	762	1100
Pigeon pea	1040	1350	2140	234	3760	766	685	780	1520	1360	253	1740	890	921	759	173	668	950
Pinto bean	911	1200	2360	98	3180	844	554	714	1390	1220	173	944	865	1140	827	220	599	903
Wheat flour (control)	543	696	802	309	4839	579	379	556	1112	416	251	772	1594	759	442	130	352	687

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1097 (Food And Agriculture Organization of the United Nations, 2016) FAO/INFOODS Global Database for Pulses on Dry Matter Basis – version 1.0 (PulsesDM1.0) – 2017

1098 Nutrient Data Laboratory, ARS, USDA National Food and Nutrient Analysis Program, Wave 9o, 2005 Beltsville MD

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Table 6: The main antinutrients in pulses.

Categories	Anti-nutritional effect	Nutritional effect
<i>Thermolabile</i>		
<i>Trypsin inhibitors</i>	<ul style="list-style-type: none"> • reduce protein bioavailability (Sarwar Gilani, Wu Xiao, & Cockell, 2012). • inactivate the digestive enzyme (Adeyemo & Onilude, 2013; Oomah, Caspar, Malcolmson, & Bellido, 2011). 	<ul style="list-style-type: none"> • cancer risk reducing factors. • regulate the activity of trypsin (Lajolo & Genovese, 2002).
<i>Protease inhibitors</i>	<ul style="list-style-type: none"> • inhibit the activity of trypsin, chymotrypsin and other intestinal proteases (Clemente & Arques, 2014; Župunski et al., 2018). • cause intestinal cell damaging and digestion disturbance (Erdaw, Bhuiyan, & Iji, 2016; Jiang, Jeschke, Hartung, & Cameron, 2008). 	<ul style="list-style-type: none"> • anti-inflammatory activity (Duranti, 2006). • can regulate proteases activity (Muricken & Gowda, 2010).
<i>Lectins</i>	<ul style="list-style-type: none"> • reduce nutrients bioavailability and solubility (Estrada-Martínez et al., 2017; Gupta et al., 2015) 	<ul style="list-style-type: none"> • can contribute to satiety (McCrorry et al., 2010).
<i>Thermostable</i>		
<i>Phytic acid</i>	<ul style="list-style-type: none"> • lowers the availability of minerals (e.g. calcium, zinc, iron, and magnesium), proteins, and starch (Nilgün Ertaş & Bilgiçli, 2014). • Reduce nutrients solubility, functionality, digestion, and absorption (Gupta et al., 2015; Martín-Cabrejas et al., 2009). 	<ul style="list-style-type: none"> • reduces cholesterol level • protects against intestinal cancer of iron origin. • natural antioxidants • protects from oxidative damage by reducing lipid peroxidation (Shi et al., 2004).
<i>Tannins</i>	<ul style="list-style-type: none"> • reduce protein digestibility by interaction of protein substrate with ionizable iron (Prasad & Singh, 2015; Sotelo et al., 2010). • cause damage to intestinal cells (Smith & Mackie, 2004). • cause inactivation of digestive enzymes (Adeyemo & Onilude, 2013). 	<ul style="list-style-type: none"> • antioxidant activity (Amarowicz, Pegg, Rahimi-Moghaddam, Barl, & Weil, 2004).
<i>Raffinose</i>	<ul style="list-style-type: none"> • limits digestion and absorption of nutrients (Wang, Hatcher, Tyler, Toews, & Gawalko, 2010). • produce digestive gases (Kumar et al., 2015; Wang et al., 2010). • 	<ul style="list-style-type: none"> • reduce the risk of intestinal cancer, fortifies the immune system, increases excretion frequency and weight as well as HDL cholesterol level. • promote the growth of the colon microflora and act as prebiotics (Gupta et al., 2015; Gupta & Abu-Ghannam, 2011).
<i>Saponine</i>	<ul style="list-style-type: none"> • bitter taste (Nilgün Ertaş & Bilgiçli, 2014). • ability to alternate intestinal cells wall (Mamilla & Mishra, 2017; Prasad & Singh, 2015). 	<ul style="list-style-type: none"> • can bond with cholesterol resulting in lower intestinal absorption of cholesterol (Shi et al., 2004). • can bond with heavy toxic metals, which reduces their availability (Kumar et al., 2015; Singh, Singh, Singh, & Kaur, 2017).



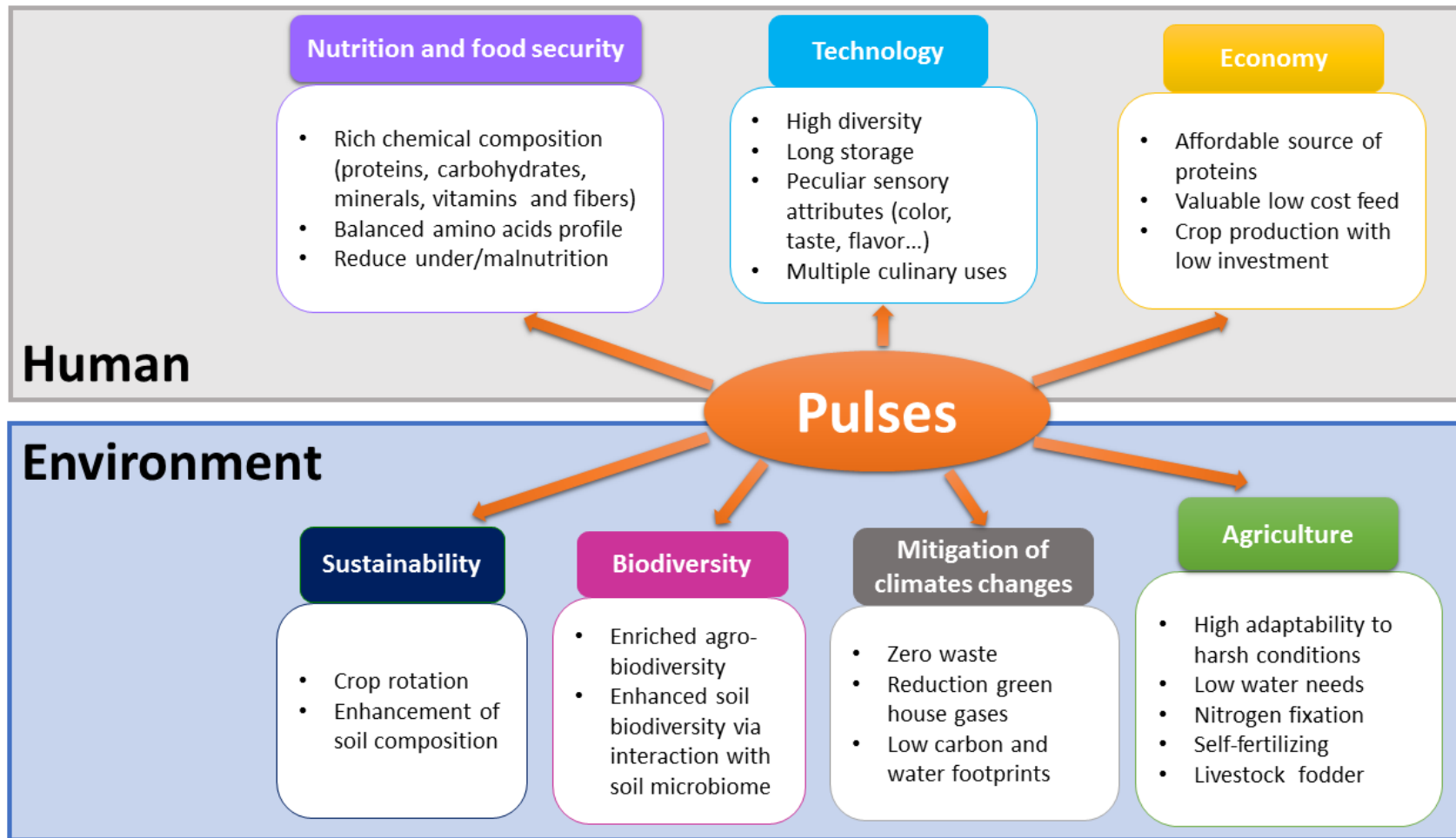
Figure 1: Classification and botanical description of pulses.

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Figure 2: Importance of pulses.

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