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Original
Current Trends in Ancient Grains-Based Foodstuffs: Insights into Nutritional Aspects and Technological Applications / Boukid, F.; Folloni, S.; Sforza, S.; Vittadini, E.; Prandi, B.. - In: COMPREHENSIVE REVIEWS IN FOOD SCIENCE AND FOOD SAFETY. - ISSN 1541-4337. - 17:1(2018), pp. 123-136. [10.1111/1541-4337.12315]

Availability:
This version is available at: 11381/2838430 since: 2021-10-19T17:12:29Z

Publisher:
Blackwell Publishing Inc.

Published
DOI:10.1111/1541-4337.12315

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

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Abstract

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

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

1. Glossary

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

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

2. An overview of ancient grains

2.1. Fundamental classes and subclasses of ancient grains

Ancient grains might be subdivided in several categories and subcategories (Figure 1A). Botanically, grains belong to monocotyledon "monocots" (one seed leaf) and dicotyledon "dicots" (two seed leaves) which are the two major subclasses of flowering plants "*angiosperms*". Three main categories are: cereals, minor cereals, and pseudocereals. Cereals are made up of rice, wheat, and maize. Minor cereals are mainly rye (*Secale cereale L.*), foxtail millet (*Setaria italica* L.), oat (*Avena sativa* L.), sorghum (*Sorghum bicolor* L.), barley (*Hordeum vulgare* L.), common millet (*Panicum miliaceum* L.) and teff (*Eragrostis tef* (*Zucc*.) Trotter) (Diao 2017). Cereals and minor cereals belong to *Poaceae* which is one of the most important families of the order *Poales* belonging to monocotyledon subclass (Figure 1B). For centuries, *Poacea*, formerly *Gramineae*, provided the most important share of human nutrition. *Poaceae*, also called grasses, contain over 600 genera and more than 10,000 species that dominate many ecological and agricultural systems (The International Brachypodium Initiative 2010). It was established also that the grasses family diverged into different subfamilies and tribes, with the sub-families being *Pooideae* (wheat, barley, and oats), *Ehrhartoideae* (rice), *Panicoideae* (maize, sorghum), and *Chloridoideae* (teff) (Charles and others 2009). Tribes are mainly *Triticeae* (wheat, rye, and barley), *Aveneae* (oat), *Paniceae* (millet), *Andropogonee* (sorghum and maize) and *Eragrosteae* (teff). On the other hand, pseudocereals are defined as non-grasses, dicots grains that diverge into several families such as *Polygonaceae*, *Amaranthaceae*, and *Lamiaceae* (Figure 1C). Amaranth (*Amaranthus caudatus L.; A. cruentus; A. hypochondriacus*), quinoa (*Chenopodium quinoa Willd.*), and buckwheat (*Fagopyrum esculentum Moench.*) are the best known pseudocereals (Fletcher 2016), while chia (*Salvia hispanica L.*) has been gaining interest recently due to its functional and nutritional properties.

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

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

The main reason behind the shifting away from ancient grains was their low yield. Plant improvement programs aimed at increasing grain yield to feed the growing populations (Okuno and others 2014) and, as a result, ancient grains were abandoned and replaced by high-yielding modern grains which contributed to the decrease of genetic diversity. Nowadays about 95% of the cultivated wheat worldwide is *Triticum aestivum*, while most of the remaining 5% is *T. turgidum* susbp. *durum* (Brouns and others 2013).

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

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

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

The increasing demand for traditional products, the request for high adaptability, and the need to preserve genetic diversity are among the reasons behind the renewed attention towards ancient species (Troccoli and Codianni 2005). The evolution of plant breeding resulted in genetic erosion and thereby the loss of genetic diversity. Therefore, there is a serious need to go beyond the uniform model of today agriculture and reintroduce germplasm characterized by high heterogeneity. Species diversity contributes to the increase of crop productivity and stability (Hooper and others 2012; Khoury and others 2014). Indeed, ancient wheat is suitable for organic farming because of their adaptability to low agronomic input; and where other wheat types would fail, they show high resistance to powdery mildew and brown rust, and disadvantageous growing conditions (such as wet, cold soils, high altitudes, and poor soils) (Konvalina and others 2010; Escarnot and others 2012). Pseudocereals are also known for their high adaptability, low needs in terms of water, fertilizer, and energy as compared to traditional cereals (Kang and others 2017; Santra and Schoenlechner 2017). As a result, the 2015 international report from Health Focus International stated that the international awareness of ancient grains was up from 26% in 2012 to 28% in 2014, with 35% of the respondents expressing an interest in ancient grains.

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

3. Composition of ancient grains versus modern grains

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

3.1. Ancient wheat

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

The main components of ancient wheat are carbohydrates, protein and fibers, similarly to modern wheat. Carbohydrate contents in durum and common wheat are slightly higher than in ancient wheat; indeed, it was found that spelt (68%) provides the lowest carbohydrate contents together with einkorn (67%). Spelt contains the lowest fiber content (5.9%), while it was reported that it is a good source of fiber (11.4 %) by Ranhotra and others (1995), which implies large sample variability. Furthermore, einkorn flour has a lower content of total dietary fiber (6.7%), than common wheat (12.7%).

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

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

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

Regarding the vitamin content, Table 4 showed that Kamut® has higher vitamin A than common wheat and durum wheat. Despite the importance of micronutrients, wheat labels usually lack this indication, and more information in this regard are found in literature. Tocols and carotenoids were exclusively discussed in scientific works. Indeed, einkorn was found to have high tocol and carotenoid contents that may make einkorn an interesting ingredient to be used in the development of new or special foods with high nutritional quality (Hidalgo and others 2016). Einkorn tocols content was higher (42.7-70.2µg/g, average =57) compared to durum wheat (40.1-62.7µg/g, average=48.1) (Lampi and others 2008). In another study, it was reported that tocols in ancient wheat, einkorn (61.80–115.85 µg /g), emmer (62.7-67.9µg/g), and spelt (62.7-67.5µg/g) were slightly higher than in durum (38.8-57.27µg/g) and common (53.2-74.9µg/g) wheat (Hidalgo and others 2006). As for carotenoids, important variability was shown; in common wheat, they are less abundant (1.4-3.05 mg/kg) than in durum wheat (1.9-5 mg/kg) and Kamut® (4.4 mg/kg), while carotenoids in einkorn were the highest and varied between 5.3 and 13.6 mg/kg (Hidalgo and others 2006). The authors also highlighted the relevant impact of cultivation area and genotype on the content of both tocols and carotenoids (Hidalgo and others 2006).

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

3.2. Pseudocereals

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

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

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

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

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

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

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

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

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

4.1. Trends in ancient wheat-based foodstuffs

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

Bread-making

Einkorn flour is generally reported as not suitable for bread-making because of its sticky dough and poor rheological properties, but the existence of accessions with high bread-making quality has been confirmed (Hidalgo and Brandolini 2011; Brandolini and Hidalgo 2011). It was reported that the screening of a wide collection of einkorns (>1000 accessions) allowed the identification of approximately 16% of the total accessions with sodium dodecyl sulfate (SDS) sedimentation values corresponding to the threshold value for bread-making potential (Borghi and others 1996). Later, Brandolini and others (2008) conducted a survey of 65 einkorn samples to study their pasting properties and concluded that einkorn had higher peak viscosity and final viscosity than modern wheat. The differences are probably related to the smaller size and different grading of einkorn starch granules as well as to the lower amylose percentage of einkorn flour (Brandolini and Hidalgo 2011). Regarding bread color, einkorn has a color lighter than common wheat and durum wheat suggesting that einkorn undergoes lower heat damage than modern wheat during baking because low α- and β- amylases limit the degradation of starch (Brandolini and Hidalgo, 2011). As a result, the reduced generation of reducing sugars in the dough limited the Maillard reactions during food processing. Low lipoxygenase activities in einkorn dough also limits the degradation of carotenoids (Hidalgo and Brandolini 2014).

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

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

Pasta making

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

Baked goods, snacks, breakfast cereals

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

Beverage making

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

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

4.2. New advances in pseudocereals-based foodstuff formulations

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

4.2.1.Pseudocereals-based foodstuff

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

Bread-making

The fortification of breads using buckwheat (50%) or quinoa (50%) flours increased the volume and softened the crumb (Alvarez-Jubete and others 2009b, 2010). Buckwheat addition (from 10 to 30%) also decreased starch retrogradation which enhanced the anti-staling properties (Torbica and others 2010). Furthermore, 100% buckwheat bread had low specific volume due to its dense structure (Hager and others 2012). The enrichment of bread by amaranth (40%) enhanced the physical, and rheological gluten-free dough as well as bread final attributes compared to corn starch-based formulations (Mariotti and others 2009). Pseudocereals addition also improved bread nutritional profiles, fitting perfectly with the expert nutritional recommendations for a gluten-free diet and gluten-free foods (Alvarez-Jubete and others 2009b, 2010; Sakac and others 2011; Wronkowska and others 2010; Koppalu and others, 2016).

Amaranth and quinoa starches are used also for gluten-free food-making because they are characterized by a low tendency to retrogradation (Abugoch 2009; Singh and Singh, 2011). They showed also higher gelatinization temperature and peak viscosity but lower swelling capacities compared to those of fine flour and middling fractions (Kumar and others 2016; Sakhare and others 2017). More attention, however, should be paid to amaranth technological processing because it requires innovative approaches due to its small seed size (Santra and Schoenlechner 2017).

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

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

Pasta-making

Commonly, corn and rice flours are used as main ingredients for gluten-free pasta production (Cabrera-Chávez and others 2012), while recently there is increasing interest in new formulations based on gluten-free blended flours (cereals and pseudocereals) to improve the nutritional aspect as well as the technological features. For instance, pasta made from corn flour and low quinoa content (0.16%) had acceptable physical properties compared to common wheat pasta (Caperuto and others 2000). About 25% of amaranth enrichment gave good pasta-making results due to the good interaction between rice starch and amaranth proteins. Moreover, Fiorda and others (2013) suggested that gluten-free pasta fortified by 30% amaranth flour had higher quality and sensory scores to those made with regular and whole wheat flour pasta. Besides improved technological quality, these blends had higher protein and fiber contents than gluten-free pasta. Noodles produced from amaranth flour (20%) had low firmness and high cooking losses (Schoenlechner and others 2011). However, its nutritional composition, in terms of mineral and fiber contents, and protein digestibility were improved when a novel and adequate extrusion-cooking process was used (Cabrera-Chávez and others 2012). Pasta fortified by chia (5 and 10%) showed that chia seeds and mucilage might be a good natural thickening agent (Menga and others 2017). Furthermore, this addition increased total phenolic acids and dietary fiber as compared to the pasta made from rice (Menga and others 2017).

Baked good, snacks, and breakfast cereals

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

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

Beverage-making

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

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

Meat industry

The addition of chia was studied to develop lipid meat products (Herrero and others 2017). Because of uncertainties in relation with the potential allergenicity, the daily intake of chia seeds should not exceed 48 g/day, according to the 2000 US Dietary Guidelines), and 15 g/day according to the European commission. Chia-incorporated meat products showed relevant results. For example, frankfurters formulated with 1% chia flour reported significant improvements in water-binding properties (Pintado and others 2015). Furthermore, scanning electron microscopy showed that chia addition improved emulsification and juiciness and, consequently, the overall acceptance was comparable to products with added fat (Ding and others 2017). The high content of fiber in chia is correlated with higher water-holding, absorption, and emulsifying activity and stability (Alfredo and others 2009). Chia oil addition to meat batter also resulted in products with good stability and homogeneous structure (Cofrades and others 2014). Furthermore, this fortification enhanced the nutritional aspect by increasing linolenic acid and reducing processing and purges (Pintado and others 2016; De Souza and others 2015). Thus, meat products containing chia might be suitable for special nutritional label (Pintado and others 2016).

4.2.2.Pseudocereal incorporation in gluten-containing foodstuff

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

Common wheat bread fortification could enable the development of a range of new baking products with enhanced nutritional value (Stikic and others 2012). Indeed, bread supplemented with quinoa flour had high acceptance with high nutritional value depending on the substitution level (Calderelli and others 2010; Iglesias-Puig and others 2015). Indeed, bread made from blends containing 5% or 10% of quinoa whole flour showed good bread-making properties, while blends with 15% of quinoa flour were not acceptable (Enriquez and others 2003). Rodriguez-Sandoval and others (2012) also showed that partial substitution with quinoa whole flour (10 and 20 %) resulted in breads with decreased specific volume. However, with up to 20% addition of purified quinoa, the rheological characteristics of dough and sensory characteristics were improved (Stikic and others 2012). A 50% substitution induced weak final quality (Alvarez-Jubete and others 2010). Indeed, bread crumb hardness increased (Iglesias-Puig and others 2015), about 6 times higher than sourdough bread with 100% substitution (Wolter and others 2014), as well as density and chewiness (Wang and others 2014). Specific volume and yellowness also were reduced (Wang and others 2014). The addition of chia (5, 10, and 15%) improved gas retention in dough and cut the time required to reach maximum dough development (Verdú and others 2015). The obtained bread had a reduced water activity and contained the same amount of moisture compared with the control (Verdú and others 2015). Indeed, the high content of fiber in chia might be the main cause of the high water-holding capacity, as it forms an active hydrocolloid which interacts better with gluten proteins (Verdú and others 2015). Therefore, the inclusion of chia increased the overall acceptability by consumers (Iglesias-Puig and Haros 2013).

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

Regarding the pasta industry, pseudocereals and durum wheat blends are still a challenge since the addition of alternative ingredients markedly affects technological and sensory properties (Rizzello and others 2017). Recently, Lorusso and others (2017) revealed that the substitution of 20% of semolina with quinoa flour improved the nutritional aspect of pasta, including free amino acids, total phenols, and the antioxidant activity of pasta; while the resulting pasta tenacity increased. Despite the great nutritional input, more work is required on the balance between substitution level and quality requirement.

5. Landraces and old wheat varieties

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

For instance, Dinelli and others (2013) studied 2 Italian durum wheat genotypes: Senatore Cappelli (1915, selection from the exotic Tunisian landrace “Jneh Khottifa”) and Urria 12 (1900) cultivated under a low-input agricultural system. Senatore Cappelli showed the lowest starch content (50.5%), while it had the highest protein content (16.38 %) as well as gluten content (12%) as compared to modern genotypes. Likewise, protein concentration showed a decreasing trend over time of cultivar releasing, dropping from about 18% in the old cultivars to about 16.5% in the modern durum wheat cultivars (De Vita and others 2007), which was consistent with the findings of Fois and others (2011). The low protein content in modern cultivars was not due to a reduced nitrogen uptake, but to the dilution effect caused by the heavier grains of modern durum cultivars (Motzo and others 2004). Regarding fiber and lipid contents, few differences were found between both groups (Dinelli and others 2013). Carotenoid and total polyphenol contents showed a non-significant trend from old to modern common wheat varieties (Dinelli and others 2013). However, phenolic profiles of landraces and old genotypes showed a number of total compounds and isomer forms much higher than those in the modern cultivars, particularly the landrace Gentil Rosso, whih had a much higher amount of total, free, and bound polyphenols (Dinelli and others 2009, 2012). As for minerals, landraces and old cultivars had higher concentrations as compared to more modern material (Hussain and others 2010, 2012), because genetic breeding did not focus on the improvement of mineral content (Hussain and others 2012). Overall, Di Silvestro and others (2012) found that old common wheat varieties had better nutrient contents when cultivated under low-input conditions compared to the modern ones, which are strictly dependent on high levels of fertilization. Therefore, beside breeding history, the biosynthesis and accumulation of micronutrients are closely influenced by genotype, environmental conditions (Migliorini and others 2016), and farming systems (Rizzello and others 2015).

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

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

6. Concluding remarks and future outlook

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

From a breeding point of view, shifting away from ancient species and the gradual shift towards a model of agriculture based on uniformity, steered by the search for higher yields, has increased the risk of genetic erosion (Dwivedi and others 2016). Diversity loss, here as in all the cultivated species, is indeed critical and dangerous, also because ancient species might help us to face threats to food security (Ceccarelli and Grando 2000; Dwivedi and others 2016). Indeed, ancient species, landraces, and old genotypes, even though much less productive than the modern ones, are perfectly suitable for marginal areas and low-input and high-stress conditions (Ceccarelli and Grando 1996) and, consequently, they could represent a solution for local communities where the commonly grown varieties are not cultivable (Migliorini and others 2016). From a nutritional point of view, reintroducing pseudocereals in the daily diet as a fortifying agent with functional added-value features, might offer to consumers a richer variety of beneficial compounds without altering the technological quality. Ancient wheat-based foodstuffs are now an increasing trend in the food market, substituting durum or/and common wheat flour for creating new lines of products. Their technological defects, as discussed, are not always associated with inner characteristics of seeds, because traditionally made products have often good-quality features. Indeed, modern processing methods or/and industrial machinery, even if perfect for modern varieties, was not be suitable for older grains. Therefore, more work is needed in order to optimize technological processing and formulations to fit their compositional and morphological characteristics.

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

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Figure caption

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

Table caption

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

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

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

Table 4: Approximate chemical composition of ancient wheat, durum wheat, and common wheat. This table contains data reported about the chemical composition of ancient wheat in terms of macro- and micronutrients in comparison with durum and common wheat.

Table 5: Approximate chemical composition of pseudocereals compared to maize and rice. This table contains data reporting on the chemical composition of pseudocereals in terms of macro- and micronutrients in comparison with maize and rice.

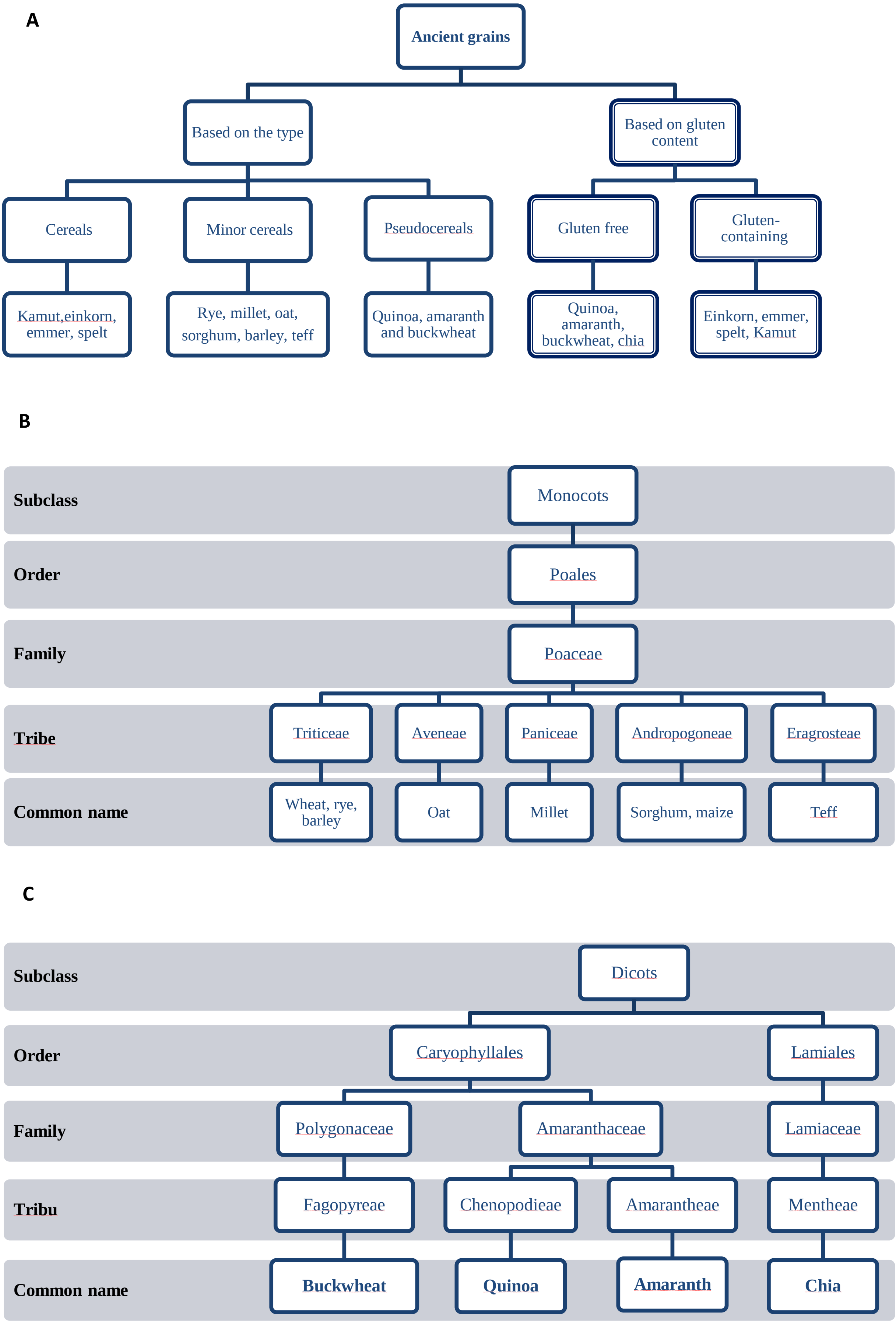
A
Ancient grains
Based on the type
Based on gluten content
Cereals
Minor cereals
Pseudocereals
Gluten free
Gluten-containing
Kamut,einkorn, emmer, spelt
Rye, millet, oat, sorghum, barley, teff
Quinoa, amaranth and buckwheat
Quinoa, amaranth, buckwheat, chia
Einkorn, emmer, spelt, Kamut
B
Subclass
Monocots
Order
Poales
Family
Poaceae
Tribe
Triticeae
Aveneae
Paniceae
Andropogoneae
Eragrosteae
Common name
Wheat, rye, barley
Oat
Millet
Sorghum, maize
Teff
C
Subclass
Dicots
Order
Caryophyllales
Lamiales
Family
Polygonaceae
Amaranthaceae
Lamiaceae
Tribu
Fagopyreae
Chenopodieae
Amarantheae
Mentheae
Common name
Buckwheat
Quinoa
Amaranth
Chia

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

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*. *Triticum urartu* (AA) and *Triticum boeoticum* (wild einkorn, AA), *Triticum turgidum* ssp. *dicoccoides* (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 20th 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.

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

Table 2: Gluten-containing grains.

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

Table 3: Gluten-free grains.

Common name	**Main species**	**Origin/History**	**References**
Buckwheat	The two major species are common buckwheat (sweet) (*Fagopyrum esculentum* Moench) and tartary buckwheat (*Fagopyrum tataricum* 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 *Amarilla de Marangani* and *Blanca de Junın*	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, *Amaranthus cruentus*, *A. hypochondriacus*, and *A. Caudatus* are the main cultivated amaranth species for grain, whereas *A. cruentus*, *A. blitum*, *A. dubius*, and *A. tricolor* are used as leafy vegetables	It was once a staple food of the Aztecs.	(Singh and Singh, 2011).
Chia	Three main species: *Salvia columbariae* Benth., *Salvia polytachya* Cavan., *and Salvia hispanica L.*.	It was found growing wild in Mexico.	(Verdú and others 2015).

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 B_6	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

Nr: Not reported

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

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 B_6	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

Nr. Not reported

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