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Technical Characteristics and Nutritional Values of Einkorn Wheat: A Literature Review

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A B S T R A C T

The first domestic wheat variety to be monocot diploid is einkorn wheat. A comprehensive evaluation of einkorn wheat's quality reveals that, in comparison to other polyploid wheat, this ancient wheat offers several dietary benefits. Einkorn wheat-based meals are high in protein, lipids (mostly polyunsaturated fatty acids), fructans, and trace minerals such as iron and zinc, but low in fiber. In terms of nutritional value, einkorn wheat has significantly better nutritional qualities due to its proper concentration of various antioxidant compounds, including carotenoids, tocols (lipid-soluble constituents consisting of tocopherols and tocotrienols), conjugated polyphenols, alkyl resorcinols, and phytosterols, as well as its low beta-amylase and lipoxygenase activity, which reduces the degradation of antioxidants during food processing. Conversely, einkorn wheat exhibits a higher polyphenol oxidase activity and comparatively lower levels of polyphenol, although these characteristics result in fewer adverse effects when compared to other varieties of wheat. However, it should be noted that einkorn wheat is unsuitable for individuals with celiac disease. The current movement in consumer preferences for functional meals suggests that wheat may still be useful for human consumption, particularly in the development of novel, high-quality food products, and specialty items.

1. Introduction

Wheat was originally planted approximately 10,000 years ago during the Neolithic Revolution when food supplies shifted from hunting and gathering to sustainable cultivation (Venske et al., 2019). The most important types of ancient wheat varieties are spelt, einkorn, emmer, and kamut (Shewry & Hey, 2015). The early crops included einkorn and emmer wheat, which are diploid (containing two sets of chromosomes) and tetraploid (having four times the usual amount of chromosomes) species, respectively. Both species are thought to have originated in the southeastern region of Turkey, with emmer resulting from spontaneous genetic hybridization between einkorn wheat and similar wild plant species. Modern durum (pasta) wheat is a developed variant of the wild emmer race, and both emmer and durum varieties are considered forms of the same species "*Triticum (T.) turgidum*". Unlike einkorn and emmer wheat, bread

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wheat was developed by crossing emmer with "*Triticum tauschii"* around 9000 years ago. Bread wheat is a hexaploid species having three genomes, each with seven chromosome pairs (Shewry, 2018). By incorporating available ancient wheat species into our food products, we may be able to achieve a holistic and sustainable method of increasing the biodiversity of cultivated cereals. Moreover, such incorporation enriches our food diversity through cereals rich in valuable nutrients. Ancient wheat genotype groups, in particular, stand out for their significant mineral content, with notably high levels of Zn and Fe (Johansson et al., 2021; Longin & Würschum, 2016). For example, spelt wheat (*Triticum spelta*), an ancient wheat variety, may have higher protein, soluble dietary fiber, and minerals than typical bread wheat (*Triticum aestivum*). Einkorn, emmer, and spelt have considerably greater crude lipid contents than whole wheat flour derived from hard red spring wheat (Kulathunga et al., 2021). Einkorn wheat, also known as monocot wheat, comprises three wild types: *T. urartum*, *T. boeoticum*, and *T. monococcum*. *T. monococcum* is the first domestic diploid wheat, having developed from *T. boeoticum*. einkorn wheat (*T. monococcum* L. subsp. *monococcum*), a near cousin of durum wheat (*T. turgidum*) and bread wheat (*T. aestivum*), is a hulled domesticated diploid wheat that existed in the Karasada area of Turkey approximately 10,000 years ago. Einkorn wheat, along with barley and emmer wheat, played a pivotal role in the advent of agriculture and then spread to Europe during the Neolithic Revolution. According to analyses of the contents of Utzi's big intestine (the frozen body of a Copper Age man discovered in the Alp mountains in 1991) and archeological remnants, it was a staple diet for European farmers for several millennia. While its wild type, *T. monococcum* ssp. *boeoticum*, is still grown in the central and eastern parts of the Fertile Crescent (the historical part of the Middle East and including the eastern Mediterranean Sea, Mesopotamia, and ancient Egypt), the traditional crops of natural einkorn wheat can currently be found in Mediterranean marginal areas, Turkey, the Balkan countries, southern Italy, southern France, Spain, Morocco and certain parts of Middle East (Figure 1) (Hidalgo & Brandolini, 2019). The findings of research by Pourabughadareh et al. (2016) demonstrated that the range of wild varieties of einkorn gathered from various regions in Iran has significant implications for genetic diversity. The provinces of Kermanshah and Lorestan were identified as suitable geographic locations for genetic variety (Pourabughadareh et al., 2016). In terms of seed characteristics, the average weight of einkorn seeds is between 25 and 28 g per thousand seeds. Seed size plays a crucial role in various compositional and qualitative traits due to the higher proportion of starchy endosperm and reduced outer pericarp and aleurone layers in larger and heavier seeds. Notably, einkorn wheat germ contains a slightly higher percentage of total seed weight (2.9%) compared to bread wheat (1.3%). However, significant distinctions were observed in the proportions of endosperm (74 vs.81%) and bran (22.9 vs. 16%). The distribution of nutrients also differs greatly across the kernel. Bran contains significant levels of protein, minerals, enzymes, and some antioxidants such as phenolics and tocotrienols. Protein, lipids, enzymes, and tocopherol are abundant in the root. The starchy endosperm contains proteins, gliadins, glutenins, and carbohydrates (Hidalgo & Brandolini, 2014).

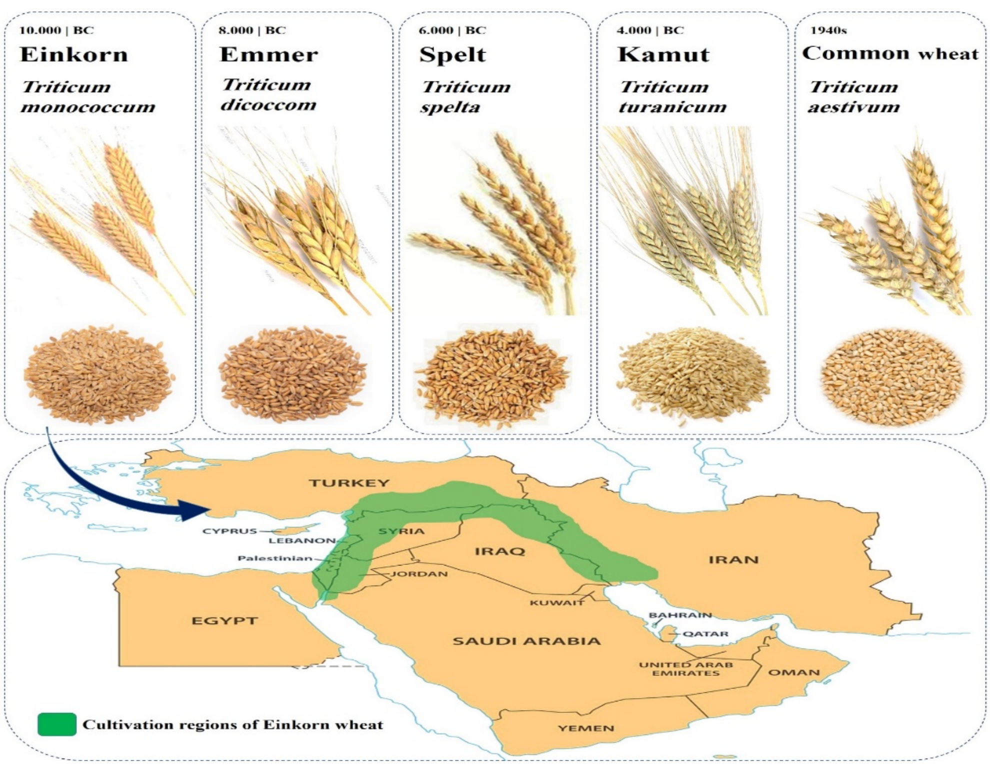

Figure 1. Domestication of einkorn wheat within the Fertile Crescent and its natural spread in the Middle East

2. Discussion

2.1 Nutritional characteristics

2.1.1 Dietary fiber and starch

The starchy endosperm makes up most of the einkorn wheat. It consists of two types of polymers: branching amylopectin and linear amylose. Grain sizes of starch vary, and they are organized into semi-crystalline particles. einkorn wheat has type A granules (12-24 mm in diameter) that develop shortly after blooming, along with smaller type B granules (5 mm) that appear a few days after peaking. The majority of the bulk of starch is made up of type A granule, which are smaller in quantity than type B granules. The type A granules of einkorn wheat are smaller than those of bread wheat (common wheat or *Triticum aestivum*), measuring 13/2 mm in diameter. Additionally, this difference in granule size affects flour qualities such as solubility, susceptibility to enzymes, pastiness, swelling, and gelatinization (Morrison & Gadan, 1987; Stoddard, 1999). Einkorn wheat contains fructans, which are small carbohydrates with, a prebiotic effect. These carbohydrate chains selectively promote the growth of beneficial bacteria that live in the colon, contributing to its prebiotic properties. (Brandolini et al., 2011).

2.1.2 Protein

Einkorn wheat kernels have more protein (18 g per 100 g of dry matter on average) than bread wheat. Endosperm is another rich source of protein (Brandolini et al., 2008; Corbellini et al., 1999). According to Table 1, the protein of einkorn wheat was higher compared to other wheat types such as durum (13.68 g/100 g), kamut (14.54 g/100 g), spelt (14.57 g/100 g), emmer (12.5 g/100 g).

2.1.3 Fats

Einkorn wheat has 50% more lipids than bread wheat. Thus, einkorn wheat has higher levels of monounsaturated fatty acids (MUFAs), lower levels of polyunsaturated fatty acids (PUFAs), and higher levels of saturated fatty acids (SFAs) than wheat bread (Hidalgo et al., 2009). The analysis of the fatty acid content of einkorn wheat reveals up to 14 different compositions. Linoleic, oleic, and palmitic acids are the most fatty acid composition which contained 50.9-54.0%, 24.8-26.4%, and 13.9-16.7% of einkorn wheat, respectively (Suchowilska et al., 2009). Compared to common wheat, einkorn wheat has more MUFAs, fewer PUFAs, and fewer SFAs. High amounts of MUFAs and PUFAs in diets, together with low SFAs content, aid in the prevention of cardiovascular illnesses. MUFAs and PUFAs impact fat and cholesterol production, which helps to reduce atherosclerosis and thrombosis. Furthermore, high MUFA and low PUFA levels lead to greater resistance to oxidation and extended shelf life of food (Hidalgo et al., 2009). According to the study, the germ of einkorn wheat kernels has the greatest fat content-more than 28% fat (Hoseney, 1994).

2.1.4 Antioxidants, vitamins, and microminerals

Vitamins are organic compounds that organisms need in small quantities. Per gram of dry matter, there are 429-678 nanograms of folate, a water-soluble form of vitamin B9 that guards against neural tube abnormalities in the developing fetus (Piironen et al., 2008). Einkorn wheat has a considerably greater carotenoids-per-meal density than polyploid wheat samples. Studies have indicated that lutein accounts for more than 90% of the yellow pigment present in all types of einkorn wheat. Lutein is the most prevalent carotenoid, found in the bud, endosperm (3.6 mg/kg), and bran (4.3 mg/kg) of einkorn wheat (Corbellini et al., 1999). Therefore, the carotenoid density of einkorn wheat is 4-8 times higher than that of bread wheat and twice that of durum wheat, and the yellow color of semolina and pasta prepared from it is considered an essential attribute (Borghi et al., 1996). Tocols (vitamin E) are composed of four kinds of tocopherols and tocotrienols: α, β, γ, and δ. They protect against long-term harm such as inflammatory illnesses, cancer, cataracts, and neurological and cardiovascular disorders. Tocotrienols are present in the bran, whereas tocopherols are mostly found in the germ. It has been demonstrated that applying steam helps tocotrienols from the bran relocate into the endosperm (Becker, 2013). Compared to bread and durum wheat, einkorn wheat has a greater total tocol content, with a maximum density of 115.85 mg/kg of dry matter and an average density of 77.96 mg/kg. Beta-tocotrienol makes up about 61.9% of the total chemical content of einkorn wheat type *T. monococcum*, making it the most common component. The next most prevalent molecules are beta-tocopherol (6.1%), alpha-tocotrienol (16.4%), and alpha-tocopherol (15.6%). Only sprouts contain tocopherols, although flour, sprouts, and the bran fraction all contain significant levels of tocotrienols (Hidalgo & Brandolini, 2019; Lachman et al., 2013). Previously, Hidalgo *et al.* (2006) looked at the tocol content, carotenoids, and nutritional characteristics of einkorn wheat. The results demonstrated that carotenoids, especially lutein, were 2-4 times greater than in other wheat, with an average of 8.41 mg/g dry matter. The most common kind of tocol was beta-tocotrienol, which was followed by alpha-tocotrienol, beta-tocopherol, and alpha-tocopherol. On average, the ratio of tocotrienol to tocopherol was 68.3 mg/g (Hidalgo et al., 2006). Plant metabolites known as polyphenols (phenolic acids, flavonoids, alkyl resorcinols, etc.) are mostly found in the outer layers of seed kernels and are vital for both plant growth and reproduction as well as defense against plant diseases. They offer protection to people against oxidative damage illnesses including cancer, stroke, and heart disease. While folic acid content and free polyphenol content in einkorn and bread wheat are similar, *T. monococcum* has a larger concentration of conjugated phenolic acids and a lower quantity of bound phenolic acids. Alkyl resorcinols are compounds with biological membrane-affecting properties and antibacterial activity that are found in higher concentrations in whole einkorn wheat flours (595 mg/kg) compared to bread and durum wheat (Andersson et al., 2008;

Hidalgo & Brandolini, 2019; Quiñones et al., 2013). The antioxidant properties and total phenolic content of the einkorn wheat and barley samples, as well as their malt extracts, were shown to exhibit noteworthy antioxidant activity across all samples, according to a study conducted by Fogarasi *et al.* (2015) The polyphenol level of the einkorn wheat samples was greater than that of the other samples and bread wheat. Single-grain wheat malt extract exhibited stronger free radical inhibitory effects but a lower phenolic content when compared to wheat samples (Fogarasi et al., 2015). Anti-inflammatory, anti-allergenic, and antioxidant characteristics are possessed by phytosterols (Bakrim et al., 2022). Additionally, phytosterols bind to cholesterol and bile acids and decrease total and low-density lipoprotein (LDL.C). The platform period can be achieved by consuming 3g of phytosterols per day, and this dose can reduce LDL cholesterol by approximately 10.7% (Li et al., 2022). Cancers of the breast, colon, prostate, and other organs may also be prevented by it. Because phytosterols physically bind to carcinogens, they have an anticarcinogenic effect (Jones & Abumweis, 2009). With an average phytosterol density of 1054 mg/kg-25% more than winter wheat-einkorn wheat, a type of Triticum, has the greatest phytosterol density. Sitosterol is the primary phytosterol in *T. monococcum* species, with total stanols, campesterol, and other substances coming in second and third. Compared to bran flour prepared from bread wheat, einkorn wheat has a greater degree of antioxidant content, making it more efficient in inhibiting free radicals (Nurmi et al., 2008; Nyström et al., 2007). *T. monococcum* has higher micronutrient concentrations than *T. estivum*, including iron (45.9-52 mg/kg, respectively), zinc (53-72 mg/kg), manganese (28-46 mg/kg), copper (9 mg/kg), strontium (5.4 mg/kg), molybdenum (1.2 mg/kg), magnesium (1.5-1.6 g/kg), phosphorus (5.2-5.4g/kg), and selenium (50.0-54.8 μg/kg) (Erba et al., 2011; Suchowilska et al., 2012). Table 1 presents some of the composition of macro and micronutrients of einkorn compared to other types of wheat.

2.1.5 Enzyme activities

A range of enzymes, including lipases, oxidases, proteases, and amylases, are active during food processing and can be found in whole-meal flour. Among these enzymes, beta-and alpha-amylases catalyze the breakdown of starch. Compared to *T. turgidum* and *T. estivaum*, whole einkorn wheat flour has reduced alpha-amylase activity. The higher activity of beta-amylase, resulting from the synthesis of high maltose during the mixing stage, contributes to severe heat damage (Maillard reaction) in baked products, consequently impacting the quality of the final product (Hidalgo & Brandolini, 2019; Hidalgo et al., 2013). PUFAs, mainly linoleic and linolenic acids, are oxidized to fatty acid radicals by the lipoxygenase enzyme. Carotenoids and tocols are two antioxidants that are oxidatively degraded by these radicals. Consequently, the increased lipoxygenase activity lowers the nutritional value of the finished goods. Einkorn wheat has a lower lipoxygenase activity (0.12-0.91 micromol/min g dry matter) than durum and bread wheat (Leenhardt et al., 2006). Polyphenol oxidases facilitate the transformation of monophenols into o-diphenols and o-diphenols into o-quinones. Polymerization and the creation of dark products are the outcomes of these interactions between amines and thiol groups, or it is the catalyst that breaks down and turns polyphenols brown. While *T. turgidum* and *T. estivum* species have lower levels of polyphenol oxidase, whole einkorn wheat flour from *T. monoccocom* species shows greater levels (Okot-Kotber et al., 2002).

Table 1. Comparison of the nutritional composition of einkorn with other types of wheat

Per 100 g	Einkorn	Durum	Kamut	Spelt	Emmer
Energy (kj)	380	339	337	338	381
Water (g)	13.8	10.94	11.07	11.02	11
Protein (g)	18.2	13.68	14.54	14.57	12.5
Protein digestibility (g)	86.2	86.8	86.7	86.6	-
Fat (g)	2.48	2.47	2.13	2.43	2.40
Fiber (g)	8.7	9.8	11.10	10.70	2.7
Carbohydrate (g)	72	71.13	70.58	70.19	71
Vitamins					
Vitamin B1 (mg)	0.5	0.42	0.57	0.36	0.36
Vitamin B2 (mg)	0.45	0.12	0.18	0.11	0.113
Vitamin B3 (mg)	3.1	6.74	6.38	6.84	5.8
Vitamin B5 (mg)	-	0.94	0.95	1.07	1.19
Vitamin B6 (mg)	0.49	0.42	0.26	0.23	0.23
Vitamin B9 (mg)	-	43	-	45	45
β-carotene (μg)	19	-	5	5	-
β-Tocopherol (mg)	-	-	0.14	0.25	2.40
γ-Tocopherol (mg)	-	-	1.08	1.71	-
Lutein and Zeaxanthin (μg)	769	-	301	169	414
Vitamin A (IU)	312	-	10	10	-
Vitamin K (μg)	-	-	1.80	3.6	-
Amino acid (AA) profiles					
Lysine (g)	1.9	2.4	2.3	2.2	1.8
Threonine (g)	2.6	3.0	2.9	2.9	5.5
Methionine (g)	1.4	1.5	1.5	1.8	0.8
Cystine (g)	2.2	2.1	2.3	2.3	3.3
Tryptophan (g)	1.3	1.3	1.2	1.3	1.30
Isoleucine (g)	2.9	2.6	2.5	2.6	4.8
Leucine (g)	6.6	7.0	7.1	6.8	0.8
Valine (g)	3.7	4.4	4.2	3.9	3.7
Phenylalanine (g)	5.0	4.4	4.5	5.1	1.5
Tyrosine (g)	2.5	2.9	2.7	2.6	8.3
Histidine (g)	2.1	2.3	2.2	2.3	0.7
Alanine (g)	2.8	3.2	3.1	2.9	4.0
Arginine (g)	3.9	4.3	4.3	4.1	10.8
Aspartic acid (g)	4.7	4.6	4.6	4.6	1.9
Glutamic acid (g)	37.0	33.7	34.8	34.9	0.8
Glycine (g)	3.1	3.6	3.5	3.7	2.3
Proline (g)	8.7	8.7	8.8	8.9	8.7
Serine (g)	4.2	4.3	4.4	4.4	0.8
Total essential AA (g)	31.6	33.9	33.7	33.8	39
Total AA (g)	96.0	96.3	97.2	97.3	-
Minerals					
Iron (mg)	4.59	3.52	3.77	4.44	4.7
Magnesium (mg)	-	144	130	136	136
Phosphorus (mg)	415	508	364	401	360
Sodium (mg)	-	2	5	8	12
Copper (mg)	-	0.55	0.51	0.51	4.1
Manganese (mg)	4.4	3.01	2.74	2.98	1.67
Calcium (mg)	41	34	22	27	38
Potassium (mg)	390	431	403	388	338
Zinc (mg)	2.24	4.16	3.68	3.28	3.28
Selenium (mg)	27.89	89.40	81.50	11.70	11.70

Data collection from: (Abdel-All et al., 1995; Akar et al., 2019; Arzani, 2019; Brandolini et al., 2008; Jiang et al., 2008; Petkova et al., 2019; USDA, 2009; Zhao et al., 2009)

2.1.6 Gluten content

It is commonly recognized that wheat gluten proteins play a role in the development of certain diseases. Gliadin, one of the short peptide chains included in wheat gluten proteins, as well as similar proteins found in barley and rye, is specifically implicated in the onset of celiac disease. These proteins, known as celiac epitopes or determining antigens, have been found to have similar effects on T cells, and immune system cells when gliadins from bread and einkorn wheat are broken down in the digestive system. However, these gliadins lose some of their immune-stimulating properties when further broken down by digestive system enzymes (Shewry, 2018). In a study, to determine the amount of gluten protein (gliadins and glutenins) in spelt, durum wheat, emmer, and einkorn, the spectrophotometric Bradford test was modified. In all four locations, emmer, spelt, and einkorn wheat had higher gluten and protein values than ordinary wheat. The ratios of gliadins to glutenins increased from common wheat (< 3.8) to spelt, emmer, and einkorn (up to 12.1), while common wheat had greater glutenin levels than einkorn, emmer, and spelt (Geisslitz et al., 2019). Nevertheless, einkorn being one of the well-researched diploid wheat, demonstrates a lower immunological response in celiac disease patients compared to other wheat species. However, it is not considered safe for celiac patients (Picascia et al., 2020).

2.2 Technological feature

Compared to bread prepared with *Turgidum* or *Testivum* kinds, bread made with *T. monoccocum* (einkorn) whole-wheat flour has a unique appearance, including a yellow crust and a pleasant and robust taste. While certain einkorn genotypes are more suitable for making bread, all variants are better than those used for cookies and pastries. Compared to bread wheat, einkorn wheat flour has a higher gliadin/glutenin ratio and less high molecular weight gluten. Moreover, einkorn wheat has a higher amylograph viscosity rating than other wheat varieties. Einkorn wheat has a greater peak and ultimate viscosity than *T. turgidum* and *T. estivum*. This is probably because the einkorn starch granules are smaller and graded differently (Hidalgo & Brandolini, 2019). La Gatta *et al.* (2017) examined the impact of using einkorn wheat flour instead of regular flour on the protein density of pasta. Throughout the trial, pasta was prepared using semolina flour and progressively more wheat flour (in percentages of 30%, 50%, and 100%). Incorporating einkorn wheat flour and durum wheat semolina flour strengthened the polymer structure of proteins during pasta production. Even though einkorn wheat flour has less gluten protein than semolina flour, pasta prepared with a 50/50 mix of the two flours showed increased density (La Gatta et al., 2017). Additionally, Brandolini *et al.* (2018) conducted a study on the quality of einkorn wheat dough to assess its compatibility with pasta production as well as the quality of the final products. There were several differences between durum and einkorn wheat pasta regarding carotenoid concentration, size, color, and image analysis characteristics.

Because of its significantly softer texture-likely due to the besser structure of the einkorn wheat gluten matrix-pasta produced with einkorn wheat flour cooked faster. While durum wheat pasta was inferior to einkorn wheat pasta nutritionally, both types were technologically equivalent (Brandolini et al., 2018). In a separate study, Løje *et al.* (2003) examined the chemical composition, functional traits, and sensory qualities of einkorn wheat. Peeled einkorn wheat samples showed several shared properties, including small grains, a very soft endosperm texture, high ash content, variable protein content, and low beta-glucan content. Einkorn wheat contained lower total dietary fiber overall than normal wheat. There were considerable differences in the amount of lysine (1.5-3.15 g per 100 g of protein) in certain samples. Most einkorn wheat samples showed high falling numbers (average 362 seconds) and high amylograph viscosity (average 1185 BU). Cooked einkorn wheat demonstrated sensory profiles comparable to other types of wheat samples, except for a softer consistency, poorer nutritional value, stickiness, and lower fiber content. Because of its high gelatinization viscosity, high protein content, low dietary fiber content, acceptable consistency, and pleasant flavor, the results showed that cooked einkorn wheat could be utilized as a food supplement or rice alternative (Løje et al., 2003). In an Egyptian study, kamut couscous (a dish made from organic wholegrain kamut brand Khorasan wheat) was highly rated by participants, describing it as savory, buttery, crispy, and delicious with many taste benefits (Abdel-Haleem et al., 2012). Kamut is used in a variety of foods, including cereals, breads, cookies, snacks, pancakes, bread mixes, bulgur, pasta, and baked goods (Brester et al., 2009). Evaluations of bread made from blends of ancient grains such as kamut and spelt revealed organoleptic and physical properties similar to those made from regular wheat flour. Therefore, incorporating ancient wheat varieties into bread mixes offers numerous nutritional and sensory advantages (Angioloni & Collar, 2011). For the first time, Hendek Ertop (2019) investigated how the bulgur manufacturing procedure affected durum and einkorn wheat. Scanning electron microscopy was employed to identify microstructural variations between einkorn and durum wheat. Einkorn wheat bulgur seeds were larger than those of durum bulgur. While the physicochemical properties were affected by the kind of wheat, the procedure for making einkorn wheat bulgur was not affected. Furthermore, the microstructural appearance of einkorn wheat bulgur samples was influenced by the cooking technique, resulting in a deeper and more brown appearance than durum wheat. Higher amounts of fat and ash were also present in einkorn wheat bulgur, as well as uncommon but essential components including zinc, iron, and aluminum (Hendek Ertop, 2019; Mirza Alizadeh et al., 2017). Another research examined the effects of heat damage, sugar compounds, amylases, and color on wheat, durum, and einkorn bread. The results indicated that furosine, hydroxymethyl furfural, and glucosyl isomaltol-indicators of heat damage-increased only during the baking stage. Furosine content in einkorn wheat was much lower. Hydroxymethylfurfural and glucosyl-isomaltol were only detected in the husk of einkorn wheat; this was however generated in smaller amounts than in bread and durum wheat. The distinct characteristics of einkorn wheat dough are most likely a result of its moderate beta-amylase activity and low maltose concentration (Mirza Alizadeh et al., 2022). The association between color and heat damage was observed, with other loaves displaying a darker color than einkorn wheat bread. The results indicate that einkorn wheat bread is less prone to heat damage than similar products, such as durum wheat and bread, thus indicating better preservation of its nutritional content (Hidalgo & Brandolini, 2011). Hidalgo *et al.* (2016) examined the impact of fast swelling on the technical and chemical properties of einkorn and bread wheat. Puffing has significantly changed the majority of the structural and chemical characteristics of einkorn and bread wheat. Most of the chemical and structural characteristics of carotenoids were significantly altered by puffing, with an average loss of 54%; however, protocol modifications were not seen (Hidalgo et al., 2016). Nakov *et al.* (2018) investigated the effects of whole einkorn wheat flour at flour levels of 0, 30, 50, 70, and 100% on the physical and chemical properties, bioactive components, and starch digestion of cookies in a laboratory setting. Cookies made entirely with bread wheat flour have a smaller diameter than those made with einkorn wheat. Einkorn wheat-enriched sweets had higher levels of protein, ash, total polyphenol, antioxidant activity, total carotenoid, and beta-glucans, but lower levels of pH and moisture. The starch digestion findings of cookies prepared with 100% einkorn wheat in the laboratory (120 min) were similar to those made with 100% bread wheat, even though the rate of digestion was slower at 180 min. These findings showed that cookies prepared with bread wheat are more nutrient-dense and had better physicochemical qualities compared to cookies made with bread wheat (Nakov et al., 2018). In a separate study, durum wheat semolina, bread wheat, and refined einkorn wheat flour were used to analyze the tocol content during the production of bread, water biscuits (a type of biscuit made just of flour and water), and pasta. The overall quantity of tocol decreased as the processing stages increased. The dough preparation for bread and water biscuits led to tocol deterioration, whereas kneading and baking bread had minimal impact. Significant deterioration (44.2%) was seen during the pasta-making process due to the prolonged dough preparation stage. The elimination of the extrusion phase led to a decrease of around 3.7% in vacuum conditions and 29.7% in non-vacuum conditions. The drying stage had negligible effects on the tocol content. Despite a noticeable decrease, einkorn wheat delivers more tocol to the final products and has a longer shelf life than durum and bread wheat (Hidalgo & Brandolini, 2010).

3. Conclusion

The increased interest in einkorn flour is attributed to its inexpensive nature and supposed great nutritional content, making it particularly ideal for low-input and organic farming. The usually accurate assessment of *T. monococcum's* nutritional value is supported by a number of recent research. Compared to typical durum and bread wheat, einkorn kernels naturally have greater levels of proteins, lipids (mostly poly and mono-unsaturated fatty acids), and fructans. Additionally, they have larger concentrations of a few always-important microminerals, such as zinc and iron. There are significant concentrations of functional antioxidants such as phytosterols, alkylresorcinols, carotenoids, tocols, and conjugated phenolics. Because einkorn whole grain flours have low amounts of lipoxygenase and beta-amylase, these antioxidants do not break down during food processing, maintaining the excellent nutritional properties of this species. Compared to bread wheat, einkorn exhibits lower amounts of dietary fiber and insoluble bound polyphenols as well as greater polyphenol oxidase activity. Current advances in low-impact and sustainable agriculture, together with the increasing use of biological and functional products, suggest that einkorn may still be utilized for human consumption. This is particularly true considering that einkorn is a potential component for making bread items, infant food, or products with high levels of tocols, carotenoids, and dietary fiber.

Authors' Contributions

Aida Mahdavi, Nesa Azimzadeh, Sara Moradpey, and Maryam Abolhassani: Data curation; Investigation; Writing-original draft. Majid Aminzare, Behrouz Tajdar-Oranj and Hamid Barani-Bonab: Writing-review & editing. Adel Mirza Alizadeh: Conceptualization; Investigation; Project administration; Supervision; Writing-review & editing.

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Conflicts of Interest

The authors declare that they have no competing interests.

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Ethical considerations

There were no ethical considerations to be considered in this research.

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