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## Seed coats of pulses as a food ingredient: Characterization, processing, and applications

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### Abstract

Background: In recognition of their multiple benefits on environment, food security, and human health, pulses are attracting worldwide attention. The seed coat is a major by-product of pulse processing, and its only markets are as low value ruminant feed and very limited use in high fibre foods. Recently, accumulating studies suggested that this underutilised by-product has greater potential as a novel natural “nutritious dietary fibre” to be used as a functional food ingredient. Scope and approach: This review discusses biochemical and physicochemical functionalities of seed coats of six globally important pulses: chickpea; field pea; faba/broad bean lentil and mung bean with a special emphasis on the emerging food pulse lupin. Food process modification and recent applications in human food of the seed coats are summarized. Bio-availability of the seed coat compounds are discussed and phomopsin contaminated lupin seed coats as a typical example of safety issue is reported. Key findings and conclusions: High levels of dietary fibre, minerals and potential health-promoting phytochemicals in the seed coats indicate their great potential to be used as a natural “nutritious dietary fibre”. However, further in-depth studies are required to improve their desirable nutritional, physiological and techno-functional properties whilst minimizing any undesirable ones.

**Keywords** Pulses; seed coat; dietary fibre; minerals; by-product; food ingredient

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## **Highlights**

- Greater pulses consumption is promoted worldwide, however pulse seed coats are a major under-utilised by-product.
- Improved nutritional, biochemical and physicochemical functionalities of pulse seed coats through processing may expand their food applications.
- High levels of dietary fibre, minerals and phytochemicals in the seed coats indicate their great potential as a natural “nutritious dietary fibre” food ingredient.
- More in-depth studies on pulse seed coats innovative processing technology, applications in food products and their physiological properties are needed.

1           **Seed coats of pulses as a food ingredient: characterization,**  
2                                   **processing, and applications**

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## **Abstract**

*Background:* In recognition of their multiple benefits on environment, food security, and human health, pulses are attracting worldwide attention. The seed coat is a major by-product of pulse processing, and its only markets are as low value ruminant feed and very limited use in high fibre foods. Recently, accumulating studies have suggested that this underutilised by-product has greater potential as a novel natural “nutritious dietary fibre” which can be used as a functional food ingredient.

*Scope and approach:* This review discusses biochemical and physicochemical functionalities of seed coats of six globally important pulses: chickpea, field pea, faba/broad bean, lentil and mung bean with a special emphasis on the emerging food pulse lupin. Food process modification and recent human food applications of the seed coats are summarized. Bio-availability of the seed coat compounds, and phomopsins contaminated lupin seed coats as a typical example of safety issue are discussed.

*Key findings and conclusions:* High levels of dietary fibre, minerals and potential health-promoting phytochemicals in the seed coats indicate their great potential to be used as a natural “nutritious dietary fibre”. However, further in-depth studies are required to improve their desirable nutritional, physiological and techno-functional properties whilst minimizing any undesirable ones.

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40 **Keywords**

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42

43 **1. Introduction**

44 “Pulses” refers to those low-fat content leguminous seeds which are harvested for dry  
45 grain (FAO, 1994). So, oilseeds (e.g. soybean and peanut), leguminous green  
46 vegetables (e.g. green peas and green beans) and leguminous fodder plants (e.g. clover  
47 and alfalfa) are traditionally excluded. Pulses are historically important in both the  
48 human diet and cropping systems as crop rotations, due to their rich-protein and  
49 biological nitrogen fixation ability. Although most pulses are not traditionally typical  
50 Western-style foodstuffs, international events like “International Year of Pulses 2016”  
51 and “Global Pulses Day” suggest that they are being promoted to be important human  
52 food world widely (Foyer, et al., 2016).

53

54 **As shown in Table 1, six** of the 11 pulses which are covered in the FAO list, chickpea  
55 (*Cicer arietinum*), lupin (*Lupinus*), field pea (*Pisum sativum*), faba/broad bean (*Vicia*  
56 *fabae*), lentil (*Lens culinaris*) and mung bean (*Vigna radiate*), are the most important  
57 pulses globally, totally accounting for **79.89%** of the world pulse production (**81.8**  
58 **million tonne**) in 2016 (FAOSTAT, 2018). **India is the largest pulse producer globally,**  
59 **followed by Canada, Myanmar and China. However,** Australia is the largest lupin  
60 producer in the world, contributing **an average of 58.22%** of the world production in

61 2012-2016 (ABARES, 2018). Australian sweet lupin (ASL, *L. angustifolius*), which is  
62 also named “narrow-leafed lupin”, is the most important lupin specie, constituting 93%  
63 of Australian lupin production and 52% of the world production (Pulse Australia, 2016).  
64 However, chickpea has overtaken lupin as Australia’s largest pulse crop since 2011-12,  
65 with a production estimated at over 2 million tonne in 2016-17 (ABARES, 2018). As a  
66 leading pulse exporter, Australia exports over 90% of its chickpeas, faba beans, lentils  
67 and mung beans, and 60% of field peas were exported, being the largest exporter of  
68 *desi* chickpea and faba bean in the world. Notably, although Australia exported only 50%  
69 of its lupin, this accounted for 90% of world lupin export in 2013.

70

71 Pulse seed has three distinctive parts, namely the seed coat, embryonic axe and  
72 cotyledon, which generally accounts for 8-16%, 1-3% and 80-90% of the whole seed  
73 respectively (Dueñas, Hernandez, & Estrella, 2006). However, the proportions of seed  
74 coat show great genetic and environmental variability both between and within species  
75 (Table 2). For example, lupin uniquely contains a much higher percentage of seed coat  
76 than others, with up to 24% in Australian sweet lupin and around 18% in white lupin  
77 (Clements, et al., 2014). Removal of pulse seed coat (dehullinig) is a primary process  
78 to produce dehulled splits, ground flours and other fractionated pulse ingredients like  
79 pulse protein and fibre. In practice, by-product generated from the dehulling process is  
80 a mixture of seed coats, embryonic axes and brokens of cotyledons (Oomah, Caspar,  
81 Malcolmson, & Bellido, 2011; Sherasia, Garg, & Bhanderi, 2017). As a consequence,

82 dehulling loss which is the main waste stream of pulse processing represents as much  
83 as 31% for sweet lupin in Australia (Sipsas, 2008), and up to 28% for lentil and  
84 chickpea in India (Tiwari & Singh, 2011). Currently the primary markets for pulse seed  
85 coats are low value animal feed and only very limited use in human foods such as that  
86 added to make high fibre breads and meat products (like sausage and nuggets). This by-  
87 product not only leads to a tough disposal problem for the millers, but also wastes a  
88 potential source of novel, nutritious and health-promoting food ingredient (Sherasia, et  
89 al., 2017).

90

91 Growing evidence suggests that pulse seed coats have considerable amount of dietary  
92 fibre which is associated with diverse types of minerals and phytochemicals (bioactive  
93 secondary metabolites in plants e.g., polyphenolic antioxidants). Therefore, besides the  
94 well-documented physiological benefits of dietary fibre, seed coats provide potential  
95 for various physiological benefits, such as those related to antioxidant and anti-  
96 inflammatory activities. Available studies on pulse seed coats mainly focus on  
97 proximate compositions and anatomical structures, with little attention paid to their  
98 phytochemical properties and physiological functionalities. The present review brings  
99 together the current research on the characterization, processing and applications of  
100 seed coats from six selected pulses, i.e., chickpea, lupin, field pea, faba/broad bean,  
101 lentil and mung bean. This information should encourage strategies which might enable  
102 the more extended use of pulses and their seed coats in human foods.

103

## 104 **2. Seed coat morphology and physical properties**

105 The pulse seed coat (often referred as hull or testa) is a protective outer layer of the  
106 pulse seed. Structures of pulse seed coats have been overviewed by Moïse, Han,  
107 Gudynaite-Savitch, Johnson, and Miki (2005) and Smykal, Vernoud, Blair, Soukup,  
108 and Thompson (2014). Anatomical structures of seed coats of field pea (Van Dongen,  
109 2003), faba/broad bean (Youssef & Bushuk, 1984), chickpea (Wood, Knights, & Choct,  
110 2011), lentil (Hughes & Swanson, 1986), lupin (Clements, Dracup, Buirchell, & Smith,  
111 2005) and mung bean (Joseph & Swanson, 1993) have been extensively examined and  
112 show great similarities. Largely, there are three specialized cross-sectional layers in  
113 typical pulse seed coats: palisade cells (macrosclereids) layer, thick-walled hourglass  
114 cells (osteosclereids) layer, and a few layers of parenchyma (Fig 1.) (Moïse, et al., 2005;  
115 Tiwari & Singh, 2011).

116

117 The seed coats significantly affect chemical exchange (e.g. water and gas),  
118 biochemistry, mechanical properties (e.g. permeability, hardness and porosity) and  
119 physiological activities (e.g. germination and metabolism) of the pulse seeds (Moïse,  
120 et al., 2005). In addition, their chemical and physical characteristics, including  
121 composition, shape, mass, smooth or rough surface, thickness, colour, density and  
122 thermal properties (e.g. thermal conductivity and thermal diffusivity) strongly affect  
123 the whole seed properties (such as density, dehulling efficiency, and cooking quality),

124 further determine post-harvest processing, end application and market price of the seeds  
125 (Souza & Marcos-Jilho, 2001). In this review, the most essential physical properties of  
126 the seed coats (i.e. colour, thickness and permeability) are discussed.

127

### 128 2.1. Colour

129 As a key quality indicator, colour of the pulse seeds is crucial to consumer acceptance.  
130 Seed coat colour varies significantly across different varieties (Table 2). In Australia  
131 for example, over 90% of field pea is *dun* coloured type, and principally light brown  
132 *desi* chickpea, beige or light brown faba bean, white with/without spots lupin, red lentil  
133 and green mung bean. It has been revealed that the pigmentations of seed coats are  
134 mainly attributed to chlorophyll and polyphenols (mainly flavonoids) (Hossain,  
135 Panozzo, Pittock, & Ford, 2011), which mainly are located in the external palisade layer  
136 (Wood, et al., 2011). The colours are associated with levels of those compounds, and  
137 thus their physiological properties like antioxidant capacity. For example, dark  
138 coloured pulses are reported to contain higher levels of polyphenols, mainly  
139 anthocyanins and condensed tannins, and correspondingly higher antioxidant activities  
140 than those of pale ones (Xu, Yuan, & Chang, 2007).

141

142 Colours of pulse seed coats are unstable during post-harvest processing and strongly  
143 affected by processing conditions. For example, the extremely high temperature (>40  
144 °C) may accelerate undesirable colour darkening process in faba bean seed coat. This

145 is accompanied by a significant loss, ranging up to 86% of total polyphenols, which  
146 may be explained by the polymerization of polyphenols into insoluble, un-extractable  
147 high molecular weight polymers (Nasar-Abbas, et al., 2009). Similar browning was  
148 found in lentils (Nozzolillo & Debezada, 1984) and chickpea (Reyes-Moreno,  
149 Okamura-Esparza, Armienta-Rodelo, Gomez-Garza, & Milan-Carrillo, 2000) when  
150 stored at high temperature. Moreover, the unpigmented varieties are supposed to be  
151 more vulnerable to seed deterioration during storage (Souza & Marcos-Jilho, 2001).  
152 However, the exact principles which are responsible for the darkening of pulse seed  
153 coats are still unclear.

154

## 155 2.2. Thickness and permeability

156 In general, the palisade cell layer mainly decides the thickness of the seed coat.  
157 Domesticated pulse varieties have thinner, softer, more permeable seed coats than wild  
158 counterparts mainly due to decreases in thickness of the palisade layer. Moreover, the  
159 proportion and thickness of the seed coat are negatively correlated with seed size. The  
160 seed coat characteristics should be carefully considered during food processing  
161 (especially dehulling) and application. For example, *kabuli* chickpea has a larger seed  
162 size and thinner seed coat than the *desi* type (Table 2). As a result, cultivars of *kabuli*  
163 are normally used as whole seeds without dehulling for paste, salads, roasted or fried  
164 to make snacks (Wood, Knights, Campbell, & Choct, 2014). By contrast, cultivars of  
165 the *desi* type are often dehulled to *dahl* (split) which are directly cooked or milled to

166 flour. Another example to show the associations between processing properties and  
167 seed coat thickness is that lentils have thinner seed coats and thus shorter cooking times  
168 than do other pulse seeds. Additionally, thicker seed coats result in longer cooking-  
169 times in field peas (Wang, Daun, & Malcolmson, 2003) and faba beans than those  
170 which have thin seed coats (Youssef & Bushuk, 1984).

171

172 The permeability of pulse seed coats change as the seed matures and are related to their  
173 structure and chemistry (Ma, Cholewa, Mohamed, Peterson, & Gijzen, 2004). Although  
174 impermeability of pulse seed coats is important to seed vitality, it is undesirable during  
175 food processing. The impermeability will contribute to lower whole-seed cookability  
176 (“hard-to-cook” phenomenon) and customer acceptability. For example, during  
177 soaking, the thick and impermeable seed coat will slow water imbibition by the seed,  
178 restrict its expansion and thus decrease the wet dehulling efficiency. The hydrophobic  
179 waxy cuticle and condensed palisade cells layer of the seed coat are major contributors  
180 to seed impermeability (Ma, et al., 2004).

181

### 182 **3. Pulse seed coat composition**

183 The nutritional composition of whole pulse seeds have been reviewed in the  
184 FAO/INFOODS global food composition database for pulses (uPulses 1.0) (FAO,  
185 2017). The composition of seed coats of the selected **six** pulses are summarized (**Table**  
186 **3**). Generally, pulse seed coats have about 8-10% moisture, 3% ash, 1-3% lipids and

187 2-8% protein, with a major carbohydrate components (60-90%), mainly insoluble non-  
188 starch polysaccharides (NSPs) (Tiwari & Singh, 2011). Of the macronutrients, we focus  
189 on carbohydrates and minerals since they make up the majority and provide a basis for  
190 the usage of the seed coat as a food ingredient.

191

192 In general, pulse seed coats have a neutral to slightly nutty flavour, although their  
193 volatile profiles are largely unknown (Pfoertner & Fischer, 2001). Pulse seed coats are  
194 the major contributors to the phytochemical content of the whole seeds (Dueñas, et al.,  
195 2006; Luo, Cai, Wu, & Xu, 2016). Some of the phytochemicals are, historically,  
196 referred to as “anti-nutritional factors (ANFs)”, as with polyphenols, phytic acid and  
197 alkaloids. However, numerous epidemiological studies now indicate their potential  
198 benefits for human health (Rochfort & Panozzo, 2007). Investigation of the  
199 micronutrients (vitamins and minerals) and other bioactive compounds in the six pulse  
200 seed coats is embryonic.

201

### 202 *3.1. Carbohydrates*

203 As mentioned above, pulse seed coats have negligible amounts of starch and  
204 oligosaccharides. Instead, they are predominantly composed of structural  
205 polysaccharides (non-starch polysaccharides, NSPs), which are mainly cellulose,  
206 hemicellulose, **pectin** (Table 3). As such, over 50 percent of the monosaccharides in  
207 seed coat are glucose from the cellulose. The other principal sugars vary between



208 species. For example, the high concentrations of xylose (21.6%), uronic acids (10.0%)  
209 and arabinose (8.4%) in **lupin** seed coat indicate relatively high contents of  
210 arabinoxylan hemicellulose and pectin (Evans & Cheung, 1993). On the contrary,  
211 uronic acids (22.3%), xylose (10.8%) and arabinose (5.2%) are the main sugars in field  
212 pea seed coat cell walls (except glucose), indicating a high content of pectin (Guillon  
213 & Champ, 2002). It is worthwhile to note that there are also significant differences  
214 between NSPs in cotyledons and seed coats. For instance, the major constituent NSPs  
215 of lupin seed coat are cellulose (from 45 to 56 g/100g dry matter (DM)), arabinoxylan  
216 hemicelluloses (~13 g/100g DM) and pectins, whereas pectic substances and  
217 hemicellulose are the predominant parts in cotyledon (Brillouet & Riochet, 1983).

218

219 Non-starch polysaccharides are classified as the principal components of the plant  
220 dietary fibre (DF) (Lovegrove, et al., 2015). In principle, seed coat contributes a  
221 significant proportion of the DF level of pulse because of their high content of NSPs,  
222 ranging from 75 to 91 g/100g DM (Table 3). In addition, most of the DF in pulse seed  
223 coats are insoluble dietary fibre (IDF), only 3.5% of total dietary fibre (TDF) in lupin  
224 seed coat is **soluble for example (Evans & Cheung, 1993). IDF levels of dehulled lentils,**  
225 **peas and chickpeas decreased by 64%, 53% and 35% respectively compared to raw**  
226 **seeds, but no significant reduction in SDF was found (Dalgetty & Baik, 2003).** However,  
227 regarding the newly proposed DF definition and analytic method (i.e. AOAC 2011.25),

228 contemporary information on DF (including oligosaccharides) for the six pulse seed  
229 coats is scarce.

230

### 231 3.2. *Minerals and trace elements*

232 Pulses provide substantial amounts of minerals. Pulse seed coats are rich in several  
233 minerals, e.g. Ca, Mg, Mn, Cu, Zn, B, Al and Na etc. (Tiwari & Singh, 2011). Notably,  
234 67.5% of total Ca, and 41.3% of total Al of the whole lupin seed were reported to  
235 concentrate in its seed coat (Hung, Handson, Amenta, Kyle, & Yu, 1988). Likewise,  
236 over 70% of Ca and 50% of iron in mung bean (Singh, Singh, & Sikka, 1968), lentil  
237 (Tiwari, et al., 2012) and chickpea (Jambunathan & Singh, 1981) are found in their seed  
238 coats. Besides the inter-species variations, minerals in seed coats vary widely inner-  
239 species. For instance, contents of most of the minerals, especially Ca, Zn, Cu, and Mn,  
240 in *kabuli* chickpea seed coat are higher than *desi* type (Jambunathan & Singh, 1981).  
241 Consequently, differences in the seed coats (like thickness and proportion) between  
242 pulses are used to explain the variations in mineral levels of the whole seeds.

243

### 244 3.3. *Phytochemicals*

245 The major phytochemicals in different pulses vary significantly. For instance, chickpea  
246 was found to be one of the major sources of dietary saponins (Oakenfull, 1981), but  
247 alkaloids are characteristically present in lupin. Although, carotenoids (a group of lipid-

248 soluble natural plant pigments) contents of field pea (Marles, Warkentin, & Bett, 2013)  
249 and chickpea (Ashokkumar, Tar'an, Diapari, Arganosa, & Warkentin, 2014) are  
250 suggested to be associated with seed coat colours, pulse seed coats are generally known  
251 as a poor source of carotenoids since they have low level of fat. In some cases,  
252 phytochemicals may cause toxic effects (e.g. favism caused by vicine and convicine in  
253 faba beans) (Klupšaitė & Juodeikienė, 2015). However, this review will discuss  
254 polyphenols and phytic acid in the six pulse seed coats, and alkaloids in lupins since  
255 they are more relevant to the potential positive physiological properties of the seed  
256 coats.

257

### 258 3.3.1. *Polyphenols*

259 Polyphenols are a wide range of secondary plant metabolites, which typically have one  
260 or more aromatic rings bearing several hydroxyl groups. The major polyphenols in  
261 whole pulse seeds are phenolic acids (e.g., benzoic/cinnamic acids and their  
262 derivatives), flavonoids (e.g., flavone and flavonol glycosides) and condensed tannins  
263 (Oomah, Patras, Rawson, Singh, & Compos-Vega, 2011). Recently, a few studies have  
264 investigated polyphenols in pulse seed coats, including chickpea (Sreerama, Neelam,  
265 Sashikala, & Pratapa, 2010), faba bean (Boudjou, Oomah, Zaidi, & Hosseinian, 2013),  
266 field pea (Marles, et al., 2013), lentil (Dueñas, et al., 2006; Oomah, Caspar, et al., 2011),  
267 and mung bean (Luo, et al., 2016; Muhammed, Manohar, & Junna, 2010).

268

269 In general, these studies confirmed that polyphenols of whole pulses seeds are  
270 essentially concentrated in the seed coats, and hence they are the predominant *in vitro*  
271 antioxidant capacity contributors. For example, 80.3-84.2% of the total polyphenol and  
272 over 83.9% of total flavonoid content of whole mung bean seed were reported to be  
273 present in the seed coat (Luo, et al., 2016; Muhammed, et al., 2010). The proportions  
274 of total polyphenol and total flavonoid content in faba bean seed coat are up to 80.0%  
275 and 89.3% of the whole seed respectively (Boudjou, et al., 2013). Similarly, total  
276 polyphenol content of chickpea seed coat (75.94 mg GAE /g DM) was relatively higher  
277 than that of cotyledon (15.24 mg GAE /g DM) (Sreerama, et al., 2010). Condensed  
278 tannins in faba bean (Boudjou, et al., 2013), mung bean (Xu, et al., 2007), and lentil  
279 (Dueñas, Hernández, & Estrella, 2002) seed coats were report to represent over 75%,  
280 50% and 54% respectively of the total tannins in the whole seeds. Notably, Xu, et al.  
281 (2007) found that polyphenols levels and *in vitro* antioxidant activities of dark coloured  
282 (like red, bronze, and black) lentil and chickpea seeds were significantly higher than  
283 those of light coloured (like white, yellow, and green) varieties. Total free phenolic  
284 acids and condensed tannins in coloured pea seed coat reached to 78.53 g/g DM and  
285 1560 mg CE/g DM comparing to 17.17 g/g DM and not detected for those in white seed  
286 coat (Troszyńska & Ciska, 2002).

287

288 In the case of lupins, total polyphenol content in seed coats of *L. mutabilis*, *L. albus*,  
289 and *L. angustifolius* which grown in Brazilia were reported to be 1.15-4.49 mg catechin

290 equivalents (CE)/g DM which were much lower than cotyledons (7.38-12.42 mg CE/g  
291 DM) (Ranilla, Genovese, & Lajolo, 2009). The results accord with findings from  
292 Lampart-Szczapa, et al. (2003), who found that polyphenols in seed coats of *L. luteus*,  
293 *L. albus* and *L. angustifolius* grown in Poland (ranging from 0.16 to 0.42 mg caffeic  
294 acid equivalents/g DM), were 1.30-6.52 times lower than those in cotyledons (0.32 to  
295 1.88 mg caffeic acid equivalents/g DM). Additionally, these authors revealed that free  
296 phenolic acids, primarily procatechuic acid and *p*-hydroxybenzoic acid, were mainly  
297 present in the seed coats. Likewise, they found that concentrations of tannins in the  
298 cotyledons were 4.33-31.00 times higher than that in the seed coat. On contrast,  
299 Petterson (1998) reported that most tannins (include proanthocyanidins) of lupin  
300 occurred in the seed coat, however, the initial data are unavailable.

301

302 These different and sometimes conflicting results of studies on polyphenols in pulse  
303 seed coat are difficult to interpret and compare since the lack of consensus on extraction  
304 methods and express ways (i.e., equivalents). Nonetheless, most of previous published  
305 studies have only extracted polyphenols with organic solvents in which case  
306 appreciable amounts of “bound” polyphenols in the seed coat matrix may remain un-  
307 extracted and thus the total polyphenol levels and antioxidant capacity may be  
308 underestimated (Saura-Calixto, 2012).

309

### 310 3.3.2. *Phytic acid*

311 Phytic acid (PA), its lower substituted homologues and its salts are referred as phytates  
312 which are commonly present in pulse seeds. Phytic acid have been implicated in the  
313 “hard-to-cook” phenomenon in pulse seeds. In addition, they are considered as the main  
314 anti-nutritional factor due to their capacity to chelate cations (in particular calcium, iron  
315 and zinc) to form insoluble complexes and therefore reduce their bio-availability  
316 (Sanchez-Chino, Jimenez-Martinez, Davila-Ortiz, Alvarez-Gonzalez, & Madrigal-  
317 Bujaidar, 2015). The content of phytic acid can be affected significantly by genetic and  
318 environmental factors, alone and in combination. However, phytic acid in mung bean  
319 (1.8-5.8 mg/g DM), pea (3.1-7.1 mg/g DM), lentil (2.5-12.2 mg/g DM), chickpea (2.8-  
320 13.6 mg/g DM), lupin (6.0-8.9 mg/g) and faba bean (5.9-15.0 mg/g DM) are generally  
321 lower than soybean (4.8-20.1 mg/g DM) (Campos-Vega, Loarca-Piña, & Oomah, 2010).  
322 Moreover, the majority of phytic acid is demonstrated to present in “the proteins bodies”  
323 in cotyledon (Campos-Vega, et al., 2010). Phytic acid of chickpea is presented in a low  
324 level (0.79 mg/g DM) in seed coat but high in cotyledon (9.82 mg/g DM) (Sreerama,  
325 et al., 2010). Beal and Mehta (1985) indicated that little (1 mg/g) or no phytic acid was  
326 found in pea seed coats.

327

### 328 3.3.3. *Alkaloids*

329 Alkaloids are mainly present in lupins. Quinolizidine alkaloids, mainly lupanine, 13-  
330 hydroxylupanine and angustifoline, are major contributors to the bitter taste of some

331 varieties of lupin seeds and are potentially toxic (Petterson, 1998). Bitter lupin varieties  
332 have alkaloid contents ranging between 0.5-6%, in contrast the sweet varieties have  
333 less than 0.02% (Resta, Boschini, D'Agostina, & Arnoldi, 2008). Moreover, alkaloids  
334 can be removed by washing with water. A maximum legal limit on alkaloid  
335 concentration in lupin flours and lupin products has been set at 0.02% by authorities of  
336 France, UK, Australia and New Zealand (Resta, et al., 2008). Little is known on  
337 distributions of alkaloids in lupin seeds, though Sipsas (2008) reported that no alkaloids  
338 were found in Australian sweet lupin seed coat, but no detailed data was found.

339

#### 340 **4. Mycotoxins contamination**

341 Pulses are vulnerable to be contaminated by fungus and the resulting mycotoxins (e.g.,  
342 aflatoxins, ochratoxins and phomopsins) during pre- or post-harvest (CAST, 2003). A  
343 further increase in human exposure of them by consuming products containing  
344 contaminated pulses may occur. However, recent systematic surveys on mycotoxins in  
345 pulses based human food are lacking. Here, phomopsins in contaminated lupin seeds,  
346 a highly representative example of mycotoxins contamination of pulses, will be  
347 discussed as a detailed case study.

348

349 Phomopsins are toxins produced by the fungus *Diaporthe toxic* (EFSA, 2012). The  
350 fungus mainly infects lupin stems but also the seeds under high humidity storage  
351 conditions (>13%). Lupin seed coat, being the outermost layer of the seed, is the most

352 vulnerable part of seed to be invaded by the fungus and thus may contain the highest  
353 level of phomopsins (EFSA, 2012). Phomopsins are suspected as the cause of lupinosis  
354 in grazing animals. A maximum legal limit (5 µg/kg) of phomopsins in lupin seeds and  
355 lupin foods has been established in Australia, New Zealand, UK and FAO (Schloss,  
356 Koch, Rohn, & Maul, 2015). **As other mycotoxins**, phomopsins are stable to food  
357 processing including soaking, cooking, and fermentation. However, seeds  
358 contaminated by phomopsins can be easily removed by seeds grading and screening  
359 since phomopsins is “almost entirely limited to dis-coloured seeds” (EFSA, 2012). In  
360 addition, resistant varieties have been developed. Extrusion which combines high  
361 pressure, high temperature and severe shear has showed the capacity to reduce other  
362 mycotoxins (e.g. aflatoxins and zearalenone) (Bullerman & Bianchini, 2007), but no  
363 studies on detoxifying phomopsins in lupin by extrusion cooking have been reported.

364

## 365 **5. Bio-availability of nutrients in pulse seed coats**

366 Bio-availability refers to the extent that nutrients can be released from food matrix into  
367 digestive fluid, and thereby available for intestinal transport, biotransformation,  
368 absorption and metabolism (Versantvoort, Van de Kamp, & Rompelberg, 2004). There  
369 is strong evidence that structure and composition of a food matrix will govern the bio-  
370 availability of many nutrients in the gastrointestinal tract (Wahlqvist, 2016).

371



372 A few published clinical studies have suggested that pea seed coat consumption may  
373 benefit cardiovascular and gastrointestinal biomarkers in humans, that may be due to  
374 multiple mechanisms caused by the high dietary fibre in the seed coat (Dahl, Whiting,  
375 Healey, Zello, & Hildebrandt, 2003; Flogan & Dahl, 2010; Mollard, Luhovyy, Smith,  
376 & Anderson, 2014). However, dietary fibre has been shown to significantly reduce bio-  
377 availability of several nutrients. For example, lupin seed coat in the diet decreased  
378 protein digestibility in rats (Bailey, Mills, & Hove, 1974). In contrast, removal of lentil  
379 seed coat significantly improved lentil iron bio-availability (DellaValle, Vandenberg,  
380 & Glahn, 2013). The compact inert insoluble fibre matrix of the seed coat may be a  
381 physical barrier to block the release of nutrients, give increased viscosity of digesta and  
382 therefore impair absorption. Besides, dietary fibre, polyphenols and alkaloids can also  
383 inhibit enzymes, and chemically bind some nutrients thus lowering their bio-  
384 availability (Khattab & Arntfield, 2009).

385

386 The fermentability of cellulose and hemicellulose in the colon was surprisingly reported  
387 to be high, 70% and 72% respectively, mainly degraded by some specialized series of  
388 gut bacteria (Flint, Scott, Duncan, Louis, & Forano, 2012). It suggests that “trapped”  
389 compounds (e.g., minerals and polyphenols) in pulse seed coats could be released in  
390 colon. In this context, dietary fibre could also modulate pH of human gastrointestinal  
391 tract, especially lower pH level in colon, to enhance release and absorption of minerals  
392 (Baye, Guyot, & Mouquet-Rivier, 2017). A large proportion of polyphenols are

393 reported to be not bioavailable in the upper part of the human gastrointestinal tract.  
394 Instead, they will reach colon and be metabolized at a large extent by gut microbiota  
395 (Saura-Calixto, 2012). However, more studies are needed to investigate digestibility of  
396 pulse seed coats in human, as well as their physiological effects on human health  
397 (including effects on colon and gut bacteria).

398

## 399 **6. Effect of processing on pulse seed coats**

400 Generally, pulses are dried in the field to achieve the target moisture of 9-20% for  
401 threshing (i.e. removal of pods), then cleaned, graded and further dried to approximate  
402 13% for storage. Storage conditions (e.g. seed moisture, relative humidity, duration and  
403 temperature) significantly affect the seed coat characteristics. For example, the seed  
404 coat colour of faba bean has been observed to darken from beige to dark brown  
405 depending upon the storage conditions (Nasar-Abbas, et al., 2009). Although pulses  
406 can be consumed either whole or dehulled splits, they require processing before  
407 consumption to (1) reduce or eliminate anti-nutritional factors, (2) improve consumer  
408 acceptability (e.g. texture, flavor), and (3) enhance nutritional properties like nutrient  
409 bio-availability. There are several conventional whole seeds processing methods,  
410 including soaking, dehulling, milling, cooking, **puffing**, germination (or sprouting) and  
411 fermentation (Patterson, Curran, & Der, 2017). But only few studies are found to treat  
412 isolated pulse seed coat using milling, boiling, and more recently extrusion cooking.

413 All have shown to affect composition, and physicochemical and nutritional properties  
414 of the seed coats.

415

#### 416 *6.1. Conventional processing*

417 Seed coat bulk density (weight of seed coat per unit volume) is low such that further  
418 processing (like grinding) is required to increase their density to reduce its storage and  
419 transport fees after dehulling (Table 4). Grinding was reported to increase solubility of  
420 pea seed coat, from 4.1% to 8.6%, accompanying by reduction in water binding  
421 capacity (WBC) and swelling capacity by 35.2% and 21.7% respectively (Ralet, Valle,  
422 & Thibaut, 1993a). Similarly, water solubility of mung bean seed coat was 0.97% with  
423 particle size of <50 mesh (<300  $\mu\text{m}$ ), whereas a much lower water solubility (0.79%)  
424 was found with particle size of >35 mesh (>500  $\mu\text{m}$ ) (Huang, 2009). The authors also  
425 found that mung bean seed coat with smaller particle size had a significantly higher  
426 swelling capacity, WBC, and oil binding capacity but lower bulk density compared  
427 with those with bigger particle size.

428

429 Soaking followed by cooking of whole pulse seeds is the traditional domestic operation  
430 to produce edible pulse products. During soaking, pulses imbibe water to expand the  
431 seed coats, and activate endogenous enzymes (cell wall polysaccharidases which can  
432 disrupt the cell wall, and phytase which can reduce phytic acid content, for example)  
433 (Wang, et al., 2003). Moreover, water soluble compounds like minerals, soluble tannins,

434 phytic acid, alkaloids and polyphenols may leach into soaking, cooking and canning  
435 water (Tajoddin, Manohar, & Lalitha, 2013). As the outer layer, the seed coat plays a  
436 crucial role in controlling these exchanges during soaking and cooking. Additionally,  
437 Güzel (2012) found that atmospheric pressure cooking (APC) and high-pressure  
438 cooking (HPC) caused darkening of chickpea and faba bean seed coats, with greater  
439 effect for HPC. The colour changes may be the results of pigment degradation. Hashemi,  
440 et al. (2015) found that starch in pea seed coat increased from 0.16% to 0.59% in dry  
441 basis after boiling for 30 min, what may be due to the increase of starch bioavailability  
442 and losses of soluble compounds during boiling.

443

444 Mung bean (Tajoddin, et al., 2013), lentil and field pea (López-Amorós, Hernández, &  
445 Estrella, 2006), chickpea (Ghavidel & Prakash, 2007), and lupins (Dueñas, Hernandez,  
446 Estrella, & Fernandez, 2009) have been used to germinate sprouts. Most of these studies  
447 confirmed that germination will increase polyphenols (prominently flavonoids) and  
448 vitamins, whereas decrease anti-nutritional factors (e.g.  $\alpha$ -galactosides, trypsin  
449 inhibitors and phytic acid). As a result, germination **can improve** antioxidant capacity  
450 and bio-availability of the nutrients. Seed coat impermeability is the main regulator for  
451 pulse germination. Moreover, the structure and composition of the seed coat will  
452 change significantly just before and during germination, possibly by enzymes (Finch-  
453 Savage & Leubner-Metzger, 2006). Although, so far, no study on the effect of

454 germination on pulse separated seed coat has been found, it can be hypothesised that  
455 changes in composition and physico-chemical properties of pulse seed coat may occur.

456

## 457 6.2. *Extrusion*

458 Extrusion cooking is a high temperature short time unit operation in which food will be  
459 melted in a sealed cylinder by high pressure, high temperature and high mechanical  
460 shear, then passed through a die (Alam, Kaur, Khaira, & Gupta, 2016). Depending on  
461 extrusion conditions (such as material particle size, feed rate, moisture, screw speed  
462 and configuration, barrel temperature and die geometry), the process results in  
463 disruption of cell wall structures, chemical reactions (such as polysaccharides  
464 depolymerization, Maillard reaction and starch gelatinization), and physical changes  
465 (e.g. solubility, morphological and rheological properties) (Singh, Gamlath, &  
466 Wakeling, 2007; Wolf, 2010). Moreover, extrusion has been used to incorporate seed  
467 coats of field pea (Schmidt, 1987), lupin (Tucek, 2009) into breakfast, pasta and snacks  
468 to increase their dietary fibre levels. But they are beyond the scope of this review.

469

470 Extrusion cooking, mainly twin-screw extrusion, is the most used technology to modify  
471 the functional properties of high fibre materials (Rashid, Rakha, Anjum, Ahmed, &  
472 Sohail, 2015; Wolf, 2010; Yan, Ye, & Chen, 2015). Water solubility of pea seed coat  
473 was reported to increase by 3.6-15.3% after extruded using twin screw extruder,  
474 accompanied by a dramatic increase (up to 220%) in soluble dietary fibre (Ralet, Valle,

475 & Thibault, 1993b). Similarly, single screw extruder increased soluble dietary fibre in  
476 pea seed coat from 5.3% to 6.7% (Arrigoni, Caprez, Amadò, & Neukom, 1986).  
477 Correspondingly, technical properties of pea seed coat, like water binding capacity and  
478 swelling capacity, were increased by extrusion cooking. On the contrary, extrusion has  
479 shown no or slightly increased effects on the technical properties of yellow pea seed  
480 coats (Arrigoni, et al., 1986). Except the conflicting results mentioned above, data from  
481 extruded wheat bran (Rashid, et al., 2015; Yan, et al., 2015), sugar beet pulp (Rouilly,  
482 Jorda, & Rigal, 2006), onion waste (Ng, Lecain, Parker, Smith, & Waldron, 1999)  
483 support the increase in the solubility of dietary fiber, as well as the improvements on  
484 their physicochemical characteristics.

485

486 Extrusion cooking has been revealed to reduce the levels of heat sensitive extractable  
487 polyphenols, which can be extracted by aqueous/organic solvents (Singh, et al., 2007).  
488 However, it can release non-extractable polyphenols, which remain in the resulting  
489 residues of the aqueous/organic extraction, from food matrix. Depolymerization of high  
490 molecular weight polyphenols (such as condensed tannins) was also reported (Awika,  
491 Dykes, Gu, Rooney, & Prior, 2003). Additionally, extrusion cooking can increase bio-  
492 availability of minerals, mainly by reducing the chelating properties of dietary fibre and  
493 the contents of other chelating compounds such as phytic acid and condensed tannins  
494 (Singh, et al., 2007). Taken together, extrusion cooking could be an applicable  
495 technology to improve the properties of pulse seed coats. However, more

496 comprehensive studies are required to investigate its effects on compositional and  
497 physicochemical properties of the pulse seed coats.

498

## 499 **7. Application of pulse seed coats in human food**

500 Pulses have been historically important sources of energy, protein and dietary fibre in  
501 human diet. Currently, pulse seed coats have only limited use in human food such as in  
502 high fibre breads and meat products. However, the high content of dietary fibre in pulse  
503 seed coats, along with considerable amounts of minerals, phytochemicals (e.g.  
504 polyphenols) suggests they could be more widely utilized as novel functional dietary  
505 fibre ingredients (Macagnan, da Silva, & Hecktheuer, 2016). There are several  
506 commercial dietary fibre ingredients manufactured from pea seed coat and lupin seed  
507 coat, both of them have been classified as GRAS (Generally Recognized as Safe).  
508 However, lupin has been listed as a food allergen what requires mandatory labelling in  
509 Europe since 2007, and most recently in Australia and New Zealand (March 2017)  
510 (FSANZ, 2017). Moreover, there are several specific regulations on contaminants and  
511 natural toxins levels of the six pulses and their derived food products, phomopsins and  
512 lupin alkaloids in lupin seed coat for example.

513

514 Like other dietary fibre ingredients, pulse seed coats have been incorporated into baked  
515 goods, in which they have shown to change physical, nutritional, and sensory properties  
516 of the products. Dalgetty and Baik (2006) found that incorporations of pea, lentil, and

517 chickpea seed coats significantly increased dough mixing time, water absorption, and  
518 loaf weight but decreased loaf volume. The observations are in accordance with the  
519 results of Sosulski and Wu (1988) who added up to 7.7% of pea seed coat into dough.  
520 The authors of these studies concluded that breads with 5% pulse seed coat addition  
521 was comparable to whole wheat breads in sensory quality but had desirable higher  
522 dietary fibre content.

523

524 In terms of adding pulse seed coats into meat products, Verma, Banerjee, and Sharma  
525 (2012, 2015) used pea hull flour (PHF) and chickpea hull flour (CHF) as dietary fibre  
526 sources to improve qualities of chicken nuggets. The studies found that incorporation  
527 of the two hull flours significantly increased product yield and dietary fibre content.  
528 However, both reduced emulsion stability of the product, and lowered its hardness,  
529 gumminess and chewiness dramatically. Product colour was also affected by initial  
530 colours of the two hull flours and formulation differences. Sensory evaluation  
531 suggested that an 8% PHF addition in low salt (40% reduction) chicken nuggets were  
532 acceptable to consumers.

533

## 534 **8. Conclusions**

535 To date, pulse seed coats are little utilised in human food. However, there is potential  
536 for the seed coat to be used as a natural “nutritious dietary fibre” which could (1) fill  
537 the “fibre intake gap”, (2) provide considerable levels of minerals and antioxidants, and



538 (3) achieve greater safe and sustainable utilization of pulses by exploiting value-added  
539 applications of their by-products (Saura-Calixto, 2012; Sharma, et al., 2016). However,  
540 in-depth studies on biochemical, and nutritional properties of pulse seed coats are still  
541 lacking. In addition, physicochemical properties (e.g. solubility, swelling capacity,  
542 water and oil binding capacities, and viscosity) of pulse seed coats will significantly  
543 associate with physiological functionalities (Wahlqvist, 2016), but the impacts of  
544 processing on physicochemical properties are also still unclear. Moreover, to minimize  
545 the negative impacts of dietary fibre and other anti-nutritional factors, while improving  
546 their desirable physiological properties, further work is needed to optimize the  
547 processing. Finally, parallel to the study of pulse seed coats incorporation into food  
548 products, more nutritional and safety studies on the products are needed. These will add  
549 to what are likely to be favourable cost and sustainability profiles.

550

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559

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867



868 **Tables**

869

870 **Table 1** Names and major types of the selected six pulses

871 **Table 2.** Morphological and physical properties of the selected six pulse seed coats

872 **Table 3.** Main carbohydrates and dietary fibre of three selected pulses seed coats

873 **Table 4.** Selected physico-chemical properties of pulse seed coats

874

875 **Table 1.** Names and major types of the selected six pulses

876

<b>Botanical name</b>	<b>FAO commodity class</b>	<b>Common/Alternative names</b>	<b>2016 World production (million tonne)</b>	<b>Main market types in Australia (• most common )</b>
<i>Pisum sativum</i>	Peas, dry	Field pea; Protein pea; Austrian winter peas (black peas); Canadian field peas (spring peas)	14.36	• Dun (including Kaspa type) White/blue Green
<i>Vicia fabae</i>	Broad beans, dry	Faba bean /Tickbean Broad bean	4.46	• <i>V. faba</i> var. minor (faba bean) <i>V. faba</i> var. major (broad bean)
<i>Cicer arietinum</i>	Chickpeas	Garbanzo beans (US); Bengal gram (India)	12.09	• Desi Kabuli
<i>Lens culinaris</i>	Lentils	Masurdahl, adas	6.32	• Red Green
<i>Lupinus spp.</i>	Lupins	Blue lupin; narrow-leaved lupin European white lupin	1.28	• <i>L. angustifolius</i> Albus ( <i>L. albus</i> )
<i>Vigna radiate</i>	Beans, dry	Mung bean (Australia) Green/golden gram (India)	~3.0	• <i>Vigna radiata</i> (green) <i>Vigna mungo</i> (black)

877 Ref: FAO (1994); FAOSTAT (2018); Sherasia, et al. (2017); Tiwari, et al. (2011); Pulse

878 Australia (2016).

879

880 **Table 2.** Morphological and physical properties of the selected six pulse seed coats

881

<b>Pulses</b>	<b>Colour</b>	<b>Seed weight (g/100 seeds)</b>	<b>Hull percentage (%)*</b>	<b>Hull thickness (<math>\mu\text{m}</math>)</b>
Lupin				
<i>L. angustifolius</i>	speckled	3.1-23.8	19.4-38.8	257.0-335.0
<i>L. albus</i>	white	12.0-86.9	12.2-27.5	nd
Field pea	green/yellow	18.7-25.6	7.2-14.0	55.9-72.0
<i>Vicia fabae</i>				
Faba bean	beige	40.0-95.0	11.0-15.4	141.0-248.0
Broad bean	beige	110.0-145.0	nd	
Chickpea				
<i>desi</i>	dark/brown	12.0-27.0	10.1-22.0	343.0-423.0
<i>kabuli</i>	beige/yellow	20.0-65.0	4.5-9.5	251.0
Lentil	red/green	4.5-7.5	7.0-11.0	25.0-65.0
Mung bean	green	2.5-4.7	8.6-23.5	30.0-330.0

882 \* Data are dry basis; nd: no data were found;

883 Ref.: Huang, et al. (1988); Miao, et al. (2001); Clements, et al. (2005, 2014); Van

884 Dongen, et al. (2003); Youssef, et al., 1984; Wood, et al., 2011; Tajoddin, et al., 2010;

885 Hasan, 2010.

886

887 **Table 3.** Main carbohydrates and dietary fibre of three selected pulses seed coats

888

Pulses	<i>L. angustifolium</i>	Field pea	Chickpea
Starch (g/100g)	0.4-0.9	0.16-1.8	0.2-0.5
Oligosaccharides (g/100g)	0.4	nd	nd
NSP (g/100g)			
Total	79.8-89.1	68.0	45.9-72.4*
Soluble	5.0	3.0-4.0	1.9-2.5
Insoluble	80.6-84.1	64.0-65.0	49.1-52.9*
Cellulose (g/100g)	44.5-51.7	62.3	18.2-29.0
Hemicellulose (g/100g)	12.7-14.4	8.2	30.4
Pectins (g/100g)	15.6-27.7	nd	0.1
Lignin (g/100g)	0.3-2.1	3.5	1.4-4.1
Dietary fibre (g/100g)			
Total	88-90.5	81.0-91.5	74.9-84.2
Soluble	3.1-3.8	4.1-11.0	nd
Insoluble	84.2-87.4	70.0-87.4	nd

889 Data are in dry basis.

890 NSP: Non-starch polysaccharides; nd: no data were found.

891 \*: A remaining 15% was not hydrolysed by the NSP analyses which was supposed to  
892 be “highly bound ligno-cellulosic compounds” (Wood, et al. 2014).

893 Ref.: Miao, et al. (2001); Evans, et al. (1993); Evans (1994); Brillouet, et al. (1983);

894 Guillon & Champ (2002); Hashemi, et al. (2015); Bailey, et al. (1974); Sosulski, et

895 al.(1988); Dalgetty & Baik (2003); Ralet, et al. (1993a); Wood, et al. (2014).

896

897 **Table 4.** Selected physico-chemical properties of pulse seed coats

898

<b>Physical properties</b>	<b><i>L. angustifolium</i></b>	<b>Field pea</b>	<b>Chickpea</b>	<b>Lentil</b>	<b>Mung bean</b>
Direct Density (g/mL)	nd	0.6	0.4	0.7	nd
Bulk Density (g/mL)	nd	0.8	0.7	0.8	0.45-0.64
Swelling capacity(mL/g)	nd	1.9-6.0	3.6	2.4	5.51-9.20
Water binding (mL/g)	7.0-8.0	4.0-7.1	6.2	3.6	3.13-4.44
Oil binding (mL/g)	1.6-1.7	1.5-2.0	1.8	1.6	1.49-1.83

899 nd: no data were found.

900 Ref.: Guillon & Champ (2002); Dalgetty, et al. (2003); Pfoertner (2001); Turnbull,

901 Baxter, and Johnson (2005); Ralet, et al. (1993b); Huang, et al. (2009).