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Re-discovering ancient wheat varieties as functional foods



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ABSTRACT

With the gluten-free food market worth almost \$1.6 bn in 2011, there is every reason for renewed interest in ancient grains. This resurgent interest is expressed in re-discovering ancient varieties as functional foods. In particular, people affected by celiac disease have to avoid all gluten in their diet and several ancient grains may offer an important alternative.

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1. Introduction

Ancient grains include chia, a forgotten food of the ancient Aztecs; quinoa which originated in the Andean region of Ecuador, Bolivia, Colombia and Peru; triticum (wheat), in the form of einkorn, known today as farro in Italy, as a type of awned wheat and one of the first crops domesticated in the Near East. Other grains, acknowledged as gluten-free ancient grains are amaranth, eaten in Mexico since the time of the Aztecs; quinoa, sorghum, millet; and teff, the main ingredient in the stable fermented flatbread, *injera*, in Ethiopia. A description of modern wheat is presented together with each one of the above mentioned grains.

1.1. Modern day wheat

The three main cash crop cereals in the world today are wheat, rice and maize. Wheat, (*Triticum* spp.), (Fig. 1) originating from the Levant region of the Near East and Ethiopian Highlands is now cultivated worldwide. The global leading ten wheat producing countries in 2013/2014 produced over 606 million metric tons of wheat. The European Union was the top ranked wheat producing country in that year. The grain has always provided an important

source of vegetable protein in human food. The grain was easily cultivated, particularly on a large scale and could be stored after harvest. This source of food enabled settlements to be established at the start of civilization as populations grew in the Babylonian and Assyrian empires known as the “Fertile Crescent”.

Wheat has the ability to self-pollinate and this attribute greatly facilitated the selection of many distinct domestic varieties. It was used to make flour for baked breads, and eventually its use spread to cakes, and in modern times to breakfast cereal, pasta, and noodles. Wheat is used in the fermentation process to make beer and other alcoholic beverages; and biofuel. Also, it provides food for domestic livestock. In England, thatching, using bundles of wheat was used for roofing in the Bronze Age and was in common use until the late 19th century.

1.2. Possible origins of ancient wheat

Archeological findings show that wheat first occurred in parts of Turkey, Lebanon, Syria, the Levant, Israel, Egypt and Ethiopia.¹ Domesticated Einkorn wheat in Turkey dates back to 9,000 B.C.² Evidence of the existence of wild barley (*Hordeum* sp) goes as far back as 23,000 B.C.³ Cultivation of wheat began to spread beyond the Fertile Crescent after about 8000 BC. Jared Diamond in his excellent book, “Guns Germs and Steel”,⁴ traces the spread of cultivated emmer wheat starting in the “Fertile Crescent” about 8500 BC, reaching Greece, Cyprus and India by 6500 BC, Egypt shortly thereafter, followed by introductions in Germany and Spain

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Fig. 1. Modern wheat.

by 5000 BC. The early Egyptians were developers of bread and with the use of oven technology, developed baking into one of the first large-scale food production industries. By 3000 BC, wheat had reached England, and Scandinavia. A millennium later it reached China. Recent findings of wheat grains in the Kunming area of Yunnan Province, China date the wheat at around 4000 BC. Wheat has spread successfully globally and is widely cultivated as a cash crop because it produces a good yield per unit area, grows well in a temperate climate in a moderately short growing season of about 120 days.

1.2.1. Crop domestication and germination

Cultivation and repeated harvesting and sowing of the grains of wild grasses led to the creation of domestic strains. Domesticated wheat has larger grains and the seeds (spikelets) remain attached to the ear by a toughened rachis during harvesting. In the case of wild strains, a more fragile rachis allows the ear to easily shatter

and disperse the spikelets. As the traits that improve wheat as a food source also involve the loss of the plant's natural seed dispersal mechanisms, highly domesticated strains of wheat cannot survive in the wild. A detailed re-evaluation of varieties of the wheat complex, particularly *Triticum* and *Aegilops* species was undertaken.⁵ In 1994, Cooper et al.⁶ screened species of wild wheats and barleys (Fig. 2) for the presence of their major flavonoid constituents. (Fig. 3) and germination inhibitors (Fig. 4). Two lignans were found as naturally occurring germination inhibitors of *Aegilops* species. The lignan named MEL I shown in Fig. 4 was synthesized⁷ using a biogenetic approach from well known precursors to lignans, the phenylpropanoids (ferulic acid and its reduced alcohol) as shown in Fig. 5.

Thirty eight species were examined and a common phenolic pattern emerged. Comparison of the wild species to the cultivated forms (*H. vulgare*, *T. monococcum*, *T. dicoccum*) showed a reduction in the total quantity of phenolics in the latter species. In 14 species of wild wheat of *Aegilops*, four species of *Triticum* and two species of *Hordeum*, a complex of rare phenolic compounds was found that showed there are quantitative differences (about 5% of the amount of these phenolic constituents) between the wild and domestic species. Importantly, it was shown that in these species of wild wheats the phenolic compounds, particularly the rare lignans, act as important germination regulators. Since these phenolics are water-dissolving germination inhibitors they may act as natural 'rain gauges'. This aspect is especially important for the germination of wheat and similar crops at the appropriate time in those species inhabiting arid regions or deserts – an attribute developed during the domestication of the wild species to the cultivated forms.⁸

1.3. Farming techniques

Although seed selection is important, improvement in wheat production is mainly due to technological advances. One of the first innovations occurred with the use of the horse and ox pulling the plows (~3000 BC). Use of seed drills was introduced by the 18th

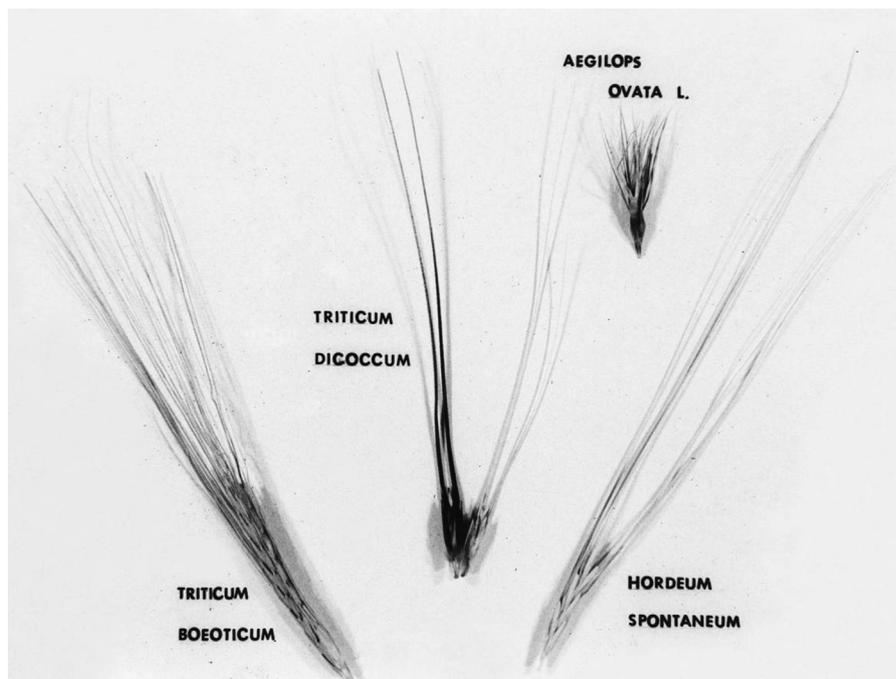


Fig. 2. Ancient varieties of wheat and barley.

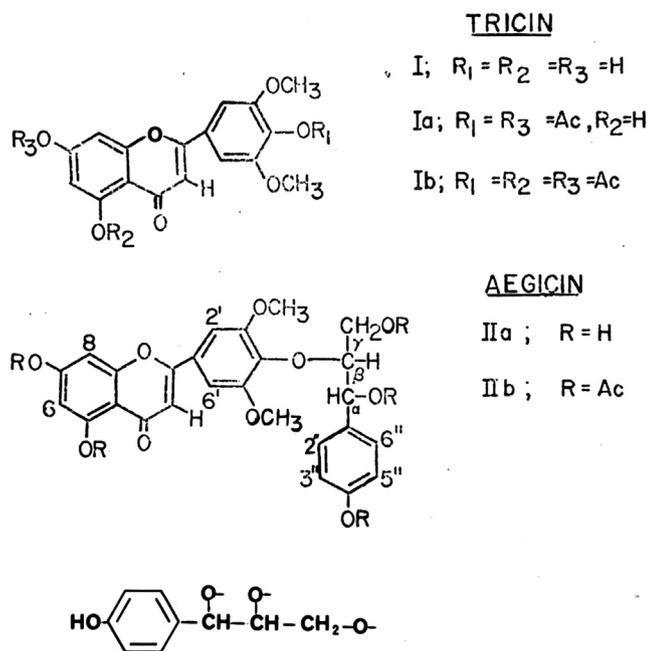


Fig. 3. Major flavonoids in *Triticum* and *Aegilops* species.

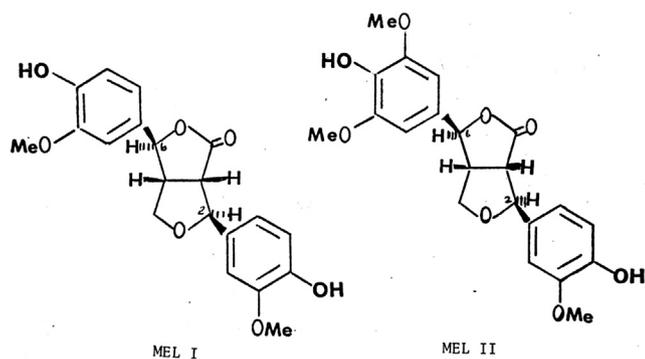


Fig. 4. Germination inhibitors found in ancient wheat.

century, followed by crop rotation to further improve productivity. In the Punjab region of India and Pakistan, as well as North China, irrigation has been a major contributor to increase grain output. Over the last 50 years, increases in both fertilizer and use of the semi-dwarf varieties in developing countries have greatly improved yields per hectare. Large expansions of wheat production occurred as new arable land was farmed in the Americas and Australia in the 19th and 20th centuries. Today, worldwide, the

addition of fertilizers, the 'combine harvester', and better commercial seed varieties all contribute to greater yields.

1.4. Major cultivated species of wheat

Common wheat, typically used in bread (*T. aestivum*, a hexaploid species) is the most widely cultivated species in the world. Durum wheat (*T. durum*, the only tetraploid form) is the second most widely cultivated wheat. Einkorn (*T. monococcum*, a diploid species) was domesticated at the same time as emmer wheat (*T. dicoccum*, a tetraploid species) but neither of these species is in widespread use. Spelt (*T. spelta*, a hexaploid species) is cultivated in limited quantities.

1.5. Wheat genetics

Some wheat species are diploid, with two sets of chromosomes, but many are stable polyploids, with four sets of chromosomes (tetraploid) or six (hexaploid). For example, einkorn wheat (*T. monococcum*) is diploid (AA, two complements of seven chromosomes, $2n = 14$).⁸ Most tetraploid wheats (e.g. emmer and durum wheat) are derived from wild emmer, *T. dicoccoides*. Wild emmer is itself the result of a hybridization between two diploid wild grasses, *T. urartu* and a wild goatgrass such as *Aegilops searsii* or *A. speltoides*. The unknown grass has never been identified among now surviving wild grasses, but the closest living relative is *A. speltoides*. The hybridization that formed wild emmer (AABB) occurred in the wild, long before domestication,⁹ and was driven by natural selection. Hexaploid wheats evolved in the farmers' fields. Either domesticated emmer or durum wheat, when hybridized with another form of wild diploid grass (*A. tauschii*) makes the hexaploid wheats, known as spelt wheat and bread wheat. These have three sets of paired chromosomes, three times as many as in diploid wheat.^{9,10}

Wild grasses in the genus *Triticum* and related genera, and grasses such as rye have been a source of many disease-resistance traits for cultivated wheat breeding since the 1930s. Synthetic hexaploids made by crossing the wild goatgrass wheat ancestor *A. tauschii* and various durum wheats are now being deployed, and these increase the genetic diversity of cultivated wheats.¹¹ In 2010, UK scientists decoded the wheat genome for the first time.¹² The gene rich regions of several chromosomes have been sequenced.^{13,14}

1.6. Nutritional importance of wheat and grinding

Wheat contains protein, fat, carbohydrate dietary fiber in the form of starch and iron. Wheat starch itself is considered an important commercial by-product of wheat, and second in economic value to the wheat gluten.

The whole grain can be milled to leave just the endosperm for white flour. The by-products of this process are bran and germ. The

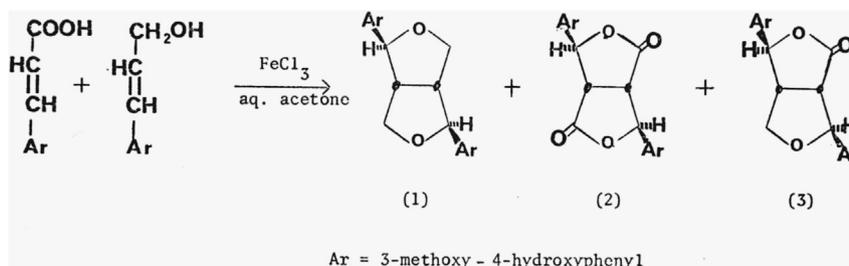


Fig. 5. One pot synthesis leading to the germination inhibitor.³

whole grain is a concentrated source of vitamins, minerals, and protein, while the refined grain is mostly starch. The four wild species of wheat, along with the domesticated varieties einkorn, emmer and spelt, have hulls. This more primitive morphology consists of toughened glumes that tightly enclose the grains and in the domesticated wheat varieties the semi-brittle rachis breaks easily on threshing. The result is that when threshed, the wheat ear breaks up into spikelets. To obtain the grain, further processing, such as milling or pounding, is needed to remove the hulls or husks. In contrast, in free-threshing forms such as durum wheat and common wheat, the glumes are fragile and the rachis tough. On threshing, the chaff breaks up, releasing the grains. Hulled wheats are often stored as spikelets because the toughened glumes give good protection against pests of stored grain.

Bread wheat protein content ranges from 10% in some soft wheat varieties with high starch content, to 15% in hard wheat varieties. However, the quality of the wheat protein is determined by the gluten that will indicate the suitability of wheat to a particular dish. Thus, “strong and elastic” gluten present in bread wheat enables dough to trap carbon dioxide during leavening, but “elastic” gluten also interferes with the rolling of pasta into thin sheets. The gluten protein in durum wheats used for pasta is strong but not elastic.

2. Cereal crops – ancient grains

The word *cereal* derives from *Ceres*, the name of the Roman goddess of harvest and agriculture. Cereals are grasses (monocot Poaceae, also known as Gramineae) cultivated for the edible components of their grain (botanically, a type of fruit called a caryopsis), composed of the endosperm, germ, and bran. Cereal grains are grown in greater quantities and provide more food energy worldwide than any other type of crop they are therefore staple crops.

In their natural form (as in *whole grain*), they are a rich source of vitamins, minerals, carbohydrates, fats, oils, and protein. However, when refined by the removal of the bran and germ, the remaining endosperm is mostly carbohydrate and lacks the majority of the other nutrients. In some developing nations, grain in the form of rice, wheat, millet, or maize constitutes a majority of daily sustenance. In developed nations, cereal consumption is moderate and varied but still substantial.

The first cereal grains were domesticated about 12,000 years ago by ancient farming communities in the Fertile Crescent region. Emmer wheat, einkorn wheat, and barley were three of the so-called Neolithic founder crops in the development of agriculture. Maize, wheat and rice together accounted for 87% of all grain production worldwide. Other grains that are important in some places, but have little production globally include teff, popular in Ethiopia yet scarcely known elsewhere. This ancient grain is a staple in Ethiopia. It is high in fiber and protein. Its flour is often used to make injera. It can also be eaten as a warm breakfast cereal similar to farina with a chocolate or nutty flavor. Its flour and whole grain products can usually be found in natural foods stores.

While each individual species has its own peculiarities, the cultivation of all cereal crops is similar. Most are annual plants; consequently one planting yields one harvest. Wheat, rye, triticale, oats, barley, and spelt are the “cool-season” cereals. These are hardy plants that grow well in moderate weather and cease to grow in hot weather (approximately 30 °C). The “warm-season” cereals are tender and prefer hot weather. Barley and rye are the hardiest cereals, able to overwinter in the subarctic and Siberia. Many cool-season cereals are grown in the tropics. However, some are only grown in cooler highlands, where it may be possible to grow multiple crops in a year. The warm-season cereals are grown in tropical lowlands year-round and in temperate

climates during the frost-free season. Rice is commonly grown in flooded fields, though some strains are grown on dry land. Other warm climate cereals, such as sorghum, are adapted to arid conditions.

Emmer wheat (*Triticum dicoccum*) also known as farro especially in Italy, is a type of awned wheat. It was one of the first crops domesticated in the Near East. It was widely cultivated in the ancient world, but is now a relict crop in mountainous regions of Europe and Asia.

Emmer's main use is as a human food, though it is also used for animal feed. Ethnographic evidence from Turkey and other emmer-growing areas suggests that emmer makes good bread and this is supported by evidence of its widespread consumption as bread in ancient Egypt. Today, emmer bread is available in Switzerland and in Italy, emmer bread (pane di farro) can be found in bakeries in some areas. Higher in fiber than common wheat, emmer's use is for making pasta. Emmer has also been used in beer production and an example is the Riedenburger eco-brewery in Bavaria, Germany which currently makes Emmerbier. As with most varieties of wheat, however, emmer is probably unsuitable for sufferers from wheat allergies or celiac disease.¹⁵

Strong similarities in morphology and genetics show that wild emmer (*Triticum dicoccoides* Koern.) is the wild ancestor and a crop wild relative of domesticated emmer (*Triticum dicoccum*). Because wild and domesticated emmer are interfertile with other tetraploid wheats, some taxonomists consider all tetraploid wheats to belong to one species, *T. turgidum*. Under this scheme, the two forms are recognized at subspecies level, thus *T. turgidum* subsp. *dicoccoides* and *T. turgidum* subsp. *dicoccom*. Wild emmer (*T. dicoccoides*) grows wild in the fertile crescent of the Near East. It is a tetraploid wheat formed by the hybridization of two diploid wild grasses, *Triticum urartu* (closely related to wild einkorn (*T. boeoticum*), and as yet unidentified *Aegilops* species related to *A. searsii* or *A. speltoides*).

Einkorn wheat (from German Einkorn, literally “single grain”) can refer either to the wild species of wheat, *Triticum boeoticum* or to the domesticated form, *Triticum monococcum*. The wild and domesticated forms are either considered separate species, as here, or as subspecies of *T. monococcum*. Einkorn is a diploid species of hulled wheat, with tough glumes (‘husks’) that tightly enclose the grains. The cultivated form is similar to the wild, except that the ear stays intact when ripe and the seeds are larger.

Einkorn wheat was one of the earliest cultivated forms of wheat, alongside emmer wheat (*T. dicoccum*). Grains of wild einkorn have been found in Epi-Paleolithic sites of the Fertile Crescent. It was first domesticated approximately 7500 BC. Evidence from DNA fingerprinting suggests einkorn was domesticated near in southeast Turkey. Its cultivation decreased in the Bronze Age, and today it is a relict crop that is rarely planted, though it has found a new market as a health food. It remains as a local crop, often for bulgur (cracked wheat) or as animal feed, in mountainous areas of France, Morocco, the former Yugoslavia, Turkey and other countries. It often survives on poor soils where other species of wheat fail.

Chia—a forgotten food of the ancient Aztecs, this grain provides the richest vegetable source of omega-3 fatty acids, it is now being domesticated for the first time in modern history to supply sufficient quantities for world demand. Chia, literally means “oily” is an annual herb which originated in Mexico and was cultivated by the Aztecs. It is grown commercially in regions of Central and South America. The seed is an abundant source of omega-3 fatty acids and provides a valuable source of vegetable omega-3 content.

The applicable parts of chia *Salvia hispanica* (Family: Lamiaceae) are the seed and the sprout. The seed contains, together with the omega-3 fatty acid, alpha-linolenic acid, significant concentrations of dietary fiber, protein, calcium, magnesium, iron, and antioxidants.

Scientific reports continue to increase on how omega-3 fatty acids are important for human health. The richest dietary sources of omega-3 fatty acids are from fish. However, eating large amounts of fish has been linked with intakes of mercury (and possibly other pollutants, such as PCBs), but the lack of omega-3s could lead to a number of adverse health conditions, including heart disease, cancer, and cognitive defects.

Due to its fatty acid and dietary fiber content, there is interest in using chia as a food source for reducing cardiovascular risk factors including diabetes, hypertension, and inflammation. Preliminary clinical research shows that consuming bread containing chia might reduce some cardiovascular risk factors such as systolic blood pressure, C-reactive protein, von Willebrand factor; yet, chia does not seem to affect lipid levels.

Quinoa – Another ancient and overlooked grain, quinoa *Chenopodium quinoa* originated in the Andean region of Ecuador, Bolivia, Colombia and Peru, where it was successfully domesticated 3,000 to 4,000 years ago for human consumption. The Incas, who held the crop to be sacred, referred to quinoa as *chisaya mama* or ‘mother of all grains’, and it was the Inca emperor who would traditionally sow the first seeds of the season using ‘golden implements’. During the European conquest of South America, the Spanish colonists scorned quinoa as ‘food for Indians’, and even actively suppressed its cultivation. The name is derived from the Spanish spelling of the Quechua name *kinwa*.

The seeds of quinoa contain the bitter-tasting saponins.^{16–18} Therefore, after harvest the commercial grains are processed to remove this coating and are generally cooked the same way as rice. The bitter taste may deter predators such as birds from eating the grains during cultivation. The saponin is a toxic glycoside, a main contributor to hemolytic effects in blood cells. In South America, the saponins derived from quinoa have many uses: clothing detergent and antiseptic for skin injuries. It should be noted that high levels of oxalic acid are found in the leaves and stems of all species of the *Chenopodium* genus. However, if properly prepared and if eaten in moderation, risks of toxicity are minimal.

Quinoa is a grain-like crop grown primarily for its edible seeds. It is a pseudo cereal rather than a true cereal, or grain, as it is not a member of the grass family. Quinoa is closely related to species such as beets, spinach, and tumbleweeds. Quinoa originated in the Andean region of Ecuador, Bolivia, Colombia and Peru where it was successfully domesticated 3,000 to 4,000 years ago for human consumption, though archeological evidence shows a non-domesticated association ~5,200 to 7,000 years ago.¹⁹

The nutrient composition is very good compared with common cereals. Quinoa grains contain essential amino acids like lysine and good quantities of calcium, phosphorus, and iron²⁰. Quinoa was of great nutritional importance in pre-Columbian Andean civilizations, secondary only to the potato, and was followed in importance by maize. In contemporary times, this crop has become highly appreciated for its nutritional value, as its protein content is very high (18%). Unlike wheat or rice (which are low in lysine), and like oats, quinoa contains a balanced set of essential amino acids for humans, making it a complete protein source. It is a good source of dietary fiber and phosphorus and is high in magnesium and iron. Quinoa is gluten-free and considered easy to digest. Because of all these characteristics, quinoa is being considered a possible crop in NASA's Controlled Ecological Life Support System for long-duration human occupied spaceflights.²¹

Kamut has been claimed to reduce the risk of chronic diseases related to whole grain consumption, in part to its high antioxidant content, which may protect against oxidative stress. Research showed that animals fed on the kamut wheat breads had a better response to oxidative stress than modern wheat²². Phase one of the

antioxidant evaluation compared the antioxidant effect of two different bread types in rats: whole grain ancient Kamut khorasan bread and whole grain modern durum wheat bread (WB). After feeding these different breads to rats for seven weeks, the rats were submitted to an exogenous oxidative stress. The researchers claim that rats fed with Kamut breads were better able to overcome the induced stress than those fed the modern durum bread and that those fed the sourdough (SKB) fared best of all. Two different bread-making processes were also compared for the whole grain ancient Kamut bread: baker's yeast (KB) and SKB. According to the researchers, the concentration of all potential antioxidant compounds was different in the three experimental breads. Total polyphenols and in particular selenium, were significantly higher in the two types of Kamut bread than WB.

In their study, the contents of vitamin E and beta-carotene were in lower concentrations in KB compared to WB, but both compounds were increased in the SKB by the sourdough fermentation.

2.1. Gluten sensitivity

Wheat protein (and the wheat starch) is easily digested by nearly 99% of the human population. However, several screening studies in Europe, South America, Australasia, and the USA suggest that approximately 0.5–1% of these populations may have undetected celiac disease.^{23–25} Celiac disease is a condition that is caused by an adverse immune system reaction to gliadin, a gluten protein found in wheat and some varieties of barley and rye. When exposed to gliadin, the enzyme tissue transglutaminase modifies the protein, and the immune system cross-reacts with the bowel tissue, causing an inflammatory reaction. This interaction leads to “flattening of the lining” of the small intestine leading to interference with nutrient absorption. The only effective treatment is a lifelong gluten-free diet. While the disease is caused by a reaction to wheat proteins, it is not the same as wheat allergy.

2.2. Gluten toxicity

In contrast with more modern forms of wheat,²⁶ there is evidence that the gliadin protein of einkorn may not be as toxic to sufferers of celiac disease. It has yet to be recommended in any gluten-free diet. Einkorn wheat does contain gluten but is different from most wheat in that it contains only 14 chromosomes as opposed to 28 in emmer or 42 in modern wheat. This alters the gluten structure which may be why it does not affect those with gluten intolerance as much as other wheat.

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