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Current Trends in Ancient Grains-Based Foodstuffs: Insights into Nutritional Aspects and Technological Applications

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1 **Current Trends in Ancient Grains-Based Foodstuffs: Insights into**
2 **Nutritional Aspects and Technological Applications**

3 Fatma Boukid^{1*}, Silvia Folloni², Stefano Sforza¹, Elena Vittadini¹, Barbara Prandi¹

4 ¹ Food and Drug Department, University of Parma, Parco Area delle Scienze 27/A, 43124 Parma, Italy

5 ² Open Fields S.r.L., Collecchio, Parma, Italy

6 *Corresponding author:

7 Fatma Boukid, Food and Drug Department, University of Parma, Parco Area delle Scienze 27/A, 43124

8 Parma, Italy; e-mail: fatma.boukid@unipr.it; tel: +390521906079

9

10 **Abstract**

11 For centuries, ancient grains fed populations, but due to their low yield, they were abandoned and
12 replaced by high-yielding species. However, currently, there is a renewed interest in ancient wheat and
13 pseudocereal grains from consumers, farmers, and manufacturers. Ancient wheat such as einkorn,
14 emmer, spelt, and Kamut®, are being reintegrated because of their low fertilizer input, high adaptability
15 and important genetic diversity. New trends in pseudocereal products are also emerging, and they are
16 mostly appreciated for their nutritional outcomes, particularly by the gluten-free market. Toward
17 healthier lifestyle, ancient grains-based foodstuffs are a growing business and their industrialization is
18 taking two pathways, either as a raw ingredient or a functional ingredient. This paper deals with these
19 grain characteristics by focusing on the compositional profile and the technological potential.

20 **Key words:** Ancient Grains, Foodstuffs, Ancient Wheat, Pseudocereals, Gluten-Free, Quality.

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24 **1. Glossary**

25 Despite the many genetic and archeological data on the origins of agriculture, from gathering to
26 cultivation to domestication to breeding, surprisingly there is no universal definition for modern or/and
27 ancient grains. The case of wheat is complex because it includes several species with different degrees
28 of ploidy, of which some evolved concurrently in different geographical areas. Herein, an attempt to
29 define some debatable terms is performed, considering the degree of human intervention, the degree of
30 breeding and the level of genetic evolution. The classifications, as well as the definition assigned to each
31 category, are research-based, and scientifically sound (Table 1). It takes also into account several factors
32 such as the history of breeding, the origin of selection, the crossing, and the pedigree.

33 In the last years, conserving the natural agrobiodiversity is challenging, and the risk of bottleneck
34 situation in breeding keeps raising. Therefore, going back to ancient species might avoid or prevent this
35 shifting. Furthermore, awareness was raised towards human health and nutrition. As a result, the
36 consumers were interested in natural, unconventional and nutritional foods, which led to the
37 development of new health-beneficial foods based on grain blends. The attention towards ancient species
38 has also been renewed by the mounting demand for traditional products, the request for species suitable
39 to be grown in marginal areas and the need to preserve genetic diversity. In this regard, this review aims
40 to provide new insights into these grains' nutritional and technological characteristics as well as the
41 current trends in their based foodstuffs, which might be extremely valuable for consumers, producers,
42 processors and farmers.

43 **2. An overview of ancient grains**

44 **2.1. Fundamental classes and subclasses of ancient grains**

45 Ancient grains might be subdivided in several categories and subcategories (Figure 1A). Botanically,
46 grains belong to monocotyledon “monocots” (one seed leaf) and dicotyledon “dicots” (two seed leaves)
47 which are the two major subclasses of flowering plants “*angiosperms*”. Three main categories are:
48 cereals, minor cereals, and pseudocereals. Cereals are made up of rice, wheat, and maize. Minor cereals

49 are mainly rye (*Secale cereale* L.), foxtail millet (*Setaria italica* L.), oat (*Avena sativa* L.), sorghum
50 (*Sorghum bicolor* L.), barley (*Hordeum vulgare* L.), common millet (*Panicum miliaceum* L.) and teff
51 (*Eragrostis tef* (Zucc.) Trotter) (Diao 2017). Cereals and minor cereals belong to *Poaceae* which is one
52 of the most important families of the order *Poales* belonging to monocotyledon subclass (Figure 1B).
53 For centuries, *Poacea*, formerly *Gramineae*, provided the most important share of human nutrition.
54 *Poaceae*, also called grasses, contain over 600 genera and more than 10,000 species that dominate many
55 ecological and agricultural systems (The International Brachypodium Initiative 2010). It was established
56 also that the grasses family diverged into different subfamilies and tribes, with the sub-families being
57 *Pooideae* (wheat, barley, and oats), *Ehrhartoideae* (rice), *Panicoideae* (maize, sorghum), and
58 *Chloridoideae* (teff) (Charles and others 2009). Tribes are mainly *Triticeae* (wheat, rye, and barley),
59 *Aveneae* (oat), *Paniceae* (millet), *Andropogonee* (sorghum and maize) and *Eragrosteae* (teff). On the
60 other hand, pseudocereals are defined as non-grasses, dicots grains that diverge into several families
61 such as *Polygonaceae*, *Amaranthaceae*, and *Lamiaceae* (Figure 1C). Amaranth (*Amaranthus caudatus*
62 L.; *A. cruentus*; *A. hypochondriacus*), quinoa (*Chenopodium quinoa* Willd.), and buckwheat
63 (*Fagopyrum esculentum* Moench.) are the best known pseudocereals (Fletcher 2016), while chia (*Salvia*
64 *hispanica* L.) has been gaining interest recently due to its functional and nutritional properties.

65 Ancient grains might also be subdivided into gluten-containing and gluten-free grains (Figure 1A).
66 Gluten containing grains are mainly ancient wheat, including einkorn, emmer, spelt, and Kamut® (Table
67 2), while the most popular gluten-free ancient grains are the pseudocereals buckwheat, quinoa, amaranth
68 and chia (Table 3).

69 **2.2. The way forward: Reasons behind the shifting away from ancient grains**

70 The main reason behind the shifting away from ancient grains was their low yield. Plant improvement
71 programs aimed at increasing grain yield to feed the growing populations (Okuno and others 2014) and,
72 as a result, ancient grains were abandoned and replaced by high-yielding modern grains which
73 contributed to the decrease of genetic diversity. Nowadays about 95% of the cultivated wheat worldwide

74 is *Triticum aestivum*, while most of the remaining 5% is *T. turgidum* subsp. *durum* (Brouns and others
75 2013).

76 Ancient wheat grew excessively tall, thereby becoming susceptible to lodging with consequent
77 significant yield loss (Okuno and others 2014). During evolution under domestication, spikelets have
78 undergone significant changes to keep the plant standing until harvest (Zhou and others 2015) to prevent
79 yield losses through seed shattering, to minimize seed dormancy, and to increase both seed size and
80 number (Peleg and others 2011; Sakuma and others 2011).

81 Later on, the green revolution, throughout the 1950s -1960s, led to the development of high-yielding,
82 disease-resistant wheat varieties with dwarfing genes (Lopes and others 2015). The new varieties were
83 selected through breeding protocols based on modern agronomic practices with high agricultural inputs
84 (Royo and others 2007; Longin and Würschum 2016).

85 **2.3. Back to basics: reasons behind the reintroduction of ancient grains**

86 The increasing demand for traditional products, the request for high adaptability, and the need to
87 preserve genetic diversity are among the reasons behind the renewed attention towards ancient species
88 (Troccoli and Codianni 2005). The evolution of plant breeding resulted in genetic erosion and thereby
89 the loss of genetic diversity. Therefore, there is a serious need to go beyond the uniform model of today
90 agriculture and reintroduce germplasm characterized by high heterogeneity. Species diversity
91 contributes to the increase of crop productivity and stability (Hooper and others 2012; Khoury and others
92 2014). Indeed, ancient wheat is suitable for organic farming because of their adaptability to low
93 agronomic input; and where other wheat types would fail, they show high resistance to powdery mildew
94 and brown rust, and disadvantageous growing conditions (such as wet, cold soils, high altitudes, and
95 poor soils) (Konvalina and others 2010; Escarnot and others 2012). Pseudocereals are also known for
96 their high adaptability, low needs in terms of water, fertilizer, and energy as compared to traditional
97 cereals (Kang and others 2017; Santra and Schoenlechner 2017). As a result, the 2015 international

98 report from Health Focus International stated that the international awareness of ancient grains was up
99 from 26% in 2012 to 28% in 2014, with 35% of the respondents expressing an interest in ancient grains.

100 Currently, ancient grains are gaining popularity as they often offer a better nutritional composition
101 (Carnevali and others 2014). Ancient wheat have been rediscovered by consumers, bakers, millers, and
102 farmers because they are good sources of proteins, lipids, fructans, trace elements, and several
103 antioxidant compounds (Hidalgo and others 2014; Hidalgo and Brandolini 2014; Longin and others
104 2015). Pseudocereals have also a good protein quality content in terms of amino acid composition (Wang
105 and Zhu 2015; Ngugi and others 2017). Thus, pseudocereals are integrated in gluten-free product
106 formulations to improve their nutritional quality and, consequently, to avoid some complications such
107 as nutrient deficiencies, bone disease, and lymphoma sensitivity (Alvarez-Jubete and others 2009a, b).

108 **3. Composition of ancient grains versus modern grains**

109 Wheat and cereals are largely consumed worldwide, supplying humans with energy and bioactive
110 components (Lachman and others 2012). However, it should be kept it mind that the nutritional
111 composition of cereal crops is closely associated with cultivation area, climatic conditions, agronomic
112 practices, and genetic diversity (Miranda and others 2012; Hidalgo and Brandolini 2017).

113 **3.1. Ancient wheat**

114 The approximate chemical compositions of ancient wheat (einkorn, emmer, spelt, and Kamut), durum
115 wheat and common wheat are displayed in Table 4. Table 4 also includes data relative to branded whole
116 wheat flour products form the Food Composition Databases of the United States Department of
117 Agriculture (USDA). The choice of branded products rather than research paper data was to give a
118 concrete overview of what is available on the market. Modern wheat (durum and common) are also
119 reported to underline their differences or/and similarities as compared to ancient wheat.

120 The main components of ancient wheat are carbohydrates, protein and fibers, similarly to modern wheat.
121 Carbohydrate contents in durum and common wheat are slightly higher than in ancient wheat; indeed,

122 it was found that spelt (68%) provides the lowest carbohydrate contents together with einkorn (67%).
123 Spelt contains the lowest fiber content (5.9%), while it was reported that it is a good source of fiber
124 (11.4 %) by Ranhotra and others (1995), which implies large sample variability. Furthermore, einkorn
125 flour has a lower content of total dietary fiber (6.7%), than common wheat (12.7%).

126 Important variability was observed between durum, common, and ancient wheat in terms of protein
127 content. According to the intensive work of Hidalgo and Brandolini (2014), einkorn protein content is
128 generally higher to that of common wheat as well as emmer and spelt. Kamut® has high protein, as
129 reported by Sumczynski and others (2015), and it presents some prolamin alleles which are closely
130 correlated to good pasta quality (Rodríguez-Quijano and others 2010).

131 Overall, the lipid content is a minor component in wheat ranging between 1.7 (einkorn) and 2.9% (spelt).
132 Remarkably, ancient wheat, except for einkorn, has higher lipid contents than that of common wheat,
133 which was consistent with the findings of Hidalgo and others (2009). Moreover. It was reported that
134 einkorn has higher monounsaturated fatty acids, lower polyunsaturated fatty acids and lower saturated
135 fatty acids than durum wheat, suggesting its beneficial effect on human health (Hidalgo and Brandolini
136 2014).

137 As for mineral content, Kamut® has comparable calcium, iron, magnesium, potassium, sodium, and zinc
138 contents to common wheat and durum wheat. Kamut® also showed higher levels for 8 out of 9 minerals
139 compared to common wheat (Abdel-Aal and others 1998). Magnesium and zinc contents of einkorn
140 (200mg/100g and 15 mg/100g, respectively) also are higher than those of common wheat (90mg/100g
141 and 3.5mg/100g, respectively) and durum wheat (144mg/100g and 4.2mg/100g, respectively), in
142 concordance with previous studies (Suchowilska and others 2009; Erba and others 2011).

143 Regarding the vitamin content, Table 4 showed that Kamut® has higher vitamin A than common wheat
144 and durum wheat. Despite the importance of micronutrients, wheat labels usually lack this indication,
145 and more information in this regard are found in literature. Tocols and carotenoids were exclusively
146 discussed in scientific works. Indeed, einkorn was found to have high tocol and carotenoid contents that

147 may make einkorn an interesting ingredient to be used in the development of new or special foods with
148 high nutritional quality (Hidalgo and others 2016). Einkorn tocopherols content was higher (42.7-70.2µg/g,
149 average =57) compared to durum wheat (40.1-62.7µg/g, average=48.1) (Lampi and others 2008). In
150 another study, it was reported that tocopherols in ancient wheat, einkorn (61.80–115.85 µg /g), emmer (62.7-
151 67.9µg/g), and spelt (62.7-67.5µg/g) were slightly higher than in durum (38.8-57.27µg/g) and common
152 (53.2-74.9µg/g) wheat (Hidalgo and others 2006). As for carotenoids, important variability was shown;
153 in common wheat, they are less abundant (1.4-3.05 mg/kg) than in durum wheat (1.9-5 mg/kg) and
154 Kamut® (4.4 mg/kg), while carotenoids in einkorn were the highest and varied between 5.3 and 13.6
155 mg/kg (Hidalgo and others 2006). The authors also highlighted the relevant impact of cultivation area
156 and genotype on the content of both tocopherols and carotenoids (Hidalgo and others 2006).

157 Overall, although only few available scientific data are found dealing with comparative studies in terms
158 of ancient wheat and modern wheat, compositional differences were observed between ancient wheat
159 and modern wheat, as well as among the different ancient grains.

160 **3.2. Pseudocereals**

161 Table 5 presents the approximate chemical composition of pseudocereals and of the 2 major gluten-free
162 cereals used worldwide (maize and rice). As in Table 4, Table 5 summarized data relative to branded
163 whole flour products from the Food Composition Databases of the United States Department of
164 Agriculture (USDA). Rice and maize together with pseudocereals were also included to provide a full
165 comparative image of macro- and micronutrients.

166 Energy provided by chia is higher than by maize and rice flours, but it is mostly due to its higher lipid
167 content. According to the data reported in Table 5, maize and rice recorded the highest carbohydrate
168 contents (85.19 and 76.5 g/100g, respectively), while amaranth and buckwheat are better sources of
169 fiber (8.9 and 10 g/100, respectively). Quinoa had the lowest fiber content (7g/100g), but it remains
170 highly dependent of the type of variety. Indeed, quinoa's fiber content was reported to range from 7.7%
171 to 13.8% (Li and Zhu 2017) and 8.8-14.1% (Nowak and Charrondi re 2016), while chia was found to
172 be the richest in fiber 34.4%, and rather consistent (Ixtaina and others 2008) (30-33g/100g).

173 Pseudocereal protein contents (13.25-16.5 g/100g) were significantly higher than those of rice (7.23
174 g/100g) and maize (7.4g/100g). Furthermore, the quality of the proteins of pseudocereals is correlated
175 with their nutritional added-value compared to rice and maize. Quinoa proteins, containing essential
176 amino acids lysine, threonine, and methionine are balanced a micronutrient composition (Wang and
177 Zhu, 2015). Amaranth has also satisfactory lysine and tryptophan contents according to FAO/WHO
178 standards, which make it a valuable fortification ingredient for meals with limited contents like maize
179 or sorghum (Ngugi and others 2017). Chia seeds provide a high-quality protein (about 16.5%) with good
180 amino acids balance, especially methionine and cysteine (Ayerza 2013).

181 As for lipid fraction, chia showed the highest value (30.7 g/100g and it is among the richest natural
182 source of the essential fatty acid α -linolenic (Menga and others 2017). Amaranth and quinoa showed
183 quite similar lipid contents (6.7 ad 6.1 g/100g, respectively), which were higher than those of rice and
184 maize (3.7 and 2.78 g/100g). The oils obtained from amaranth contain linoleic and α -linolenic fatty
185 acids. Quinoa was reported to be particularly rich in linoleate and linolenate (Chillo and others 2009),
186 while chia seeds are rich in those essential fatty acids (omega 3 and omega 6) (Mohd Ali and others
187 2012; Costantini and others 2014).

188 Regarding micronutrients, chia had interesting minerals composition in particular about twice of the
189 values of Ca and P as compared to rice and maize. Buckwheat, amaranth, and quinoa grains are
190 considered good sources of minerals such as Zn, Cu, Mn, K, Na, Ca, and Mg (Chillo and others 2009;
191 Singh and Singh, 2011). Chia was remarkably rich in vitamin A (16.2 μ g/100g). Quinoa (2.44 μ g/100g)
192 showed high content in vitamin E as compared to rice (0.6 μ g/100g). Buckwheat seeds also are rich in
193 thiamine (vitamin B1), riboflavin (vitamin B2) and pyridoxine (vitamin B6) (Dziadek and others 2016;
194 Guo and others 2017), and they also are abundant in several natural antioxidants, such as tocopherols,
195 rutin, quercetin, flavonoids, and phenolic acids.

196 Taking in account all the above-mentioned, the good composition of pseudocereals is not only suitable
197 to individuals with medical needs, but also to consumers seeking “healthy” foodstuffs (Pellegrini and
198 Agostoni, 2015; Balestra and others 2015).

199 **4. Ancient grains-based foodstuffs: nutritional added value and** 200 **technological characteristics**

201 Because ancient grains have a rich and balanced micronutrient composition, they might be suitable raw
202 ingredients to enhance technological quality or/and health benefits (Arzani 2011; Randall and others
203 2012; Chandi and others 2015). From an economic point of view, ancient grains are low-inputs crops
204 with lower needs in fertilizers and they might be a suitable crop in lower-income countries. Quinoa, for
205 example, is known for its tolerance to soil salinity indicating its suitability to harsh conditions (Wu and
206 others 2016).

207 Thus, ancient crops rediscovering to be a part of the daily human diet might be reinforced by a further
208 understanding of their technological properties and applications.

209 **4.1. Trends in ancient wheat-based foodstuffs**

210 The increasing popularity of ancient wheat as environmentally friendly cereal crops is stimulating
211 research into their utilization in both traditional and new foods (Messia and others 2012). Hulled wheat
212 species (einkorn, emmer, and spelt) are often used as whole grains for salads or soups, while they are
213 used differently for processing, with einkorn and emmer mainly used for pasta products and spelt mainly
214 used for bakery products (Benincasa and others 2015).

215 ***Bread-making***

216 Einkorn flour is generally reported as not suitable for bread-making because of its sticky dough and poor
217 rheological properties, but the existence of accessions with high bread-making quality has been
218 confirmed (Hidalgo and Brandolini 2011; Brandolini and Hidalgo 2011). It was reported that the
219 screening of a wide collection of einkorns (>1000 accessions) allowed the identification of
220 approximately 16% of the total accessions with sodium dodecyl sulfate (SDS) sedimentation values
221 corresponding to the threshold value for bread-making potential (Borghetti and others 1996). Later,
222 Brandolini and others (2008) conducted a survey of 65 einkorn samples to study their pasting properties
223 and concluded that einkorn had higher peak viscosity and final viscosity than modern wheat. The

224 differences are probably related to the smaller size and different grading of einkorn starch granules as
225 well as to the lower amylose percentage of einkorn flour (Brandolini and Hidalgo 2011). Regarding
226 bread color, einkorn has a color lighter than common wheat and durum wheat suggesting that einkorn
227 undergoes lower heat damage than modern wheat during baking because low α - and β - amylases limit
228 the degradation of starch (Brandolini and Hidalgo, 2011). As a result, the reduced generation of reducing
229 sugars in the dough limited the Maillard reactions during food processing. Low lipoxygenase activities
230 in einkorn dough also limits the degradation of carotenoids (Hidalgo and Brandolini 2014).

231 Kamut® bread showed good sensory properties and loaf volumes, highly resembling bread obtained
232 from modern wheat (Pasqualone and others 2011). Indeed, it was found that it is more suitable than
233 durum wheat for the fermentation processes at acidic conditions because an increase in the bread volume
234 and the metabolic heat production by yeast were observed (Balestra and others 2015).

235 A comparative study with spelt varieties showed acceptable sensory scores with significant differences
236 among the varieties (Korczyk Szabó and Lacko Bartošová 2013), leading to conclude that spelt might
237 be a suitable raw material for bread making, but it remains closely related to the choice of spelt variety
238 (Korczyk Szabó and Lacko Bartošová 2015). Compared to common bread, spelt genotypes had high
239 crumb elasticity, but low crumb cell homogeneity, which are probably due to its special dough
240 rheological attributes (Callejo and others 2015). Nutritionally, these breads had less total starch, more
241 resistant starch, and less rapidly digested proteins in comparison to bread made with modern wheat
242 flours (Bonafaccia and others 2000). Spelt and emmer sourdoughs had slightly higher pH values than
243 wheat sourdough but titratable acidity, concentration of free amino acids, and phytase activity were
244 higher than in common wheat sourdough (Coda and others 2010). Specific volume and crumb of spelt
245 breads showed higher resemblance to those of wheat breads than emmer. Sensory analysis also revealed
246 that spelt and emmer can be made into acceptable bread products (Coda and others 2010).

247 *Pasta making*

248 Little information was found in the scientific literature on 100% ancient wheat-based pasta due to its
249 low pasting properties (Brandolini and others 2008). Indeed, 100% einkorn pasta showed less compact

250 structure than durum wheat, resulting in high cooking losses and low ability in binding water (Pasini
251 and others 2015). However, pasta made by a mix of 50/50 semolina/einkorn showed a high aggregation
252 of gluten (La Gatta and others 2017). Higher carotenoid levels also were found during kneading because
253 of the low enzyme activities in einkorn (Hidalgo and others 2010). Marconi and others (2002) assessed
254 gluten properties of 3 spelt genotypes (Rouquin, Redoute, and HGQ Rouquin (Rouquin improved for
255 gluten quality)) using SDS sedimentation, gluten index values, and alveograph and farinograph
256 parameters. Compared to durum wheat pasta, spelt pasta dried at high temperature had darker color
257 which might be attributed to higher furosine, probably correlated with higher reducing sugars or
258 damaged starch contents in the semolina (Marconi and others 1999; 2002). Although ancient crops are
259 commonly reported to have a low technological quality of proteins (gluten strength) (Brandolini and
260 others 2008), spelt (HGQ Rouquin) allowed the production of pasta with satisfactory cooking quality
261 (Marconi and others 2002). As a matter of fact, 100% emmer pasta had improved organoleptic value
262 and lower glycemic index than durum pasta (Fares and others 2008). Moreover, pasta cooking did not
263 damage the polysaccharide composition (soluble and insoluble), but it induced a drastic loss in terms of
264 tocopherol and carotenoid contents (Fares and others 2008).

265 ***Baked goods, snacks, breakfast cereals***

266 Einkorn flour was reported for its excellent aptitude to produce many foodstuffs and it is currently
267 trending as a material for manufacturing new special foods with high nutritional quality such as crackers
268 and snacks (Hidalgo and Brandolini 2010; Brandolini and Hidalgo 2011; Hidalgo and others 2016,
269 Hidalgo and Brandolini 2017). For instance, compared to einkorn, puffed modern kernels seem more
270 appealing (Hidalgo and others 2016). However, from a nutritional point of view, puffed einkorn kernels
271 had good composition, in terms of proteins and bioactive compounds (Hidalgo and others 2016).
272 Compared to commercial products, flakes and muesli made by Kamut® and spelt had acceptable sensory
273 features (appearance, consistency and flavor), and they showed the highest total phenolic, flavonoid,
274 and crude fiber contents (Sumczynski and others 2015). Furthermore, tortillas partially substituted by
275 whole Kamut® flour (60%) showed high resemblance with that standard (Carini and others 2010). Spelt
276 flour addition (5, 10 and 15%) to corn grits decreased the expansion ratio and fracturability, whereas

277 bulk density and hardness of extrudates increased (Jozinović and others 2016). Moreover, color changed,
278 the peaks of viscosity (hot and cold) decreased, and less retrogradation was observed.

279 *Beverage making*

280 A few studies have focused on ancient wheat-based alcoholic and/or nonalcoholic beverages. Einkorn
281 wort exhibits standard properties, and the resulting beers showed excellent foam stability and distinct
282 pleasing carbonation taste. As a result, it is suggested as a potentially new raw material to produce
283 organic beer (Fogarasi and others 2015). Einkorn malts had high radical cation scavenging activities, as
284 measured by DPPH and ABTS methods, but the phenolic content was lower when using wheat (Fogarasi
285 and others 2015). As well, emmer malt is characterized by a very high extract yield and good
286 saccharification time, and good foam stability, but weak final attenuation, low polyphenol content, and
287 darker color than the barley malt beers (Esslinger 2009; Mayer and others 2011). Barley malt enriched
288 by emmer showed different sensory profiles as well as different compositions in terms of concentrations
289 of organic acids, carbohydrates, amino acids, dietary fibers, vitamins, and antioxidant and phytase
290 activities (Coda and others 2011). Spelt malt had an appropriate extract yield and apparent attenuation
291 limit in comparison with barley and wheat malt (Muñoz-Insa and others 2013). However, low spelt
292 soluble nitrogen caused a low Kolbach index; high viscosity caused lautering and filtration problems. As
293 a result, this cereal can be used in “normal” barley malt houses under commonly used malting
294 conditions, but it remains interesting to optimize beer production from mixes of ancient wheat malt and
295 barley malt. Furthermore, hulled malts exhibit lower soluble protein contents with higher free amino
296 nitrogen and total free amino acid values than dehulled malts (Marconi and others 2013). More studies
297 are required to determine the influence of the glume or husk on malt and technological aspects.

298 Blends of rice and emmer flours (ratio 94:6) also allowed the production of a good yogurt-like beverage
299 in terms of textural, sensory, and nutritional properties (Coda and others 2012).

300 **4.2. New advances in pseudocereals-based foodstuff formulations**

301 The development of new products based on pseudocereals is, currently, more of necessity rather than a
302 choice. The attention towards these ancient grains have been renewed by the increasing demand for
303 natural and health-beneficial foods. They are also naturally gluten-free seed perfectly suitable as a
304 reinforcement of the gluten-free market which is nowadays mainly based on maize and rice.

305 **4.2.1.Pseudocereals-based foodstuff**

306 Gluten-free foodstuff-making is a challenge for technologists and nutritionists due the absence of gluten,
307 which provides the viscoelastic properties of dough (De la Barc and others 2010). Nutritionally,
308 pseudocereals represent a healthy alternative to compensate for the deficiencies of a gluten-free diet
309 (Saturni and others 2010), because most of the gluten-free products currently available in the market are
310 made basically from refined flour or starches which are characterized by low contents of high-quality
311 protein, fiber, calcium, and iron (Cabrera-Chávez and others 2012; Molina-Rosell and others 2015).

312 ***Bread-making***

313 The fortification of breads using buckwheat (50%) or quinoa (50%) flours increased the volume and
314 softened the crumb (Alvarez-Jubete and others 2009b, 2010). Buckwheat addition (from 10 to 30%) also
315 decreased starch retrogradation which enhanced the anti-staling properties (Torbica and others 2010).
316 Furthermore, 100% buckwheat bread had low specific volume due to its dense structure (Hager and
317 others 2012). The enrichment of bread by amaranth (40%) enhanced the physical, and rheological
318 gluten-free dough as well as bread final attributes compared to corn starch-based formulations (Mariotti
319 and others 2009). Pseudocereals addition also improved bread nutritional profiles, fitting perfectly with
320 the expert nutritional recommendations for a gluten-free diet and gluten-free foods (Alvarez-Jubete and
321 others 2009b, 2010; Sakac and others 2011; Wronkowska and others 2010; Koppalu and others, 2016).
322 Amaranth and quinoa starches are used also for gluten-free food-making because they are characterized
323 by a low tendency to retrogradation (Abugoch 2009; Singh and Singh, 2011). They showed also higher
324 gelatinization temperature and peak viscosity but lower swelling capacities compared to those of fine
325 flour and middling fractions (Kumar and others 2016; Sakhare and others 2017). More attention,

326 however, should be paid to amaranth technological processing because it requires innovative approaches
327 due to its small seed size (Santra and Schoenlechner 2017).

328 The combination of sourdough lactic acid bacteria and pseudocereals was successfully employed in the
329 formulation of new pseudocereals-based products (Dallagnol and others 2012; Gobbetti and others
330 2014). During sourdough fermentation, several reactions, such as acidification and proteolysis, greatly
331 contribute to the increase in bread extensibility, softness, and volume (Nionelli and Rizzello, 2012). For
332 instance, quinoa addition (3.75%) improved shelf-life of bread (Coda and others 2010; Dallagnol and
333 others 2012). Likewise, 100% bread made from buckwheat sourdough improved bread quality, thereby
334 reducing the need of additives (Moroni and others 2009, 2010, 2011). Sourdoughs obtained with teff (5,
335 10 and 20%) and buckwheat (15%) also enhanced bread aroma and increased fruity, cereal, and toasty
336 notes as well as increased the perceived elasticity (Campo and others 2016). On the other hand,
337 fermentation stimulated protein hydrolysis, which increased the concentrations of free amino acids
338 (Dallagnol and others 2012), offering bioactive peptides and amino acids unavailable in gluten-free
339 products.

340 Recently, steeping and germination were suggested to be able to reduce the levels of antinutrients,
341 thereby enhancing the bioavailability of minerals in amaranth grains, resulting in a nutrient-dense
342 complementary food (Ngugi and others 2017).

343 *Pasta-making*

344 Commonly, corn and rice flours are used as main ingredients for gluten-free pasta production (Cabrera-
345 Chávez and others 2012), while recently there is increasing interest in new formulations based on gluten-
346 free blended flours (cereals and pseudocereals) to improve the nutritional aspect as well as the
347 technological features. For instance, pasta made from corn flour and low quinoa content (0.16%) had
348 acceptable physical properties compared to common wheat pasta (Caperuto and others 2000). About
349 25% of amaranth enrichment gave good pasta-making results due to the good interaction between rice
350 starch and amaranth proteins. Moreover, Fiorda and others (2013) suggested that gluten-free pasta
351 fortified by 30% amaranth flour had higher quality and sensory scores to those made with regular and

352 whole wheat flour pasta. Besides improved technological quality, these blends had higher protein and
353 fiber contents than gluten-free pasta. Noodles produced from amaranth flour (20%) had low firmness
354 and high cooking losses (Schoenlechner and others 2011). However, its nutritional composition, in terms
355 of mineral and fiber contents, and protein digestibility were improved when a novel and adequate
356 extrusion-cooking process was used (Cabrera-Chávez and others 2012). Pasta fortified by chia (5 and
357 10%) showed that chia seeds and mucilage might be a good natural thickening agent (Menga and others
358 2017). Furthermore, this addition increased total phenolic acids and dietary fiber as compared to the
359 pasta made from rice (Menga and others 2017).

360 ***Baked good, snacks, and breakfast cereals***

361 New trends and formulations of pseudocereal foodstuffs are spreading to produce health-beneficial and
362 tasty products, particularly baked good, snacks, and breakfast cereals. For example, quinoa was largely
363 used as an ingredient for baked goods (Rizzello and others 2015). Muffins fortified with 25% quinoa
364 flour are soft and have good overall consumer acceptability. However, 100% quinoa flour muffin had
365 low overall consumer acceptability due to the bitter taste of quinoa flour (Bhaduri 2013). An increase in
366 quinoa supplementation (30%) also increased the hardness of cookies, which was attributed to the high
367 content of fiber and protein (Brito and others 2015). The specific volume also was reduced resulting in
368 less bulky cookies, and also the final color was darker (Brito and others 2015).

369 On the other hand, Burgos and Armada (2015) demonstrated amaranth suitability to precooked products
370 due its high expansion and yellow index. Chia flour was incorporated at different levels in cakes (25%,
371 50%, and 75%) (Borneo and others 2010) and corn tortillas (5%, 10%, 15%, and 20%) (Rendón-
372 Villalobos and others 2012), and gluten-free bread (from 4% to 15%) (Moreira and others 2013;
373 Steffolani and others 2014; Da Mota Huerta and others 2016). Chia flour played the role of hydrocolloid,
374 indeed, because it significantly increased the water-holding capacity of the dough (Da Mota Huerta and
375 others 2016; Olivos-Lugo and others 2010; Steffolani and others 2014).

376 ***Beverage-making***

377 A fermented quinoa-based beverage was recently formulated using 2 varieties (Pasankalla and Rosada
378 de Huancayo) (Ludena Urquizo and others 2017). The obtained drinks had viable and stable microbiota
379 during storage (28 days) and the fermentation was mostly homolactic (Ludena Urquizo and others 2017).
380 Pasankalla-derived drinks had higher protein contents, lower saponin concentration, and lower loss of
381 viscosity during the fermentation process compared to Rosada de Huancayo drinks (Ludena Urquizo
382 and others 2017). Buckwheat showed lower malt extracts, longer saccharification times, higher total
383 protein and fermentable amino nitrogen content, and higher values of the iodine test and color as
384 compared to barley malts (Deželak and others 2014). However, fermentability values, wort pH, soluble
385 protein content, and volatile compounds were comparable and, consequently, the organoleptic
386 perception of the buckwheat beverage was good (Deželak and others 2014).

387 The aqueous extract of pseudocereal flours was incorporated in fermented lactose-free dairy products.
388 High incorporation of quinoa extracts (70 and 100%) increased the viscosity due to the high protein
389 content (Bianchi and others 2015), while low addition (30%) was more appreciated by the tasters, as
390 well as the obtained drink presented better nutritional features (protein, fat, ash, and total solid levels)
391 (Bianchi and others 2015). Regarding lactose-containing products, El-Deeb and others (2014) suggested
392 that 75 or 100% quinoa addition allowed the production of fermented milk beverages without altering
393 bacterial growth. After 10 days, these beverages had the highest scores in terms of body, texture, color,
394 and appearance. Moreover, the nutritional value was enhanced such as iron and some amino acids
395 (phenylalanine, methionine, histidine and leucine).

396 ***Meat industry***

397 The addition of chia was studied to develop lipid meat products (Herrero and others 2017). Because of
398 uncertainties in relation with the potential allergenicity, the daily intake of chia seeds should not exceed
399 48 g/day, according to the 2000 US Dietary Guidelines), and 15 g/day according to the European
400 commission. Chia-incorporated meat products showed relevant results. For example, frankfurters
401 formulated with 1% chia flour reported significant improvements in water-binding properties (Pintado
402 and others 2015). Furthermore, scanning electron microscopy showed that chia addition improved

403 emulsification and juiciness and, consequently, the overall acceptance was comparable to products with
404 added fat (Ding and others 2017). The high content of fiber in chia is correlated with higher water-
405 holding, absorption, and emulsifying activity and stability (Alfredo and others 2009). Chia oil addition
406 to meat batter also resulted in products with good stability and homogeneous structure (Cofrades and
407 others 2014). Furthermore, this fortification enhanced the nutritional aspect by increasing linolenic acid
408 and reducing processing and purges (Pintado and others 2016; De Souza and others 2015). Thus, meat
409 products containing chia might be suitable for special nutritional label (Pintado and others 2016).

410 **4.2.2.Pseudocereal incorporation in gluten-containing foodstuff**

411 Fortification of staple foods is an effective strategy to deliver and increase the intake of micronutrients
412 in the diet and can reduce micronutrient deficiencies (Yusufali and others 2012). As amply mentioned
413 above, pseudocereals have a good chemical composition in terms of bioactive components (Padalino
414 and others 2016).

415 Common wheat bread fortification could enable the development of a range of new baking products
416 with enhanced nutritional value (Stikic and others 2012). Indeed, bread supplemented with quinoa flour
417 had high acceptance with high nutritional value depending on the substitution level (Calderelli and
418 others 2010; Iglesias-Puig and others 2015). Indeed, bread made from blends containing 5% or 10% of
419 quinoa whole flour showed good bread-making properties, while blends with 15% of quinoa flour were
420 not acceptable (Enriquez and others 2003). Rodriguez-Sandoval and others (2012) also showed that
421 partial substitution with quinoa whole flour (10 and 20 %) resulted in breads with decreased specific
422 volume. However, with up to 20% addition of purified quinoa, the rheological characteristics of dough
423 and sensory characteristics were improved (Stikic and others 2012). A 50% substitution induced weak
424 final quality (Alvarez-Jubete and others 2010). Indeed, bread crumb hardness increased (Iglesias-Puig
425 and others 2015), about 6 times higher than sourdough bread with 100% substitution (Wolter and others
426 2014), as well as density and chewiness (Wang and others 2014). Specific volume and yellowness also
427 were reduced (Wang and others 2014). The addition of chia (5, 10, and 15%) improved gas retention in
428 dough and cut the time required to reach maximum dough development (Verdú and others 2015). The

429 obtained bread had a reduced water activity and contained the same amount of moisture compared with
430 the control (Verdú and others 2015). Indeed, the high content of fiber in chia might be the main cause
431 of the high water-holding capacity, as it forms an active hydrocolloid which interacts better with gluten
432 proteins (Verdú and others 2015). Therefore, the inclusion of chia increased the overall acceptability by
433 consumers (Iglesias-Puig and Haros 2013).

434 Recently, Rizzello and others (2016) carried out a study to investigate wheat bread enrichment by quinoa
435 flour sourdough. They concluded important improvements in chemical composition, namely free amino
436 acids, soluble fibers, total phenols, phytase, and in antioxidant activities (Rizzello and others 2016). The
437 sensory features of wheat bread made using 20% of quinoa sourdough were also improved with regards
438 to the use of quinoa flour (Rizzello and others 2016). However, in buckwheat and wheat sourdough
439 breads, acidification increased crumb porosity compared to control breads (Wolter and others 2013).
440 Blends made by 30% of buckwheat and common wheat flours were more effective in enhancing
441 antioxidant activity in comparison with amaranth and quinoa (Chlopicka and others 2012). Moreover, it
442 might improve bread quality attributes such as taste, color, and odor (Chlopicka and others 2012).
443 Fortified bread with 2.5% buckwheat showed acceptable crust and crumb color and taste, and also odor,
444 elasticity and the appropriate bread volume (Gawlik-Dziki and others 2009). Likewise, the addition of
445 chia increased the content of fiber, total antioxidant activity, and ω -3 fatty acid in the final products
446 (Coelho and de las Mercedes Salas-Mellado 2015; Constantini and others 2014). Chia flour significantly
447 increased water absorption and reduced the extensibility of dough (Steffolani and others 2014). It was
448 reported also that chia had thickening potential (Vázquez-Ovando and 2009) and it might replace as
449 much as 25% of oil or eggs in cakes, while yielding a more nutritious product with acceptable sensory
450 characteristics (Borneo and others (2010)

451 Regarding the pasta industry, pseudocereals and durum wheat blends are still a challenge since the
452 addition of alternative ingredients markedly affects technological and sensory properties (Rizzello and
453 others 2017). Recently, Lorusso and others (2017) revealed that the substitution of 20% of semolina
454 with quinoa flour improved the nutritional aspect of pasta, including free amino acids, total phenols, and

455 the antioxidant activity of pasta; while the resulting pasta tenacity increased. Despite the great nutritional
456 input, more work is required on the balance between substitution level and quality requirement.

457 **5. Landraces and old wheat varieties**

458 Landraces and old wheat varieties were the most cultivated until the late 19th century (Belderok
459 2000). Therefore, modern varieties were developed to create more productive plants with modified
460 chemical composition and others quality attributes. Comparative studies on old and modern varieties
461 have focused mainly on the physiological basis of yield (Giunta and others 2007). On the other hand, to
462 discriminate between wheat varieties, qualitative and quantitative gliadin and glutenin compositions
463 are the traits commonly adopted (Vita and others 2016). However, few studies were dedicated to
464 screen the compositional and technological aspects of landraces and old genotypes.

465 For instance, Dinelli and others (2013) studied 2 Italian durum wheat genotypes: Senatore Cappelli
466 (1915, selection from the exotic Tunisian landrace “Jneh Khottifa”) and Urria 12 (1900) cultivated under
467 a low-input agricultural system. Senatore Cappelli showed the lowest starch content (50.5%), while it
468 had the highest protein content (16.38 %) as well as gluten content (12%) as compared to modern
469 genotypes. Likewise, protein concentration showed a decreasing trend over time of cultivar releasing,
470 dropping from about 18% in the old cultivars to about 16.5% in the modern durum wheat cultivars (De
471 Vita and others 2007), which was consistent with the findings of Fois and others (2011). The low protein
472 content in modern cultivars was not due to a reduced nitrogen uptake, but to the dilution effect caused
473 by the heavier grains of modern durum cultivars (Motzo and others 2004). Regarding fiber and lipid
474 contents, few differences were found between both groups (Dinelli and others 2013). Carotenoid and
475 total polyphenol contents showed a non-significant trend from old to modern common wheat varieties
476 (Dinelli and others 2013). However, phenolic profiles of landraces and old genotypes showed a number
477 of total compounds and isomer forms much higher than those in the modern cultivars, particularly the
478 landrace Gentil Rosso, which had a much higher amount of total, free, and bound polyphenols (Dinelli
479 and others 2009, 2012). As for minerals, landraces and old cultivars had higher concentrations as
480 compared to more modern material (Hussain and others 2010, 2012), because genetic breeding did not

481 focus on the improvement of mineral content (Hussain and others 2012). Overall, Di Silvestro and others
482 (2012) found that old common wheat varieties had better nutrient contents when cultivated under low-
483 input conditions compared to the modern ones, which are strictly dependent on high levels of
484 fertilization. Therefore, beside breeding history, the biosynthesis and accumulation of micronutrients
485 are closely influenced by genotype, environmental conditions (Migliorini and others 2016), and farming
486 systems (Rizzello and others 2015).

487 From a technological point of view, De Vita and others (2007) studied the rheological properties of
488 some Italian landraces, including Timilia (released in 1900, indigenous landrace population from Sicily),
489 Russello S.G.7 (1910, selection from landrace “Russie”), Senatore Cappelli and Aziziah (1925, selection
490 from landraces). Old genotypes (Timilia, Russello S.G.7 and Senatore Cappelli) were characterized by
491 the lowest baking strength (alveographic W value), and dough-gluten properties (P and L alveographic
492 values) (De Vita and others 2007). Modern cultivars showed about twice and thrice the dough W values
493 of the landraces, and about a 50% and 100% greater P, respectively (Sanchez-Garcia and others 2015).
494 However, no significant differences were observed between 7 old (Sieve, Verna, Gentil Rosso, Andriolo,
495 Gambo di ferro, Frassineto, and Abbondanza), 2 mixtures, and 4 modern (Bolero, Blasco, Arabia, and
496 Bologna) varieties, in terms of P/L (Migliorini and others 2016). Gluten Index (GI) was higher for
497 modern cultivars than for landraces and old durum wheat varieties (Motzo and others 2004, Fois and
498 others 2011). Breeding induced a notable increase in GI, which was reflected by an improvement of
499 grain protein quality (Motzo and others 2004). Nevertheless, protein content, rather than gluten
500 quality, has a dominant role in determining pasta cooking quality of high-temperature-dried pasta
501 (Dexter and others 1977; D’Egidio and other 1990), explaining why some durum wheat old varieties
502 such as Senatore Cappelli and others give good pasta texture (Fois and others 2011). Regarding bread-
503 making, breads from landraces were scored as acceptable by consumers (Migliorini and others 2016).
504 Although modern bread wheat varieties showed great variability in bread-making quality attributes
505 (Sanchez-Garcia and others 2015), the landrace Andriolo showed interesting sensory aspects (Migliorini
506 and others 2016). In terms of aroma profile, landraces and older cultivars of bread wheat had a soft aroma,
507 while modern varieties had a much stronger aroma (Starr and others 2013).

508 Discussing the quality attributes of big wheat collections is expensive and time-consuming, and the
509 available comparative studies on wheat quality traits are usually restricted to small sets. Moreover, many
510 modern varieties were selected to fulfill specific technological transformations, as for example the
511 Italian durum wheat cultivar Svevo and, consequently, processing landraces and old varieties using the
512 same technologies might explain the difference in the end-product quality. Thus, drawing sound
513 conclusions about the poor technological quality of landraces lacks strong evidences and pleads to much
514 argumentation. Besides breeding new adapted lines for the low-input sector, landraces and old genotypes
515 are naturally suitable to produce organic food and support environmentally friendly practices (Di
516 Silvestro and others 2012).

517 **6. Concluding remarks and future outlook**

518 The rediscovery of ancient grains provides new alternatives to farmers, consumers, and the food
519 industry, such as seen in terms of gluten-free (non-wheat ancient grains) and gluten-containing
520 foodstuffs.

521 From a breeding point of view, shifting away from ancient species and the gradual shift towards a model
522 of agriculture based on uniformity, steered by the search for higher yields, has increased the risk of
523 genetic erosion (Dwivedi and others 2016). Diversity loss, here as in all the cultivated species, is indeed
524 critical and dangerous, also because ancient species might help us to face threats to food security
525 (Ceccarelli and Grando 2000; Dwivedi and others 2016). Indeed, ancient species, landraces, and old
526 genotypes, even though much less productive than the modern ones, are perfectly suitable for marginal
527 areas and low-input and high-stress conditions (Ceccarelli and Grando 1996) and, consequently, they
528 could represent a solution for local communities where the commonly grown varieties are not cultivable
529 (Migliorini and others 2016). From a nutritional point of view, reintroducing pseudocereals in the daily
530 diet as a fortifying agent with functional added-value features, might offer to consumers a richer variety
531 of beneficial compounds without altering the technological quality. Ancient wheat-based foodstuffs are
532 now an increasing trend in the food market, substituting durum or/and common wheat flour for creating
533 new lines of products. Their technological defects, as discussed, are not always associated with inner

534 characteristics of seeds, because traditionally made products have often good-quality features. Indeed,
535 modern processing methods or/and industrial machinery, even if perfect for modern varieties, was not
536 be suitable for older grains. Therefore, more work is needed in order to optimize technological
537 processing and formulations to fit their compositional and morphological characteristics.

538 Thus, ancient grains might constitute an alternative, which can co-exist in the current market with the
539 undoubtedly needed modern high-productive varieties. Certainly, methods and technologies to obtain
540 novel products with high technological quality and health-beneficial and affordable price are needed.
541 Also, blends of pseudocereals and ancient wheat might be considered for creating new health-beneficial
542 food products.

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981 **Figure caption**

982 Figure 1: Major classes and subclasses of ancient grains. A: Classification of ancient grains; B:
983 Taxonomy of the most cultivated cereals; C: Taxonomy of the most known pseudocereals. This figure
984 explains the classes and subclasses of ancient grains in terms of ancient wheat and pseudocereals.

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1009 **Table caption**

1010 **Table 1:** Glossary. This table gives the definitions of the key terms used for wheat and pseudocereals.

1011 **Table 2:** Gluten-containing grains. This table focuses on the main ancient wheat characteristics.

1012 **Table 3:** Gluten-free grains. This table shows the main characteristics of pseudocereals.

1013 **Table 4:** Approximate chemical composition of ancient wheat, durum wheat, and common wheat. This

1014 table contains data reported about the chemical composition of ancient wheat in terms of macro- and

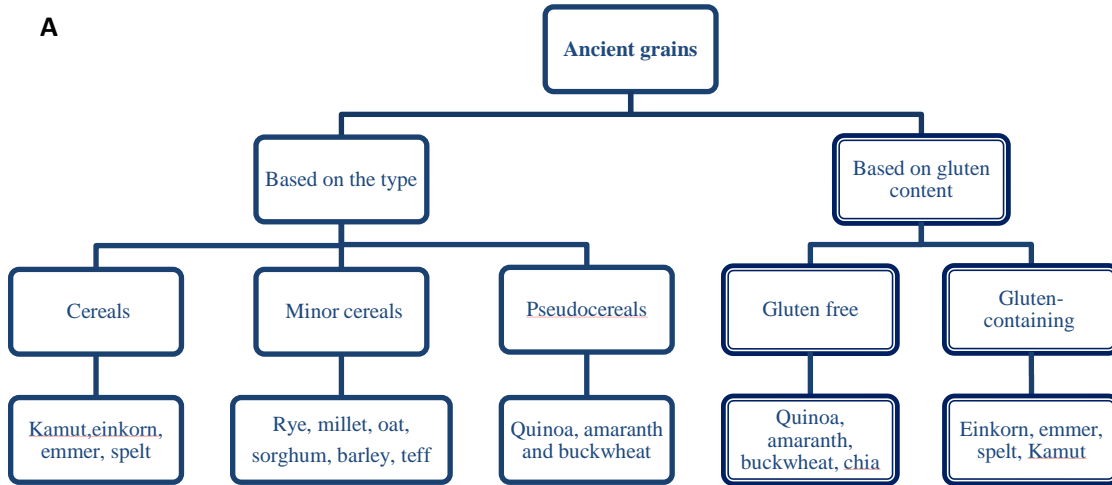
1015 micronutrients in comparison with durum and common wheat.

1016 **Table 5:** Approximate chemical composition of pseudocereals compared to maize and rice. This table

1017 contains data reporting on the chemical composition of pseudocereals in terms of macro- and

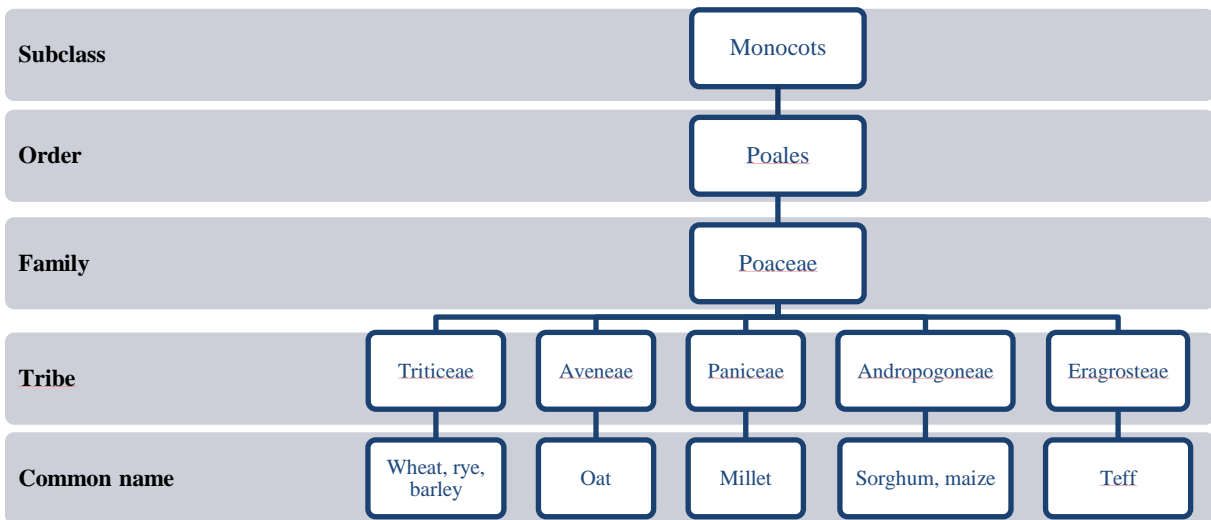
1018 micronutrients in comparison with maize and rice.

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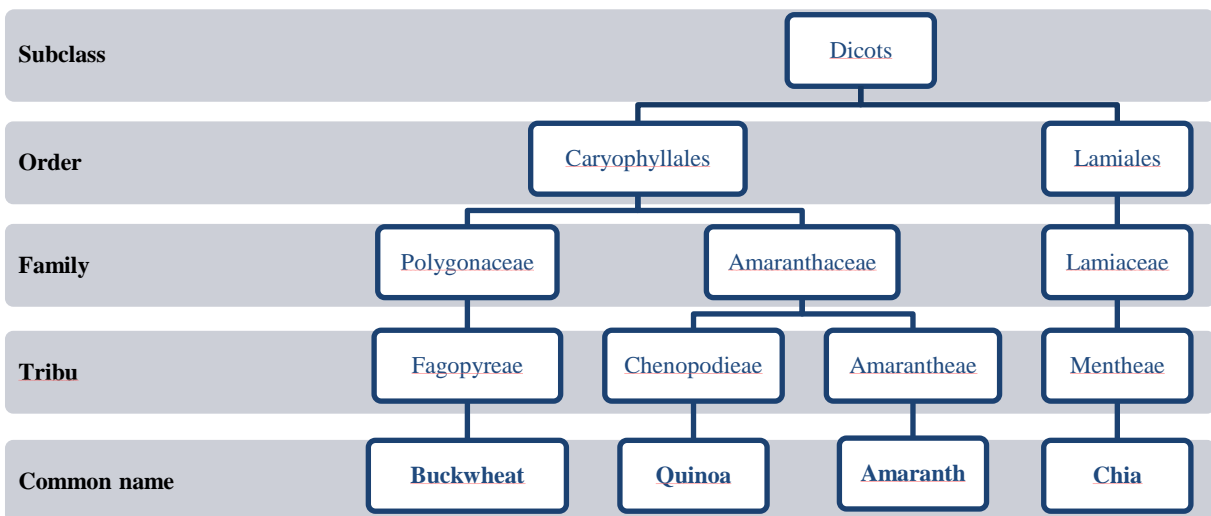
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1022 **Figure 1:** Major classes and subclasses of ancient grains. A: Classification of ancient grains; B: Taxonomy of the most
1023 cultivated cereals; C: Taxonomy of the most known pseudocereals.

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1046 **Table 1:** Glossary.

| Key terms | Definition |
|---------------------------------------|--|
| Wild species or wild ancestors | are the species naturally grown in the Old World, before any cultivation and domestication*. <i>Triticum urartu</i> (AA) and <i>Triticum boeoticum</i> (wild einkorn, AA), <i>Triticum turgidum</i> ssp. <i>dicoccoides</i> (wild emmer, AABB) are the wild progenitors of modern wheat. |
| Domesticated* wheat | is obtained by the selection of novel spontaneous mutations or recessive alleles in cultivated populations or among the wild populations (Hebelstrup 2017). |
| Ancient grains | are represented by populations of primitive grains , which were not subject to any modern breeding or selection, and which retained characters of wild ancestors, such as large individual variability, ear height, brittle rachis, and low harvest index (Giambanelli and others 2013). |
| Ancient wheat | refers to emmer, einkorn, Khorasan wheat (Oriental wheat) and spelt. |
| Pseudocereals | are mainly amaranth, quinoa, buckwheat, and chia. |
| Landraces and old varieties | are developed by natural and human selection, genetically heterogeneous, locally adapted, and they too were cultivated until the middle of the 20 th century (Nazco and others 2012; Lopes and others 2015; Mohammadi and others 2015; Soriano and others 2016). |
| Modern varieties | are the result of the continued modern breeding progress, aiming to select homogeneous lines with stable and improved characters, mainly Rht dwarfing gene to avoid lodging. Currently, thanks to international breeding programs, these varieties are cultivated worldwide ensuring higher productivity than landraces. |

1047 *Note: The shift from wild to domesticated involved an evolutionary process of morphological, physiological, and
1048 genetic events, referred to as 'domestication syndrome' (Hammer 1984). The two most important events of the
1049 domestication syndrome are: a non- brittle rachis mutation that resulted in non-shattering domesticated wheat
1050 and a non-hulled mutation which resulted in free-threshing domesticated wheat, where the husk covering the seed
1051 comes off during threshing. Domestication involved other traits, such as increase in both seed size and number,
1052 loss of germination inhibition, lower grain protein and mineral concentrations, and increased grain carbohydrate
1053 content (Zohary and Hopf 2000; Fuller 2007; Gegas and others 2010; Sakuma and others 2011; Peleg and others
1054 2011). *Triticum aestivum* L. and *Triticum turgidum* subsp. *durum*, which are free-threshing wheat, represent the
1055 final step of *Triticum* domestication (Salamini and others 2002).

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1067 **Table 2:** Gluten-containing grains.

| Common name | Binomial name | Origin/History | References |
|--|---|---|--|
| Einkorn wheat | <i>Triticum monococcum</i> L., subsp. <i>monococcum</i> (2n = 2x = 14, AA), | Domesticated diploid wheat from ssp. <i>aegilopoides</i> through the acquisition of a non-brittle rachis. | (Hidalgo and Brandolini 2017; Faris and others 2014). |
| Emmer wheat, also known as farro in Italy | <i>Triticum turgidum dicoccum</i> (2n = 4x = 28, genome AABB) | The domesticated form of wild emmer, which derived from <i>T. urartu</i> , (2n = 2x = 14, AA), donor of the genome A, and another unknown species of the <i>Sitopsis</i> section, donor of the B genome, for which the closest known relative is goat grass (<i>Aegilops speltoides</i> , 2n = 2x = 14, SS). | (Salse and others 2008; Chatzav and others 2009; Ozkan and others 2010; Peng and others 2011). |
| Spelt wheat | <i>Triticum aestivum subsp. spelta</i> (2n = 6x = 42; genome AABBDD) | It is suggested to be the ancestral form of <i>T. aestivum</i> ; however, it is also hypothesized to be probably derived from a secondary hybridization between emmer wheat and a hexaploid wheat (<i>T. aestivum</i> L. ssp. <i>compactum</i> Host em). | (Dovrak and others 2011; Guzmán and others 2012) |
| Khorasan wheat or Kamut® | <i>Triticum turgidum subsp. turanicum</i> (2n = 4x = 28, genome AABB) | This wheat originated in the Khorasan region and was always known in the Mediterranean basin, where many populations exist. Its origin is probably as far in time as durum wheat. Kamut® is the registered trademark for Khorasan wheat produced under the controlled value chain of Kamut International. | (Michalcová and others 2014) |

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1079 **Table 3:** Gluten-free grains.

| Common name | Main species | Origin/History | References |
|------------------|--|---|---|
| Buckwheat | The two major species are common buckwheat (sweet) (<i>Fagopyrum esculentum</i> Moench) and tartary buckwheat (<i>Fagopyrum tataricum</i> Gaertn.) | One of the traditional crops cultivated in Asia and Central and Eastern Europe. | (Moreno and others 2014; Kang and others 2017) |
| Quinoa | The two commercial varieties are <i>Amarilla de Marangani</i> and <i>Blanca de Junin</i> | Among the most popular crops for the people of rural South America. | (Vega-Gálvez and others 2010; Graf and others 2015) |
| Amaranth | 60 plant species, <i>Amaranthus cruentus</i> , <i>A. hypochondriacus</i> , and <i>A. Caudatus</i> are the main cultivated amaranth species for grain, whereas <i>A. cruentus</i> , <i>A. blitum</i> , <i>A. dubius</i> , and <i>A. tricolor</i> are used as leafy vegetables | It was once a staple food of the Aztecs. | (Singh and Singh, 2011). |
| Chia | Three main species: <i>Salvia columbariae</i> Benth., <i>Salvia polytachya</i> Cavan., and <i>Salvia hispanica</i> L.. | It was found growing wild in Mexico. | (Verdú and others 2015). |

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1083 **Table 4:** Approximate chemical composition of ancient wheat, durum wheat and common wheat.

| | Einkorn | Emmer | Spelt | Kamut® | Durum wheat | Common wheat |
|------------------------------|----------------|--------------|--------------|---------------|--------------------|---------------------|
| Energy (kcal/100g) | 333 | 362 | 324 | 337 | 339 | 340 |
| Carbohydrate (g/100g) | 67 | 72 | 68 | 71 | 71 | 75 |
| Protein (g/100g) | 13.3 | 12.8 | 14.7 | 14.5 | 13.7 | 10.7 |
| Fiber (g/100g) | 6.7 | 10.6 | 5.9 | 11.1 | 11.6 | 12.7 |
| Lipid (g/100g) | 1.7 | 2.1 | 2.9 | 2.1 | 2.5 | 2 |
| Minerals | | | | | | |
| Calcium (mg/100g) | Nr | Nr | 17.6 | 22 | 34 | 34 |
| Iron (mg/100g) | 3.6 | 1.5 | 3.1 | 3.8 | 3.2 | 5.4 |
| Magnesium (mg/100g) | 200 | 128 | Nr | 130 | 144 | 90 |
| Phosphorus (mg/100g) | Nr | Nr | Nr | 364 | 508 | 402 |
| Potassium (mg/100g) | Nr | Nr | Nr | 403 | 431 | 435 |
| Sodium (mg/100g) | Nr | Nr | Nr | 5 | 2 | 2 |
| Zinc (mg/100g) | 15 | 4.8 | Nr | 3.7 | 4.2 | 3.5 |
| Vitamins (µg/100g) | | | | | | |
| Vitamin A | Nr | Nr | Nr | 0.3 | 0 | 0 |
| Vitamin B₆ | 0.4 | Nr | Nr | 0.26 | 0.42 | 0.38 |
| Vitamin C | Nr | Nr | Nr | 0 | 0 | 0 |
| Vitamin E | Nr | Nr | Nr | 0.61 | 0 | 1.01 |

1084 Nr: Not reported

1085 United States Department of Agriculture. USDA Food Composition Database. Available from:
 1086 <http://ndb.nal.usda.gov/>.

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1093 **Table 5:** Approximate chemical composition of pseudocereals compared to maize and rice.

| | Pseudocereals | | | | Maize | Rice |
|------------------------------|----------------------|--------|----------|------|--------------|-------------|
| | Buckwheat | Quinoa | Amaranth | Chia | | |
| Energy (kcal/100g) | 343 | 368 | 378 | 486 | 370 | 363 |
| Carbohydrate (g/100g) | 71.5 | 64.2 | 66.7 | 18.4 | 85.19 | 76.5 |
| Protein (g/100g) | 13.25 | 14.1 | 15.5 | 16.5 | 7.4 | 7.23 |
| Fiber (g/100g) | 10 | 7 | 8.9 | 34.4 | 7.4 | 4.6 |
| Lipid (g/100g) | 3.4 | 6.1 | 6.7 | 30.7 | 3.7 | 2.78 |
| Minerals (g/100g) | | | | | | |
| Calcium (mg/100g) | 18 | 47 | 133 | 631 | Nr | 11 |
| Iron (mg/100g) | 2.8 | 4.57 | 8 | 7.72 | 2.67 | 1.98 |
| Magnesium (mg/100g) | 231 | 197 | Nr | 335 | 259 | 112 |
| Phosphorus (mg/100g) | 347 | 457 | Nr | 860 | Nr | 337 |
| Potassium (mg/100g) | 460 | 563 | Nr | 407 | Nr | 289 |
| Sodium (mg/100g) | 1 | 5 | 22 | 16 | Nr | 8 |
| Zinc (mg/100g) | 2.4 | 3.1 | Nr | 4.58 | Nr | 2.45 |
| Vitamins (µg/100g) | | | | | | |
| Vitamin A | Nr | 4.2 | Nr | 16.2 | Nr | Nr |
| Vitamin B₆ | 0.21 | 0.487 | Nr | Nr | Nr | 0.736 |
| Vitamin C | Nr | Nr | 5.3 | 1.6 | Nr | Nr |
| Vitamin E | Nr | 2.44 | Nr | 0.5 | Nr | 0.6 |

1094 Nr. Not reported

1095 United States Department of Agriculture. USDA Food Composition Database. Available from:
1096 <http://ndb.nal.usda.gov/>.

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